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# INTER- AND INTRA-BEACH THERMAL VARIATION FOR GREEN TURTLE NESTS ON ASCENSION ISLAND, SOUTH ATLANTIC

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Nest temperatures for green turtles (*Chelonia mydas*) nesting on Ascension Island, South Atlantic (7°57'S 14°22'W), were examined. Temperature probes were placed into nests on two beaches, Long Beach (26 nests) and North East Bay (8 nests). Within these beaches there was relatively little thermal variation (SD of nest temperature was 0·32°C for Long Beach and 0·30°C for North East Bay). To examine inter-beach thermal variation temperature probes were buried at 55 cm on 12 beaches. Inter-beach thermal variation was large and was related to the beach albedo with the darkest beach (albedo, 0·16) being 4·2°C warmer than the lightest coloured beach (albedo, 0·73).

## INTRODUCTION

Marine turtles exhibit temperature-dependent sex determination with the sex of the offspring being influenced primarily by the incubation temperature of the eggs (Yntema & Mrosovsky, 1982). Females are produced from warmer nests and vice versa, with the temperature at which 50% females and 50% males are produced being generally termed the 'pivotal' temperature (Yntema & Mrosovsky, 1982). For marine turtles, population survival is therefore dependent on the occurrence of a sufficient range of incubation temperatures to produce offspring of both sexes. The question of how this necessary range of incubation temperatures is realized is therefore of great scientific and conservation interest (cf. Janzen & Paukstis, 1991; Mrosovsky & Provancha, 1992).

A range of mechanisms has been implicated in influencing marine turtle nest temperatures and hence hatchling sex. There may be marked seasonal variations in sand temperature. For example, for loggerhead turtles (*Caretta caretta*) nesting in Georgia and South Carolina, USA, Mrosovsky et al. (1984) found that more males were produced from nests laid at the start and end of the nesting season when the sand was relatively cool, while more females were produced during the warmer interim period. For populations that nest over a wide area there may be geographical variations in incubation temperature. For example, for loggerhead turtles nesting on the east coast of the USA, markedly lower temperatures occur in nests at the northern limit of their nesting range (North Carolina) than at the southern limit (Florida) (Mrosovsky, 1988). Incubation temperature may vary with the position of the nest on a beach. For example, for green turtles (*Chelonia mydas*) nesting at Tortuguero, Costa Rica, Morreale et al. (1982) reported that nests at the back of the beach tended to be cooler due to shading from supra-littoral vegetation and thus produced a greater proportion of male hatchlings than nests on the open unshaded beach. The mean sand temperature may also vary with depth, providing the potential for depth-related differences in the hatchling sex ratio. Nests may also undergo marked cooling following periods of prolonged heavy rain (Morreale et al., 1982).

Ascension Island is situated in the South Atlantic (7°57'S 14°22'W) and is a major rookery for green turtles. Several thousand nests are laid annually on the island, on a total of 32 beaches, with the height of the nesting season occurring between February and May (Mortimer & Carr, 1987). Ascension Island is unusual in that a wide range of incubation temperatures is unlikely to be produced by many of the previously described mechanisms. First, on Ascension Island the seasonal changes in sand temperature at nest depths are small (Carr & Hirth, 1962). Second, the eggs are laid very deeply (Hays et al., 1993) and hence depth-related differences in nest temperature are likely to be minimal (Carr & Hirth, 1962). Third, annual precipitation at Ascension Island is so sparse (mean 19 cm, Mortimer & Carr, 1987), mean relative humidity so low (65%, Duffey, 1964) and nest depth so great, that rainfall seldom percolates to nest level (Mortimer, 1990) and hence marked rain-induced changes in nest temperature are unlikely to occur. Finally, the island's small size (97 $km^2$) and isolation (>2000 km from the nearest landfall) precludes any latitudinal variations in nest temperature for this population. A range of nest temperatures on Ascension Island may, however, be produced by other mechanisms. First, there may be large thermal variations dependent on the location of a nest on a beach. Second, it is known that beaches on Ascension Island differ markedly in one very obvious feature, their colour (Stancyk & Ross, 1978), and this may contribute to inter-beach thermal variations. The objectives of this study were therefore to quantify both the inter- and intra-beach thermal variations on Ascension Island and consider whether these factors might lead to the production of mixed hatchling sex ratios.

## METHODS

Two of the major nesting beaches on Ascension Island, Long Beach and North East Bay, were patrolled at night between 8 February and 8 April 1992 to locate turtles attempting to nest. Turtles encountered were first observed through 8x50 binoculars to ascertain their orientation and stage of nesting and then approached from behind to minimize disturbance. While the eggs were being laid, temperature probes (model CM-U-V5-1, Grant Instruments Ltd, Barrington, Cambridge, UK) were placed in nests. These probes were factory calibrated for accuracy and precision to a give a maximum deviation from the true temperature of 0·2°C and a modal deviation of 0·1°C.

Readings of the nest temperature were taken at least once a day on the first five days of incubation, and from these readings a mean temperature for each nest was calculated. To quantify diel nest temperature variations, continuous (30-min interval) measurements of the nest temperature over complete 24-h periods were made by connecting the probe terminals to a data logger (Grant Instruments' Squirrel, model SQ8-4U). These 24-h measurements were made on the third, fourth or fifth day of incubation.

For 12 beaches, the sand albedo was quantified by measuring the sand reflectance in relation to the reflectance of a grey card of known albedo (0·5). To measure reflectance we used a wide-waveband-sensitivity light meter (Mastersix, Gossen GMBH, Germany, maximum sensitivity in the range 400–750 nm) set on a narrow field (15°) response. The light meter was held 15 cm above the beach, pointing vertically downwards. We measured alternately the reflectance from the beach sand and the grey card placed on the sand surface. To ensure that albedo was not inaccurately calculated as a result of changes in the incident light intensity between the sand and grey card measurements, we firstly made all measurements when there was no cloud-cover obscuring the sun, and secondly repeated measurements until neither sand nor grey card reflectance varied over three consecutive readings. Sand albedo was then calculated as:

$$\text{Sand albedo} = \frac{\text{sand reflectance} \times \text{grey card albedo}}{\text{grey card reflectance}} \quad (1)$$

On each beach we measured sand albedo at ten separate sites, all located 5 m above the spring tide high water line. At three of these sites on each beach we also measured the sand temperature at a depth of 55 cm. To do this we dug down to 50 cm and then inserted four temperature probes a further 5 cm down into the sand, i.e. on each beach the sand temperature was measured 12 times. We then refilled the excavation hole and recorded the temperatures once they had stabilized (<3 min). The temperature variation between the 12 measurements on each beach was always <0·3°C. To ascertain whether there was any longer-term temperature stabilization, we left five probes from independent excavations in the sand for a further seven days. All these probes showed only small (≤0·3°C) non-monotonic temperature changes during this period.

## RESULTS

Measurements of the temperature over a complete 24-h period were made for nine nests. None of these continuous readings showed any evidence of a diel temperature cycle (mean difference between daily maxima and minima, 0·06°C ±0·12SD; maximum difference, 0·3°C).

The temperature was recorded in 26 nests laid on Long Beach and in eight nests laid on North East Bay. The thermal variation between nests was small on both beaches (SD of the mean nest temperature was 0·32°C for Long Beach and 0·30°C for North East Bay). However, nests on North East Bay were consistently warmer than those on Long Beach (mean temperatures 30·2°C and 28·1°C, respectively, $t_{12}$=16·7, P<0·001). For the temperature measurements made in the sand at 55 cm, but not in nests, the mean temperature recorded on North East Bay was 31·4°C and on Long Beach was 29·0°C, i.e. 1·2°C and 0·9°C warmer than the respective mean nest temperatures for these two beaches.

Between the 12 beaches on which the sand temperature was measured at 55 cm there was a large thermal variation, with the temperature on the warmest beach (Pebbly East) being 4·2°C greater than that on the coolest beach (Blowhole) (N=12 beaches, mean temperature at 55 cm = 29·3°C, SD=1·5°C). This inter-beach thermal variation was related to the beach albedo, with darker coloured beaches (i.e. lower albedo) being significantly warmer (Figure 1).

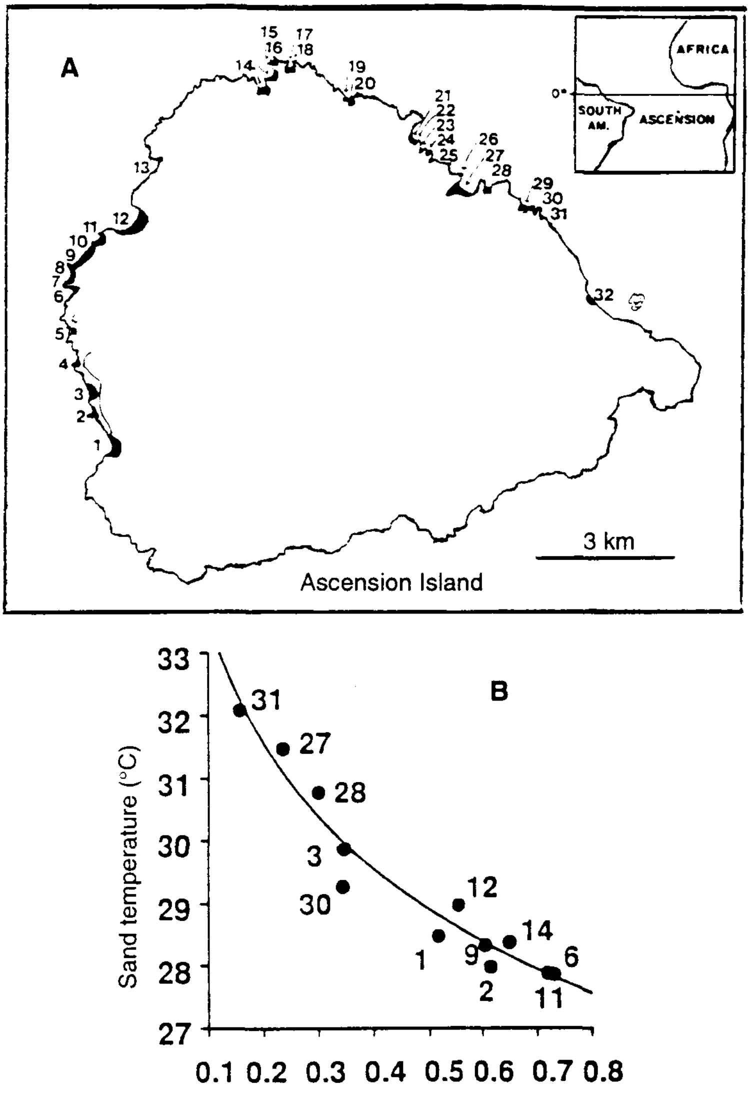


Figure 1. (A) A map showing the geographical location of Ascension Island (inset) and the position of the study beaches on the island (modified from Mortimer & Carr, 1987). 1, South West Bay; 2, Turtleshell; 3, Clarkes; 4, Payne Point; 5, Mitchell's Cove; 6, Blowhole; 7, P.O.L. South; 8, P.O.L. North; 9, Deadman's; 10, Fort Hayes; 11, Georgetown; 12, Long Beach; 13, Comfortless Cove; 14, English Bay (EB); 15, EB 1; 16, EB 2; 17, EB 3; 18, EB 4; 19, Ladies Loo West; 20, Ladies Loo; 21, Porpoise Point (PP) 1; 22, PP 2; 23, PP 3; 24, PP 4; 25, PP 5; 26, Porpoise Point; 27, North East Bay; 28, Beach Hut; 29, Hannay; 30, Pebbly West; 31, Pebbly East; 32, Spire. (B)The sand temperature at a depth of 55 cm on different beaches in relation to the beach albedo. A lower albedo represents a darker beach. The number next to each point identifies the beach with the key as in (A). Sand temperature (°C) = 26·9 – 6·66 $\log_{10}$ (beach albedo) ($F_{1,10}$=179, $r^2$=0·95, $P$<0·001).

## DISCUSSION

The thermal characteristics of nesting beaches may be described by either placing temperature probes into nests or simply burying probes in the sand (cf. Morreale et al., 1982; Mrosovsky & Provancha, 1989). The former is the more desirable method for examining the thermal variation between nests. However, placing probes into individual nests is expensive both in terms of the time required and the equipment costs. As a consequence of these constraints we applied both techniques, placing probes into nests on two of the beaches on Ascension Island and simply burying probes in the sand on 12 beaches. The sand measurements were made at a depth of 55 cm since this was the deepest depth that we found it possible to dig to quickly (<5 min) thus minimizing the chances of the sand changing temperature during our digging. Since 55 cm is shallower than the typical nest depth on Ascension Island (65–90 cm, Hays et al., 1993) it would be expected that these sand measurements would be slightly warmer than the actual nest temperatures on the respective beaches. This was, indeed, found to be the case with the temperature at 55 cm being 0·9°C warmer than the mean nest temperature on Long Beach and 1·2°C warmer than the mean nest temperature on North East Bay. Nevertheless the sand measurements at 55 cm would still be expected to give an indication of the relative inter-beach thermal variation.

Marked diel cycles in nest temperature have been reported for freshwater turtles (Packard et al., 1985) and at shallow depths on marine turtle nesting beaches (e.g. 30 cm, Mrosovsky & Provancha, 1989). However, we found no evidence of any diel temperature cycle in the nests of green turtles on Ascension Island. Similarly in green turtle nests in Costa Rica, Standora & Spotila (1985) reported that diel temperature variations were very small (<0·5°C). Presumably, since green turtle nests are very deep, diel temperature variations occurring near the surface are very much reduced at nest depths.

Intra-beach thermal variation on turtle nesting beaches may be large. For example, at the green turtle rookery at Tortuguero, Costa Rica, nest temperatures may vary by up to 3°C, depending on the extent of nest shading by supra-littoral vegetation (Morreale et al., 1982). However, on Ascension Island we recorded only very small intra-beach thermal variation (SD≈0·3°C). This may reflect the fact that there is only very sparse supra-littoral vegetation on Ascension Island (Carr & Hirth, 1962) and hence a lack of heterogeneity in terms of exposure of the sand surface to solar radiation.

There was a marked variation in the albedo of beaches on Ascension Island, with the lightest beach (Blowhole, albedo = 0·73) having an albedo 4·5 times that of the darkest beach (Pebbly East, albedo = 0·16) (Figure 1). Although sand albedo has not been measured previously in the context of turtle nesting beaches, differences in beach coloration on Ascension Island have been noted before and have been attributed to differences in the proportions of sand of biogenic and volcanic origin, with lighter beaches having a greater proportion of calcium carbonate (Stancyk & Ross, 1978; Mortimer, 1990). While the intra-beach thermal variation on Ascension Island was small, the inter-beach variation was, in contrast, large, with darker beaches being markedly warmer than lighter coloured beaches (Figure 1). Darker beaches were presumably warmer as a result of increased absorption of solar radiation. Furthermore, while we recorded the sand temperature on 12 beaches, a total of 32 beaches is used by nesting sea turtles on Ascension Island (Mortimer & Carr, 1987; Figure 1). Consequently the true extent of inter-beach thermal variation may be even larger than that reported here. The very tight correlation found here between beach temperature and sand albedo on Ascension Island ($r^2$=0·95, Figure 1), suggests that other abiotic factors which may potentially vary between beaches (e.g. exposure of the beach to winds and the slope of the beach) are of minor importance in influencing the inter-beach thermal variations. Furthermore, the same general pattern between beach colour and temperature has been reported for nesting beaches in eastern Australia, with visibly darker beaches being 1–2°C warmer than visibly lighter coloured beaches (Limpus et al., 1983). This suggests that the importance of sand albedo in influencing nest temperature is not unique to Ascension Island.

While the pivotal temperatures of various sea turtle populations has been quantified (Janzen & Paukstis, 1991), the pivotal temperature for green turtle eggs laid on Ascension Island is unknown. Given that pivotal temperatures may vary between populations (Limpus et al., 1985) we have not attempted to predict the expected hatchling sex ratio from the temperatures we recorded. Nevertheless once the pivotal temperature for this population has been established, the temperatures reported here will allow baseline calculations of the hatchling sex ratio on Ascension Island.

The marked variation in beach albedo on Ascension Island may clearly be of profound importance for the survival of this green turtle population. Since seasonal (Carr & Hirth, 1962), depth-related (Carr & Hirth, 1962) and within beach (this study) variations in nest temperature are small, variations in beach colour are likely to be a major avenue by which a large range of incubation temperatures are realized and hence hatchlings of both sexes produced.

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