

Islands and turtles.

The influence of choice of nesting beach on sex ratio.

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ABSTRACT

Some implications of turtles nesting on beaches with differing temperature regimes in the southern Great Barrier Reef are discussed in relation to temperature dependent sex determination. The mainland beaches have the greatest potential for female production. Within a coral cay, the highest female sex ratio can be expected from the northerly-aspect beach. The overall female production will be modified by a differential mortality occurring between mainland and coral cay beaches for *Caretta caretta*.

INTRODUCTION

For a beach dune system to function as an important turtle rookery, it principally must be a good turtle egg incubator. The required low salinity sand with suitable moisture content<sup>1</sup> at turtle nest depth can be found above the spring high tide level on most coastal or island sand dunes. The same is not true of suitable temperatures. Temperature is regionally very variable. However, at the one nest site, sand temperature fluctuates only a few tenths of a degree in a 24hr period unless it rains or there is prolonged cloud cover. Both can cause sharp drops of several degrees in temperature. The turtle nesting beaches of the southern Great Barrier Reef region are of two main types. Those of the mainland and inshore continental islands are composed of brown quartz and feldspar based sands while those of the coral cays are of white calcareous sands of different reflective and thermal properties. In addition while the mainland beaches are generally elongate with an easterly or north-easterly aspect, the coral cays are usually elongate along SE-NW axis, yielding beaches with a pronounced northern or southern aspect. Beach orientation can further modify sand temperatures. The temperature regimes of turtle rookeries are of special interest in recent years, since the discovery that temperature of incubation determines the sex of the embryonic turtle<sup>2,3,4</sup> and some other reptiles<sup>5,6</sup>. The present study examined hatching success and hatchling sex ratio from turtle eggs laid on the Capricorn Group cays of the southern Great Barrier Reef and on nearby mainland beaches.

METHODS

In Laboratory incubation experiments, a *Caretta caretta* clutch (tag No. X24535, 5 Dec 1980) laid on Heron Island was subdivided randomly into groups of 10 eggs in sterilised Mon Repos sand moistened to 7.7% by weight with demineralised water and incubated at constant temperature ( $\pm 0.5^{\circ}\text{C}$ )<sup>3</sup>. Incubation temperatures were chosen at  $25^{\circ}$ ,  $26^{\circ}$ ,  $27.5^{\circ}$ ,  $29^{\circ}$ ,  $30.5^{\circ}$  and  $32^{\circ}\text{C}$ . The resulting hatchlings were sexed by histological examination of the gonads<sup>3,7</sup>, and the theoretical temperature that would produce a sex ratio of 50% female hatchlings (Sex determining temperature, 50% female = SDT<sub>50</sub>) was calculated<sup>8</sup>.

Beach sand temperature ( $\pm 0.5^{\circ}\text{C}$ ) was measured 50cm below the surface (a depth at which turtle eggs usually occur<sup>9</sup>) in the turtle nesting area using a mercury-glass thermometer at Mon Repos ( $24^{\circ}48'S$ ,  $152^{\circ}27'E$ ) on the mainland at Bundaberg and at Heron Is. ( $23^{\circ}26'S$ ,  $151^{\circ}55'E$ ). At Heron Is., sand temperatures

were sampled from the northerly and southerly oriented turtle nesting areas. At each beach, temperature records from several sites were averaged for the nightly record.

To sample the hatchling sex ratio produced at Mon Repos, 10 *C. caretta* hatchlings per clutch were collected from natural nests at emergence for each of 5 clutches at 7d intervals throughout the hatchling emergence season. At Heron Is., samples were similarly collected from (a) all *C. caretta* clutches located at emergence, i.e. the collection was not biased to collect equal samples from different habitats, and (b) a series of *Chelonia mydas* clutches obtained over a spread of about 2.5 months and collected from both the northern and southern beaches on generally same nights with a maximum of five clutches per week from any one beach. All hatchlings were sexed histologically. Hatching success was determined by excavating nests after the hatchlings had emerged, and counting hatched and unhatched eggs. Hatching success was expressed as the percentage of the whole clutch.

## RESULTS AND DISCUSSION

### 1. Constant temperature incubation.

Previous studies have shown that sea turtle eggs do not hatch when incubated outside the temperature range  $24^{\circ}$ - $34^{\circ}\text{C}$ <sup>10</sup>. Figure 1A illustrates the typical good hatching success that occurs over the temperature range  $25^{\circ}$ - $32^{\circ}\text{C}$  where if other conditions are optimal, most eggs can be expected to hatch. The incubation period was an inverse power function of temperature; the higher the temperature the shorter the incubation period (Figure 1B). The incubation period ranged 49-89d for  $32^{\circ}$ - $25^{\circ}\text{C}$  constant temperature incubation, respectively. The hatchling sex ratio was completely reversed over this temperature range. At  $25^{\circ}$  and  $26^{\circ}\text{C}$ , 100% of the hatchlings were males while, in contrast, at  $30.5^{\circ}$  and  $32^{\circ}\text{C}$ , 100% of the hatchlings were females. At the intermediate temperatures of  $27.5^{\circ}$  and  $29^{\circ}\text{C}$  intermediate sex ratios resulted. The theoretical temperature required to produce 50% females (SDT<sub>50</sub>) from this clutch was  $28.7^{\circ}\text{C}$  (95% confidence limits:  $27.8^{\circ}$ - $29.7^{\circ}\text{C}$ ).

These results demonstrate that *C. caretta* in east Australia have a temperature dependent sex determination (TDSD) mechanism similar to that of *C. caretta* from eastern USA. However, the USA sample has a higher SDT<sub>50</sub> by  $1.3^{\circ}\text{C}$ <sup>2</sup>. It has been shown previously that *Chelonia mydas* from eastern Australia also exhibits TDSD with an SDT<sub>50</sub> between  $26^{\circ}$  and  $29^{\circ}\text{C}$ <sup>3</sup>. The stage of embryonic development during which sex is determined has not been precisely defined, but it is most likely to occur during the first two thirds of embryonic development<sup>2,11</sup>. The implications of this TDSD phenomenon in turtles is not well understood and a study is in progress in east Australia to determine variation in SDT<sub>50</sub> within species, between species, and between rookeries, and when the sex is determined during embryonic development<sup>12</sup>.

### 2. Beach incubation.

The sand temperatures measured at 50cm depth during the 1980-1981 turtle breeding season (Figure 2) gave results similar to past studies<sup>1,12</sup>. Typically, the Heron Is. sand was at least  $1-2^{\circ}\text{C}$  cooler than the mainland sand and, within Heron Is., the beach with the northern aspect was often a degree or more warmer than the beach with the southern aspect. The temperatures for Mon Repos and Heron Is. were well below  $34^{\circ}\text{C}$ , the upper lethal limit for incubation. During the breeding months of October to March, the temperature was also above  $24^{\circ}\text{C}$  - the minimum lethal temperature for incubation. Outside the nesting season, the sand temperature at both beaches was below  $24^{\circ}\text{C}$  and decreased to about  $19^{\circ}\text{C}$  in

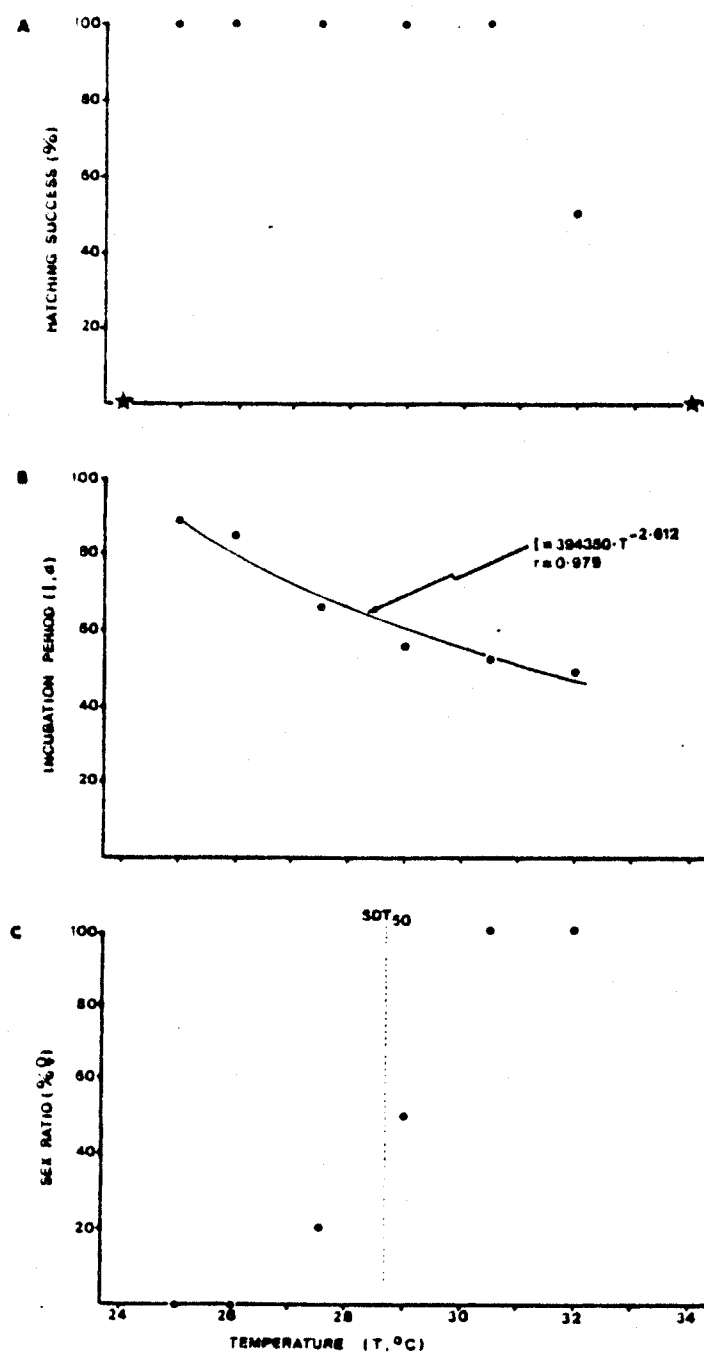


FIGURE 1. The hatch success, incubation period and hatchling sex ratio resulting from incubation of samples of ten *Caretta caretta* eggs (randomly selected from clutch, X24535, laid Heron Is.) each incubated at a different constant temperature. ★ denote the lethal temperature limits beyond which turtle eggs will not hatch.

mid-year. Preliminary results indicate that the sand temperature measured at Heron Is. was typical of sand temperatures measured throughout the white coral sands of the Capricorn Bunker cays while those at Mon Repos were typical of the brown sand beaches of the adjacent mainland. The clutches occasionally laid on Heron Is. after mid April produced no hatchlings, presumably because of the low sand temperatures. The temperature regime of these beaches determines that turtle eggs can successfully incubate only during the summer months, the usual period when sea turtles are stimulated to nest on them.

| Rookery                         | Hatching success $\bar{x} \pm SD$ (range, no. clutches) |                              | Between species<br>t test<br>(t,df,p) |
|---------------------------------|---------------------------------------------------------|------------------------------|---------------------------------------|
|                                 | <i>Caretta caretta</i>                                  | <i>Chelonia mydas</i>        |                                       |
| Heron Is.                       | 72.4 $\pm$ 28.0%(16.5-99.1,17)                          | 92.0 $\pm$ 7.3%(67.2-100,60) | 4.9,75,p<0.001                        |
| Mon Repos                       | 90.7 $\pm$ 8.4%(62.7-100,60)                            |                              |                                       |
| Between rookery t test (t,df,p) | 4.5,75,p<0.001                                          |                              |                                       |

TABLE 1. Hatching success of undisturbed clutches of turtle eggs from south Queensland rookeries during the 1980-1981 breeding season.

Within this southern Great Barrier Reef region, *Caretta caretta* nests extensively on the mainland and the coral cays, in contrast with *Chelonia mydas* which nests almost exclusively on the coral cays. In the absence of disturbances to the eggs from outside the nest, the principal factor determining hatchling production is the viability of the eggs. As seen above (Figure 1A,2), the temperature regimes of the south Queensland turtle beaches at nesting time are in the range that should produce good hatching success in undisturbed clutches. High hatching success was measured for *Chelonia mydas* eggs (92%) at Heron Is. and *Caretta caretta* eggs (91%) at Mon Repos. In contrast the *Caretta caretta* eggs at Heron Is. have a low hatching success (72%, Table 1). Poor hatching success (not measured precisely) was also observed with *Caretta caretta* on Wreck Is., the adjacent cay to Heron Is., while the *Chelonia mydas* hatching success on Wreck Is. was qualitatively rated as good. Extensive fungal invasion of eggs which fail to hatch was observed regularly on the coral cays but not on the mainland. Whether this is the cause of this habitat-specific differential mortality of *Caretta caretta* eggs or not, there is a significantly higher chance of *Caretta caretta* eggs hatching if laid at Mon Repos rather than Heron Is. and some other coral cays.

The weekly sex ratios of Mon Repos *Caretta caretta* hatchlings (mainland, warm beach with sand temperatures usually greater than measured SDT50) and those from Heron Is. (coral cay, cool beach with sand temperature usually lower than measured SDT50) in the 1980-1981 breeding season are compared in Figure 3. The warmer mainland beach consistently produced a high female ratio, usually greater than 50% while the Heron Is. sex ratio was usually less than 40% female. This result was obtained even though 13 of the 17 clutch samples from Heron Is. were obtained from the warmer northern side. On a week by week comparison, Heron Is. had an approximately 30% lower female ratio than Mon Repos. These data by themselves can not be used to derive the overall sex ratio for the season's hatchling production. Account must also be taken of the changes in nightly emergence rate through the breeding season. The data does, however, show that for *Caretta caretta* the mainland beaches have the potential for producing a high proportion of females while the adjacent coral cays could produce principally males.

There were insufficient clutches for *Caretta caretta* available to compare sex ratios of hatchlings from the opposite sides of Heron Is. with its different temperature regimes. The sex ratios of hatchling *Chelonia mydas* collected from opposite sides of Heron Is. in 1980-81 confirmed preliminary results<sup>9</sup>. The warmer northern beach of Heron Is. produced *Chelonia mydas* with a high female sex ratio ( $\bar{x}$  = 63.1%, SD = 36.4, range = 0-100%, n = 13 clutches and 130 hatchlings) while the cooler southern beach produced a low female sex ratio ( $\bar{x}$  = 29.5%, SD = 33.0, range 0-100%, n = 12 clutches and 120 hatchlings. These

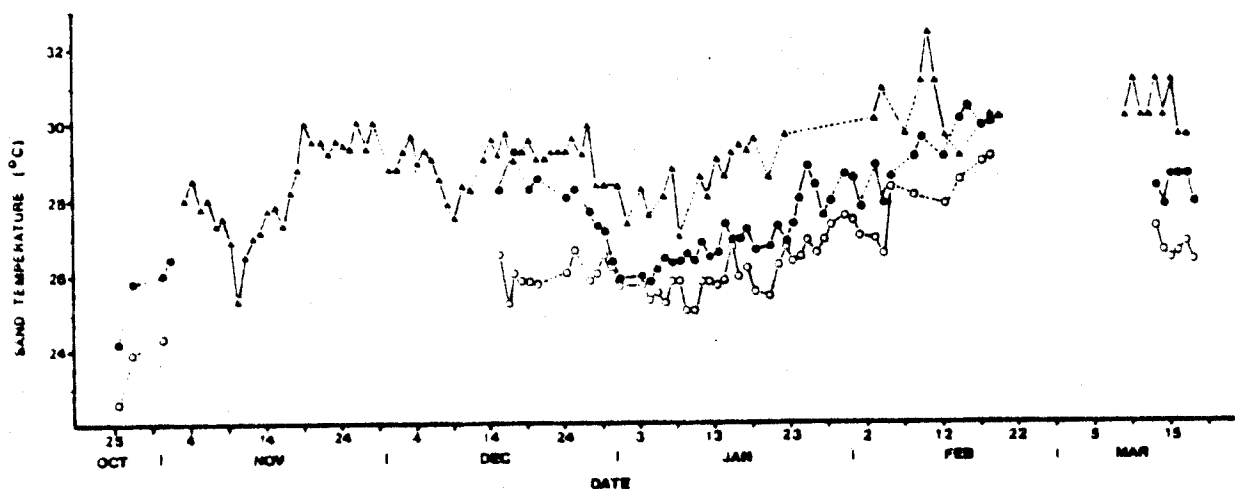


FIGURE 2. Sand temperatures measured at 50 cm depth from Mon Repos (▲) and the north (●) and south (○) beaches Heron Island during the 1980-1981 turtle breeding season. All measurements taken in the turtle nesting habitat and averaged over several sites per night.

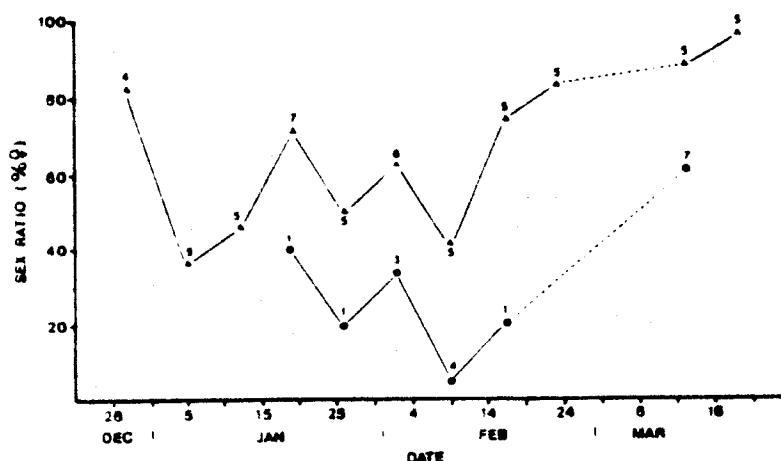


FIGURE 3. Weekly fluctuations in the sex ratio of hatchling *Caretta caretta* from Mon Repos (▲) and Heron Island (●), 1981-1982 breeding season. The weekly number of clutches sampled (10 hatchlings per clutch) are shown.

sex ratios from opposite sides of the island were significantly different ( $t$ -test:  $t = 2.41$ ,  $df = 23$ ,  $0.05 > p > 0.02$ ) and each was significantly different to a 1:1 sex ratio ( $\chi^2$ -test,  $p < 0.005$ ). Substantially more nesting occurs on the northern beach, thus increasing the probability of female production for the island. Because the measured *Caretta caretta*  $SDT_{50}$  was  $28.7^{\circ}\text{C}$ , and given that the northern beach of Heron Is. in the 1980-1981 nesting season was usually cooler than this, the *Chelonia mydas* sex ratio of 63.1% female from that beach in that season suggests that the *Chelonia mydas*  $SDT_{50}$  could be lower than that of *Caretta caretta*.

### 3. General Comments.

*Chelonia mydas*, in choosing the Capricorn Bunker cays as a rookery area, is choosing a beach incubation system which provides a high hatching success and, if the 1980-1981 season is typical, a high probability of a balanced sex ratio

or even an excess of females. Human interference in the system may be having the hitherto unsuspected effect of altering the turtle sex ratio on Heron Is. where beach retaining walls and beach rock, increasingly exposed since the construction of the harbour, have effectively excluded turtle nesting for about a quarter of the main female producing beach.

The principal nesting area for *Caretta caretta* in the South Pacific Ocean is within the Capricorn Group and, in spite of the low hatching success, these cays almost certainly produce the largest number of *Caretta caretta* hatchlings for all east Australian rookeries. Of particular interest, however, is the question of hatchling sex ratio. If the *Caretta caretta* populations breeding in eastern Australia are relatively stable populations (and there is no evidence to suggest otherwise), and if the traditional theory of a turtle returning to her natal beach to breed holds true, then the coral-cay-nesting *Caretta caretta* would appear to be maintaining population stability with a male biased hatchling sex ratio. In contrast, the mainland nesting *Caretta caretta* would appear to be maintaining population stability with a very different female biased hatchling sex ratio. Such a situation seems incongruous. An alternative concept is that they return not to a specific beach but to a region, perhaps as large as that encompassing the southern Great Barrier Reef cays and the adjacent mainland. In that way, the excess males produced in one beach could be balancing the excess of females from another. Whether such a "balance" exists in relation to environmentally determined sex is not clear, and it should be noted that no reliable measure of a "natural sex ratio" for a sea turtle population exists. However a population genetics study is in progress to determine the genetic separateness of the Heron Is. and Mon Repos *Caretta caretta* populations. Whatever the result, the mainland *Caretta caretta* rookeries, in particular Mon Repos, are more important than previously recognised. Their high hatching success and female biased sex ratio make them important sources of females. If they share the same deme as the nearby coral cays, then they may also be important for producing the female hatchlings necessary for maintenance of the stability of the *Caretta caretta* nesting populations of the Capricornia Section of the Great Barrier Reef Marine Park. Planning for conservation of turtle nesting habitats should no longer consider only the length of beach available and nesting density but also whether adequate male and female producing beaches are available.

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