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Some distinguishing characteristics of nesting beaches of the green turtle *Chelonia mydas* on North West Cape Peninsula, Western Australia

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Abstract

On an 85 km stretch of coastline along the western and northwestern edge of North West Cape Peninsula, Western Australia, are numerous beaches used for nesting by the green turtle *Chelonia mydas.* Many other beaches in the area are not so used. Nesting beaches displayed three characteristics that distinguished them from non-nesting beaches: the salinity of the sand moisture at nesting depth was lower, the salt content of surface sand was lower, and the beaches were sheltered from prevailing winds. Several beaches on which turtles did not nest exhibited these characteristics, but possessed sand platforms of reduced elevation above sea level. These observations are discussed in relation to the question of what cues green turtles use in selecting nesting beaches.

Introduction

Green sea turtles, *Chelonia mydas*, select the same beaches year after year for nesting, while avoiding other seemingly almost identical beaches (e.g. Carr *et al.,* 1978). The factors that influence nesting beach selection are unknown. The question is doubly perplexing because green turtles are "curiously flexible regarding their incubating medium" (Hirth and Carr, 1970, p. 28). Composition of nesting beaches ranges from fine sand to coarse shell or coral fragments, from mainly calcareous to mainly igneous and from dark to light in colour. No relationship has been found between nesting beach selection and pH, calcium carbonate content, water content, organic content, particle size or colour of the sand (Hirth and Carr, 1970; Hirth 1971; Hughes, 1974; Stancyk and Ross, 1978; Mortimer, 1982).

Hendrickson and Balasingham (1966) reported that fine-grained beaches were preferred by *Chelonia mydas* along the coast of Malaysia, but investigations elsewhere do not support the general validity of this observation (Stancyk and Ross, 1978).

Bustard and Greenham (1968) reported that the growth and survival of the eggs of *Chelonia mydas* were negatively correlated with the salinity of the moisture of the incubation medium, and that salinities as high as that of seawater caused 100% mortality. Accordingly, we tested the hypothesis that the salinity of the sand moisture in nesting beaches is lower than that in non-nesting beaches. The results of our tests generated several subsidiary hypotheses, which were also subsequently examined. These are described below.

Study area

North West Cape Peninsula is situated along the central west coast of Western Australia. Running along a north-south axis, it forms the western boundary of Exmouth Gulf (Fig. 1). Located around Latitude 22°S, Longitude 114°E, the peninsula is 96 km long and averages about 21 km in width. Bisecting it lengthwise is the Cape Range, an anticlinal outcropping of tertiary limestone with a maximum elevation of about 300 m. The range is bordered on either side by a coastal plain averaging 1.5 km in width.

The area is arid. Annual rainfall is highly variable, with a mean of 288 mm at the Yardie Creek weather station within our study area. Most of the rain occurs in a very few intense cyclonic storms, which may drop more than 50 mm of rain in a few hours.

Between Vlaming Head and North West Cape (the northern extremity of the peninsula) a fringing reef borders the coast. South of Vlaming Head, most of the west coast of the peninsula is bordered by the Ningaloo Reef Tract, a flourishing barrier-type coral reef separated from the shore by a shallow lagoon from 0.5 to 3 km wide. Roughly one-third of the coastline consists of wave-cut limestone benches elevated 1 to 3 m above mean high water. Interspersed with these benches along the coast are

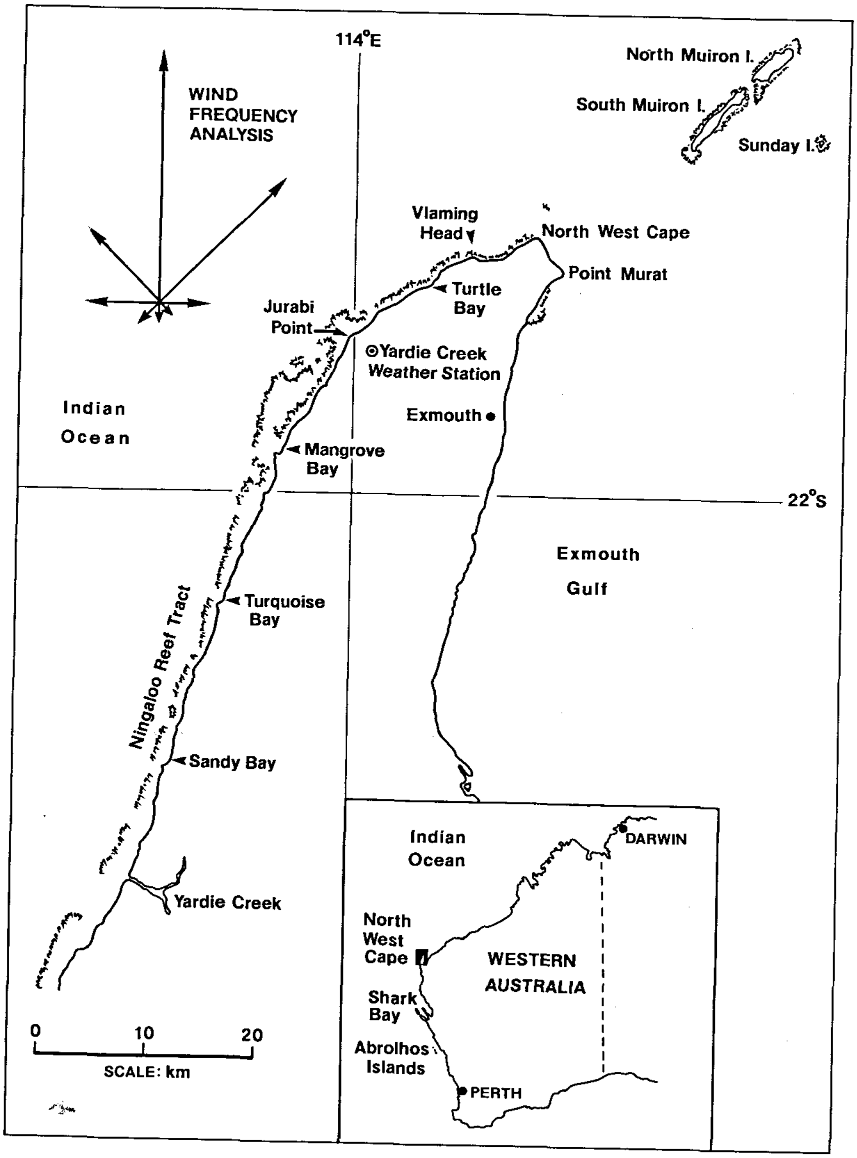

Fig. 1. North West Cape Peninsula, Western Australia. (Wind frequency analysis was based on 39 yr of records taken at Carnarvon by Australian Bureau of Meteorology.)

beaches consisting of medium-sized, mainly calcareous, particles of sand.

Green turtles, *Chelonia mydas,* regularly nest on certain beaches along the entire west and north-west coasts (but not on the east coast) of the peninsula. The present study took place along an 85 km stretch of coast running from North West Cape south-eastward along the west coast to Yardie Creek (Fig. 1).

The hinterland of this coastline reflects the rainfall pattern. There are no perennial streams, although the coastal plain is cut by many erosion channels which contain water for brief periods after heavy rains. The vegetation consists of low, drought-tolerant shrubs and grasses.

In many areas the beach slopes upward to a sand platform elevated 1.0 to 3.0 m above mean high-water spring tide and of varying width. It is on certain of these platforms that most of the nesting of *Chelonia mydas* takes place. A stable foredune typically rises to a height of 2 to 4 m immediately behind the platform. Some nesting takes place on the top or seaward slope of this dune. Occasional nesting depressions were found on the beach itself, below the sand platform. At some locations, additional dune lines run behind and more or less parallel to the first foredune. The dunes and sand platform are usually vegetated, primarily by broad-leaved spinifex, *Spinifex longifolius.* Nest pits were usually located at the base of, or within 2 m of clumps of this vegetation.

Unstable dune complexes occur at several locations along the coast. Here the beach is backed directly by a much taller and wider and largely unvegetated dune system that, according to inhabitants of the area, changes perceptibly in shape and extent over periods of a few years. Very few nests were found at these sites.

The tides in the area are semi-diurnal and the height of mean high-water spring tide at the northern tip of the peninsula is 2.0 m (Australian National Tide Tables 1982).

Materials and methods

This study was carried out during 4- to 6-d periods in each of November 1981, February and August 1982 and January 1983. Work was aided by two complete aerial photographic surveys of the study coast made on 11 November 1981 and 16 December 1982 at an elevation of 760 m. By using a stereo viewer and pairs of overlapping photographs, we were able to distinguish individual *Chelonia mydas* and their tracks, and body pits made by nesting turtles. The photographs were taken at low tide in the morning, during spring-tide periods.

Three sand samples were taken from each of 31 beaches (16 nesting, 15 non-nesting) on or near the beach platform at a depth equal to that at which the turtles deposited their eggs, i.e., 0.7 to 1.0 m. Samples of about 25 g of sand were stored in air-tight plastic vials. The moisture content of the sand was determined by weighing the samples before and after drying for 48 h at 110 °C. The salinity of the moisture was measured after adding 10 ml of distilled water to the dried sand, shaking the mixture to redissolve the salts, and titrating 1 ml aliquots of the supernatant against $AgNO_3$ with a 5% K_2CrO_4 indicator, standardized by titration against international standard seawater. The salinity value was then adjusted to conform to the original moisture content of the sand as previously determined for each sample.

The depth of the water table and the salinity of the groundwater underlying nesting and non-nesting beaches were determined by driving two or three 1.5 m sections of galvanized water pipe into the sand. The bottom end of the first pipe was fitted with a cone-shaped steel head to facilitate passage through the sand. Five holes, 1 cm in diameter, were drilled at 6 cm intervals above the head on either side of the pipe. Stainless steel screens with 0.6 mm apertures were inset over the holes flush with the outer surface of the pipe and soldered in place. These facilitated entry of groundwater while excluding most sand particles.

Water depth was determined by lowering a rod into the pipe and measuring the depth from the surface to the water mark left on the rod when it was removed. A small plastic tube attached to the bottom of the rod enabled the removal of about 1 ml of groundwater. The salinity of this groundwater was measured to 0.5‰ using a refractometer. The height above sea level of the beach surface at the point where the pipe entered the sand was determined using a clinometer. These measurements enabled us to determine the depth of the water table below the beach surface and the elevation of the water table above sea level at the time of measurement. In several instances, changes in the height of the water table of up to 21 cm in response to changes in tide height were observed.

Results and discussion

Although very little has been published concerning *Chelonia mydas* in Western Australia, it is clear that large numbers occur in waters off the north and north west coasts (Limpus, 1982). A commercial fishery for the species existed in the vicinity of the North West Cape Peninsula until 1971. All species of sea turtles are now protected throughout Australia.

Limpus (1982) provides a partial listing of nesting areas for *Chelonia mydas* in Western Australia. The southernmost regular rookery for this species occurs in Shark Bay (Fig. 1: inset), 350 km south of our study area, most notably at the northern end of Dirk Hartog Island. [Green turtles are very commonly seen 250 km south of Shark Bay in the Abrolhos Islands (Fig. 1: inset), the southernmost coral reef area in the Indian Ocean. Nesting has not been observed there.]

Dense nesting of green turtles is reported to occur in the Muiron Islands ~20 km northeast of North West Cape (Fig. 1). Our 1981 aerial photographs include the Muiron Islands and reveal very heavy nesting activity. Although we found no evidence of nesting of any species of sea turtle except *Chelonia mydas* on the North West Cape Peninsula, loggerhead turtles are reliably reported to share the Muiron Island rookeries with green turtles. As we were unable to visit the Muiron Islands, we cannot tell what fraction of the nest depressions and nesting tracks observed in our aerial photographs are due to green turtles.

Along the northwest coast of North West Cape Peninsula, i.e., between Jurabi Point and North West Cape (Fig. 1), turtles nested on all beaches which were not fronted by elevated beach rock or backed by dunes too steep for turtles to climb. Here, during the week of 2 November 1981, an aggregation of turtles was observed in Turtle Bay (Fig. 1). More than 100 turtles could be seen in shallow water over a sandy bottom near the beach within an area of 0.06 km^2. Many of them were courting or mating. A similar sized aggregation is visible at the same location in aerial photographs taken on 3 December 1981. This was the largest breeding aggregation we encountered during our studies. The largest rookery in the entire study area (judging by the number of nesting depressions) was also located here, with heaviest nesting activity along the southwestern edge of the bay.

Along the west coast, i.e., from Jurabi Point to Yardie Creek, many beaches which appeared suitable for nesting showed little or no evidence of nesting activity during our study. Several rookeries were located along this coast, however, with the largest in the area being at Turquoise Bay (Fig. 1).

Beach analyses

For purposes of statistical analysis, beach sample sites were divided into two groups – those where 15 or more nest depressions were visible within a 30 m radius and those which contained no nest depressions. A third category of beach, where only an occasional nest depression was present, is not discussed here. Also not examined were beaches where beach rock outcropping or dune steepness prevented access. (A few aborted tracks were found on the seaward slope of the latter dunes, indicating that turtles occasionally attempted to scale them.)

The mean salinity of the sand moisture of the nesting beaches (2.8‰) was about one-half that of moisture in the non-nesting beaches (5.8‰) and the difference was highly significant (Table 1). In both types of beaches, sand-moisture salinity was usually less than 25% of seawater salinity, although a few individual samples contained salinities considerably higher than the means (maximum 11.3‰ in a single nesting beach sample, 22.9‰ in a single non-nesting beach sample).

Having established that the salinity of sand moisture was lower in nesting beaches than in non-nesting beaches in the study area, we sought an explanation for this difference in the groundwater underlying these beaches. Where an aquifer is in hydraulic contact with the sea and its head is above sea level it will discharge to the sea. From an unconfined (non-artesian) aquifer this discharge typically occurs at the coastline in a zone running from slightly above the low-tide mark to a few tens or hundreds of meters seaward. The rate of discharge typically decreases exponentially with distance from shore. In some areas impermeable strata intruding in or behind the beach may block this flow. [See Johannes (1980) for a review of these principles.]

In a formation broken by irregularly spaced caverns or fissures, the spatial pattern of groundwater flow and of groundwater salinity will also be irregular (Wentworth, 1947). Such is the case in the North West Cape Peninsula; reservoirs of useful shallow groundwater are found in association with subterranean drainage channels, and sites located away from drainage channels yield saline water, if any (Sofoulis, 1949). Thus, the salinity and rate of discharge of groundwater can be expected to vary from place to place along the coast of the study area.

These facts prompted us to investigate the possibility that the salinities of the sand moisture in the beaches in the study area were a function of the salinity of the underlying groundwater.

The depth to the water table beneath the sand platforms in our study area ranged from 240 to 290 cm. Groundwater salinities ranged from 12 to 36‰ and did not differ significantly between nesting and non-nesting beaches. Groundwater salinities were generally much higher than the salinities of the overlying moisture at nest depth. Groundwater salinities varied considerably along single nesting beaches ranging, for example, from 12.5 to 31‰ along the nesting beach at Turquoise Bay (Fig. 2).

A layer of beachrock, the upper surface of which was above the water table, underlay two nesting beaches we examined. On two occasions at these beaches our groundwater probes struck shallow pools of water resting in depressions in this beach rock.

Capillary action draws moisture in sand vertically to a maximum distance above the water table of about 40 cm (e.g. Olsson-Seffer, 1909). Thus, capillary movement of groundwater is not responsible for the moisture present in

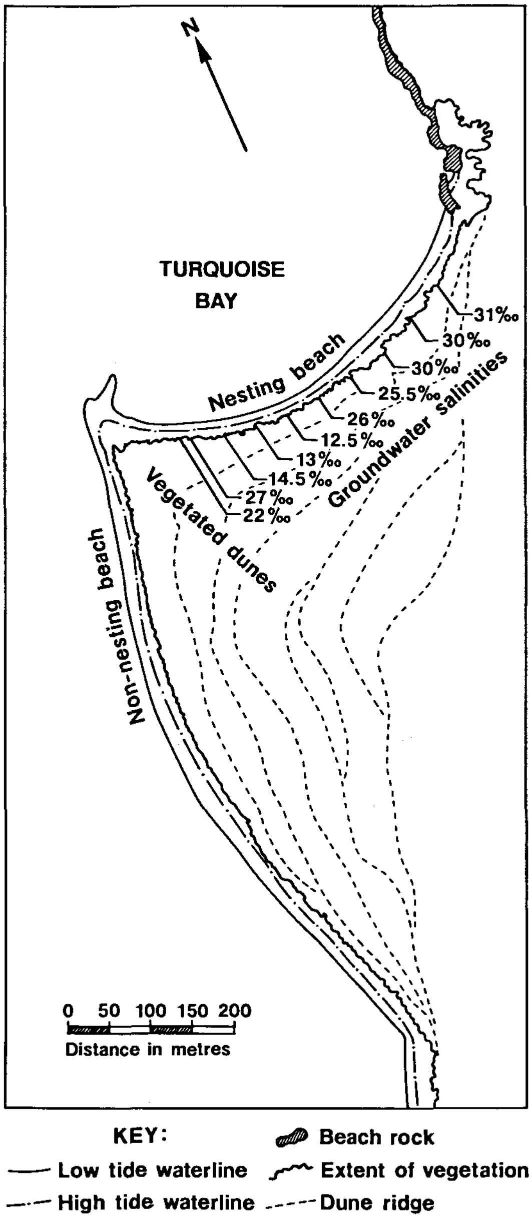

Fig. 2. Turquoise Bay nesting beach, showing groundwater salinities at the seaward edge of dune vegetation

Table 1. Salinity and salt analysis of nesting and non-nesting beaches. Values are means (standard errors in parentheses)

	Nesting beaches	Non-nesting beaches	*P*
Salinity of sand moisture at depths of 0.7–1.0 m.[a]	2.8‰ (0.54) $n=16$	5.8‰ (0.56) $n=15$	< 0.002
% salt in surface sand[b]	0.023% (0.005) $n=10$	0.127% (0.027) $n=10$	< 0.001

[a] 3 samples taken at each beach
[b] 5 samples taken at each beach

the sand at nesting depth (140 to 220 cm or more above the water table) in the study beaches.

Others have noted that sand within coastal beaches and dunes always contains moisture even in the presence of high evaporation and transpiration rates, or in the absence of rain or of a water table close enough to the surface to supply this moisture via capillary forces (e.g. Olsson-Seffer, 1909; De Jong, 1979). Olsson-Seffer proposed that this moisture originates as water moving upward from the water table as water vapour and condensing in the upper layers when temperatures are lower there. He called this process "internal dew formation". De Jong (1979) confirmed that the moisture he found in California beach dunes originated largely from below. A number of other investigators have demonstrated the process of internal dew formation (also called vapour-phase transport) experimentally, although the precise mechanism involved remains unclear (e.g. Gurr *et al.*, 1952; Rollins *et al.*, 1954; Philip and de Vries, 1957; Rose, 1968).

Internal dew formation would explain our results. Water vapour travelling upward from the water table in this fashion would not transport salts with it. Consequently, the salinity of sand moisture derived from this water vapour would not reflect the salinity of the groundwater from which it originated.

Nevertheless, sand moisture in the study beaches does contain *some* salts, and the salinity of this moisture is significantly different in nesting and non-nesting beaches. What, then, is the origin of these salts, and why are sand-moisture salinities lower in nesting beaches?

An examination of the siting of nesting beaches in the study area suggested an answer. The prevailing winds in the study area are from the south and southwest. All the major nesting beaches on the west coast study area are sheltered by promontories to the immediate south (e.g. Turquoise Bay, Fig. 2) and are thus somewhat protected from prevailing winds and associated salt spray. As described above, all accessible beaches along the northwest coast of the study area are used for nesting. Here, the entire coastline is sheltered from the prevailing winds and associated salt spray. This suggested to us that the salt in the sand moisture of beaches in the study area originated from salt spray falling on the surface, the salts subsequently being carried beneath the surface by occasional rain. If this is correct, then the salt content of the sand at the surface of nesting beaches protected from prevailing winds should be lower than on unprotected beaches.

An analysis of five surface-sand samples from each of 10 nesting (protected) beaches and 10 non-nesting (unprotected) beaches confirmed this. Surface sand at nesting beaches contained a mean of 0.023% salt by weight, whereas surface sand at non-nesting beaches contained a mean of 0.127% salt. The difference is highly significant (Table 1).

Certain beaches along the west coast of the study area which were sheltered from prevailing winds nevertheless showed little or no evidence of nesting activity (e.g. beaches at Mangrove Bay and Sandy Bay). Sand moisture salinities and surface salt concentrations here were low – characteristic of nesting beaches rather than other non-nesting beaches. But such beaches were also characterized by unusually low sand platforms, about 100 to 130 cm above mean high spring water level. The depth to the water table on the sand platforms was only about 100 to 150 cm. Nesting on such platforms would place the eggs at or near the level of the water table during spring high tides, and thus in danger of seawater inundation. Conceivably, nesting green turtles are able to gauge the height of the sand platforms on prospective nesting beaches, generally rejecting those which are less than a certain height above water level.

Conclusions

Along the west and northwest coast of the North West Cape Peninsula, *Chelonia mydas* nesting beaches are characterized by lower sand-moisture salinities at nest depth, lower salt content of surface sand, and more protected locations relative to prevailing winds than non-nesting beaches. No relationship between these features and the depth of the water table or the salinity of the groundwater beneath these beaches was found.

It is not obvious to us how any of these features could be perceived by turtles searching for nesting sites. Green turtles generally appear to choose their nesting beaches before moving landward from the surf zone. Even if they had the ability to detect small differences in the salt content of surface sand, this ability would not enable them to make their choice while still in the surf zone. It also seems doubtful that the degree of protectedness from prevailing winds would provide them with a cue, unless they select their nesting beaches some hours before emerging to nest. This is because green turtles nest at night; the winds in the study area are often brisk during the day but frequently cease during the night.

It is possible that none of the three features described here determine the suitability of a beach for nesting. For example, the sand-moisture salinity in non-nesting beaches, although higher than in nesting beaches, was nonetheless very low relative to seawater and would not seem to constitute an impediment to successful incubation of green turtle eggs. Possibly some other unidentified features of nesting beaches which are associated with the variables we have examined are the ones which render these beaches suitable for nesting. C. Limpus (personal communication) has drawn our attention to the fact that beaches sheltered from prevailing winds may be more stable than those which are not, and that the risk of exposure and destructions of nests due to beach erosion may therefore be reduced. We do not have information on the stability of beaches in our study area to test the significance of this factor.

In conclusion, we have established three characteristics that distinguish nesting from non-nesting beaches. But we cannot confirm that any of these are essential for nesting or, if they are, how green turtles might be able to detect them. Moreover, in the absence of comparative studies in other geographic areas, it would be unwarranted to assume that the distinguishing features of nesting beaches on the North West Cape Peninsula are characteristic of green turtle nesting beaches elsewhere; reproductive strategies of sea turtles, including nesting beach selection, may differ in different populations.

We hope, nonetheless, that our observations will provide useful clues for others seeking to determine what constitutes a suitable beach for green turtle nesting. The answer is important; until the essential features of a suitable nesting beach are known we cannot determine what types of environmental disturbances to avoid in order to protect these features, or predict with confidence what beaches might be suitable for the establishment of new rookeries.

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