

Thermal Profiles of Sea Turtle Hatcheries and Nesting Areas at Praia do Forte, Brazil

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ABSTRACT. – Sand temperatures at sea turtle nest depth were taken in both open-air beach hatcheries and natural nesting areas at Praia do Forte, Bahia, Brazil. The mean sand temperatures at 30 and 60 cm depths in the hatcheries were not significantly different from those in natural areas with similar characteristics. The slightly higher differences between maximum and minimum daily temperatures in one of the hatcheries that was irrigated were unlikely to have had major effects on sex ratio. The present study indicates nest relocation into open-air beach hatcheries at Praia do Forte had very minor effects on sex ratios of hatchling loggerhead turtles, *Caretta caretta*.

KEY WORDS. – Reptilia; Testudines; Cheloniidae; *Caretta caretta*; sea turtle; hatcheries; temperature; sex ratio; nest relocation; conservation; Brazil

The transfer or relocation of eggs from unsafe nesting areas to protected hatcheries is a common practice in the management of a number of Chelonian and crocodilian species. In the case of marine turtles in Brazil, nests at risk are relocated in many areas primarily due to erosion, tides, and non-human predators.

Although it is recognized that nest transfer may affect embryonic development (Blanck and Sawyer, 1981), the use of hatcheries can be viewed as acceptable, even if only as an interim measure, when the chances of survival are otherwise very low. The possible repercussions, however, underscore the need to evaluate the consequences of relocation.

The aim of this study was to determine if incubating sea turtle eggs in hatcheries in Brazil was likely to affect the sex ratio of the emerging hatchling population. Incubation temperatures have been found to influence sex determination in many reptiles (Raynaud and Pieau, 1985). Thus, comparing temperature profiles between hatchery and natural nesting areas should indicate whether sex ratios are similar. Despite their potential importance for population structure and reproduction, comparisons such as these are rarely carried out, possibly due to methodological or logistic constraints. We hope that the description of the methods and findings given here may prove helpful to those interested in evaluating influences of relocation on sex ratios.

Loggerhead sea turtles (*Caretta caretta*) commonly nest along the coast of mainland Brazil. The beach at Praia do Forte, Bahia, is one of the main nesting areas (Marcovaldi and Marcovaldi, 1989). Loggerheads are also the most abundant species at this site (D'Amato and Marczwski, 1993; Marcovaldi and Laurent, 1996). Nests are relocated from stretches of this beach to two protected open-air beach hatcheries designed to simulate natural conditions (D'Amato and Marczwski, 1993). This work is under the direction of Projeto TAMAR/IBAMA (the Brazilian Sea Turtle Conservation Program), which has been protecting sea turtles on a national scale for 15 years. As part of TAMAR's continued

efforts to evaluate and improve hatchery and conservation practices, we monitored sand temperatures at sea turtle nest depth both in the hatcheries and in areas of natural nesting of loggerhead turtles at Praia do Forte.

MATERIALS AND METHODS

Study Area and Location of Thermometers.—The main nesting season for loggerhead turtles at Praia do Forte is from September to March, with peak nesting in November and December (Marcovaldi and Laurent, 1996). We monitored sand temperatures at 30 and 60 cm depth from 7 October 1994 to 16 March 1995 in areas of Praia do Forte beach where loggerheads commonly nest, in additional sites close to the high tide line where only occasional nesting occurs, and in open-air beach hatcheries to which eggs had been relocated for protection. Temperatures were not obtained from the nests themselves. Beach vegetation in this area is dominated by coconut palms (*Cocos nucifera*).

Temperature Monitoring Sites.—Two beach sites where nesting was especially common were selected for temperature monitoring. One of these was ca. 2.5 km south of the hatcheries and the other ca. 2.5 km north. At both sites one transect was established in an open area where palm trees were few, and another transect in the more common condition where palms provided some shade in the afternoon. Along each transect, temperatures were monitored at two sites, one fairly high on the beach, and the other on the mid- to lower beach, but still well above the high tide line. Thus there were a total of 8 beach sites, 4 to the north and 4 to the south of the hatcheries, with 4 in open areas and 4 in areas with coconut palms on the landward side. Along three of the four transects an additional third site was monitored from 1 Nov on the lower beach near the high tide line where loggerhead turtles occasionally nest.

Open-Air Beach Hatcheries.—Sand temperatures were also monitored in two open-air hatcheries located on the

beach well above the high-tide line in a fenced-off area, about halfway between the two monitored natural nesting areas. One of the hatcheries (measuring 6.65 x 15.45 m) contained relatively coarse-grained yellow sand, similar to the sand on the north beach; the other (measuring 5.30 x 11.80 m) contained sand obtained from nearby inland dunes that was somewhat finer-grained and whiter than that on the south beach. Both hatcheries contained sand to about 1.25 m depths. These hatcheries were referred to as the yellow and the white hatcheries. In each one, two monitoring sites were chosen to include the area where most nests were located.

As part of TAMAR's continuing efforts to optimize hatchery procedures, water was sprinkled over the yellow hatchery almost daily for 1-3 hours from 16 November to 4 March. This measure, referred to as irrigation, was intended to keep incubation duration and humidity levels similar to those in natural areas. Fresh water was pumped into spigots attached to three movable wooden stakes. Early morning or afternoon irrigation was used to increase sand humidity, while irrigation during the hottest hours of the day, usually around noon, aimed at cooling the surface sand and had little effect on sand humidity levels due to rapid evaporation.

Sand Temperatures, Calibration, and Equilibration. — As well as recording from both 30 and 60 cm depth, both thermocouples (copper/constantan) and thermistors were used at each site and depth, unless otherwise noted. Both thermistors and thermocouples were calibrated against mercury thermometers that had themselves been calibrated against a Sybron-Taylor mercury thermometer: The latter had certified calibration against platinum resistance thermometers that had been calibrated by the US National Bureau of Standards. Even in the unlikely event that the certified Sybron-Taylor thermometer had been **miscalibrated**, the relationships between temperatures recorded in different parts of the beach would not be altered, as all our thermometers used this single thermometer as a reference. The readings from the thermistors and thermocouple recorders were displayed to the **nearest 0.1°C**, and the mercury thermometers had scales with 0.1°C intervals. If a 0.1°C error had occurred at calibration of the mercury thermometers, and at calibration of the thermistors/thermocouples, and when reading these in the field, an error of $\pm 0.3^\circ\text{C}$ would be possible.

Calibration of the thermocouple recorder was checked periodically at least **monthly**, and calibration of the **thermistor** recorders was checked at the beginning and end of the season. Whenever a temperature probe was buried or replaced, before any readings were taken, at least **12 hrs** were allowed for equilibration.

Mean Sand Temperatures. — Two different ways of determining mean temperatures over 24-hr periods were used. The first method depended on the use of thermistor devices that recorded the maximum and minimum temperatures since the last reading. The memory was cleared on one day and then, at the same time the next day, the maximum

and minimum temperatures were recorded. A mean of the maximum and minimum over 24 hrs gives a value close to the mean of temperatures taken repeatedly over 24 hrs. Validation of this procedure and a description of the recorders is given in Godfrey and Mrosovsky (1994). Maximum-minimum recorders were not deployed at the lowest 3 sites at the margin of the high tide zone lest they be swept away.

The second method of determining 24-hr mean temperatures made use of thermocouples read to the nearest 0.1°C with a digital thermometer (Physitemp Instrument Inc., Clifton, NJ) once per day; the time chosen varied according to logistic constraints and was usually before 0730 hrs or after 1700 hrs. Because there are daily changes in temperature even at the depth of turtle nests, it was necessary to adjust each reading taken at a given time of day to obtain an estimate of mean temperature over a 24-hour period. These adjustments were based on readings taken on other occasions every 3 hours round-the-clock. These round-the-clock measurements were made approximately once a month at each monitoring site and depth. To obtain a mean 24-hr temperature from a reading taken at a particular time of day, first the round-the-clock data on the closest available date were selected (usually this was within 2 weeks of a single reading; it was always within 3 weeks). Once the closest round-the-clock recordings had been **obtained**, the values from those recordings were plotted. From this plot it was then possible to determine the difference between the temperature at a particular time of day and the mean of the closest round-the-clock readings. This difference was then used to adjust single values taken at that same time of day to the closest mean value. Since the amplitude of the daily temperature cycle at 30 cm depth was generally about 2°C, adjustment factors needed to transform single readings to mean temperature levels seldom exceeded 1°C. At 60 cm depth, the amplitude of temperature cycles was about 0.5°C; therefore adjustment factors seldom exceeded 0.25°C for this depth.

Rainfall. — A rain gauge was placed in one of the open-air hatcheries and was usually checked each day. There were a few occasions when the rain gauge was not checked for up to 3 consecutive days. Evaporation of small amounts of rainfall in such periods could mean that rainfall was underestimated. However, errors are probably slight as particular attention was paid to checking the gauge daily when rains occurred.

Nest Depths. — The distance from the beach surface to the top of the egg **mass** was measured in 26 loggerhead nests at laying or soon after. The depth to the bottom of the egg chamber was measured in 49 nests that were excavated after emergence had occurred. The mean values for the top and bottom of the eggs were 36 and 54 cm respectively. These are not very precise values as measurements were made by different members of TAMAR's staff, using slightly different methods. Further, beach surfaces are not perfectly flat, and wind and tide action during the incubation period probably caused depth **measurements** taken when nests were

laid to differ from the same measurements taken after hatchling emergence. However, they do indicate that most clutches of loggerhead turtles at this site lie at depths encompassed by the 30 and 60 cm used in the temperature monitoring.

Shade Monitoring. — To assess whether and when coconut palms shaded the monitored sites, transects on the beach were visited repeatedly once each month, and it was noted if sites were uniformly shaded, partially shaded, or unshaded.

Sand Grain Size. — Samples of sand from the surface and from 40 cm below the surface were collected from the two beach areas and the two open-air hatcheries. Amounts of about 100g were washed in distilled water, dried, and passed through a series of 5 sieves with meshes of 1.0, 0.5, 0.25, 0.125, and 0.062 mm. The amount passing through each sieve was weighed, and each sand type classified according to grain size. This characteristic was measured to investigate relationships between grain size and thermal properties of the sand.

Data Analysis. — Because of logistic constraints, it was not always possible to monitor all temperature sites on a given day. Therefore, temperatures of different sites were not compared on a day-to-day basis but for half-month time intervals. The main aim was to obtain estimates of the average temperature for each of the 11 half-month time intervals of the season for each of the four main areas monitored (i.e., white and yellow hatcheries, north and south beaches). To obtain these estimates of average temperature for each time interval, the following steps were taken:

1. The means for each of the 11 half-month intervals were initially calculated separately for the thermistor and corrected thermocouple readings for each site and depth. For more than 82% of the 132 intervals (11 half-months x 12 sites), there were 5 or more readings available from each depth and from thermocouples and thermistors. For more than 70% there were 6 or more readings. For the thermistors, 11% of the intervals had fewer than 3 readings. However, in these cases there were 3 or more values from thermocouples. Most (9 out of 15) of the cases with few readings came from the first interval because monitoring was only started on 7 October, halfway through the interval.

2. The half-month interval values for thermocouple and thermistor readings were averaged. Both methods for estimating mean temperatures over 24 hrs depended on certain assumptions about daily temperature changes (see above), but since it was not possible to determine which method was superior, averages were taken. This had relatively little impact on absolute temperature values because differences between the two methods averaged 0.3°C, with the thermocouples usually giving higher values. Even if there were some minor inaccuracies in specifying actual temperatures, these should have had negligible effects on estimates of differences in temperature between hatchery and beach areas, which was the main focus of this study.

3. From the half-month interval values for each site we obtained a mean value for the four areas (white and yellow

hatchery, north and south beach) by grouping the values from the available sites in each of these areas. However, data from 30 and 60 cm depths were kept separate, and analyses were done separately for each depth.

4. Differences between the four areas were assessed with repeated measures analysis of variance, using INSTAT2 GraphPad software. Bonferroni corrections were used in assessing the significance levels for subsequent t-tests.

RESULTS

Hatchery-Beach Comparisons. — A prominent feature of the data was a seasonal increase in temperature from October to February. This was approximately 3.5°C and occurred at all sites (Fig. 1).

There were statistically significant differences between the temperature means of various areas ($F = 20.4$, 30 cm; $F = 31.7$, 60 cm; $p < .0001$ in both cases). The t-tests showed that the white hatchery was cooler than the yellow hatchery and the north beach ($p < .001$), but not significantly different from the south beach ($p > .05$). The south beach was also cooler than the north beach and the yellow hatchery ($p < .01$). The temperatures of the north beach and yellow hatchery were not significantly different ($p > .05$). These significance levels applied to both the 30 and 60 cm depths.

The temperature differences between sites, although highly significant because of large sample sizes, were small in absolute terms. The greatest difference found was between the white and yellow hatchery but this averaged only about 1°C over the season (Fig. 2).

Irrigation of Yellow Hatchery. — Irrigation reduced the temperature of the yellow hatchery, as intended (Fig. 3). The effect was more pronounced at 30 cm depth than at 60 cm. However, at both depths, there were significant negative correlations between the mean duration of irrigation in hours per day for half-month intervals and the amount by which the yellow hatchery was warmer than the white hatchery (30 cm, $r = -.85$, $p < .001$; 60 cm, $r = -.72$, $p = .013$).

A second effect of the irrigation of the yellow hatchery was an increase in the daily variation in temperature. Data on the daily range of temperatures were obtained by taking the difference between the maximum and minimum values recorded by the thermistors. These ranges increased in the yellow hatchery during the half-month intervals with irrigation. There were significant correlations between the ranges as a function of the duration of irrigation in the yellow hatchery. These increases cannot be attributed to more variable weather, because ranges remained more or less constant in the non-irrigated white hatchery over the season (Fig. 4) and in the north beach area.

The effects of irrigation were not masked by rainfall because for much of the nesting season, especially during the middle of the season when irrigation was used, there was little rainfall. The average rainfall in mm/day for the 11 half-month intervals was 1.8, 2.5, 0.4, 3.3, 0.3, 0.7, 0.9, 0.0, 1.0, 0.4, and 2.2.

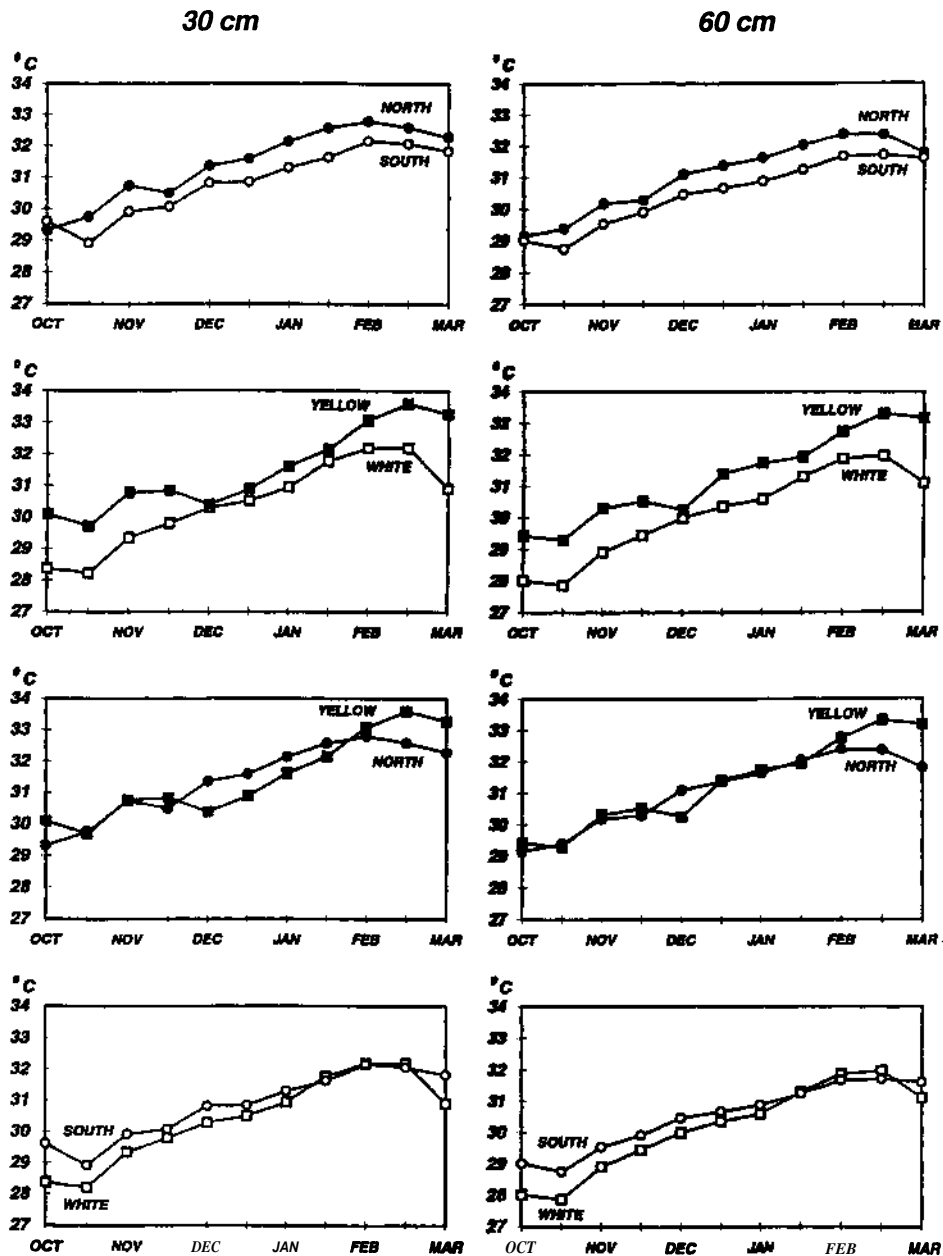


Figure 1. Selected temperature comparisons between nesting and hatchery areas. These illustrate the differences between the two hatcheries and the two beach areas (top 4 panels), and the similarity between the white hatchery and south beach, and between the yellow hatchery and north beach (lower 4 panels). The start of each month is shown on the x axis.

Palm Trees.— For the sites high on the beach nearest the tree line, those near palms were not significantly cooler than those in more open ground (paired t-tests, $p > .05$, in every case differences were not $> 0.2^{\circ}\text{C}$). In fact, on the south beach the site near palms was actually slightly warmer; at this site shade was not noted until after 1500 hrs, and even then it did not always persist for the rest of the afternoon. This was also true for shade at the north site near palms, except that at the start and end of the season (October and February) shade was first noted between 1300 and 1400 hrs. Sites on the mid-beach were too far from the treeline to be affected by shade until after 1700 hrs; shade at this time would make little difference

because it began to get dark around 1815 hrs. A few instances of shade were noted around 1600 hrs but this shade was usually partial and did not persist uninterruptedly over the rest of the afternoon. **Overall**, we found no evidence of any differences in temperature related to shade from palm trees.

Distance From Water.— There was a gradient of about 0.4°C between temperatures on the lower and upper portions of the beach. The means for the 9 intervals from 1 November to 16 March for high, mid-, and low beach sites, respectively, were 31.7 , 31.4 , and 31.3°C at 30 cm, and 31.3 , 31.1 , and 31.0°C at 60 cm. Although these differences are not large they were significant due

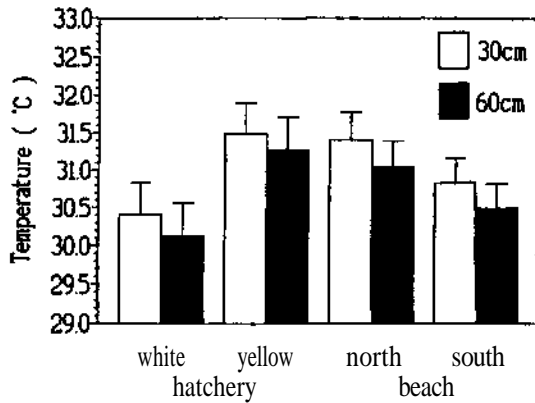


Figure 2. Means and standard errors for temperatures for each area for the entire season.

to large sample sizes (repeated measures analysis of variance, $p < .01$).

Sand Size. — Particle size of the sand in the yellow hatchery and the north beach was similar, and was larger in both than that in the south beach and the white hatchery (Table 1). The grain sizes were similar at the surface and at 40 cm depth (data not shown).

DISCUSSION

Temperatures at nest depth in the open-air beach hatcheries at Praia do Forte were on average close to those of natural areas with similar sand characteristics, suggesting that differences in sex ratio are not great. In the case of the yellow hatchery, this similarity in temperature was achieved by irrigating the sand for a few hours a day during the hottest parts of the season.

At the start of the season, when temperatures are cooler, nearer 29°C, it is conceivable that the use of the white hatchery might lead to small increases in the number of males produced. Even though overall the temperature of the white hatchery was not significantly different from that of the south beach, the data suggest that the hatchery might be cooler than the beach at the start of the season (Fig. 1). Further work would be required to substantiate this.

Although both open-air hatcheries were similar to beach sites in terms of mean temperatures, irrigation in the yellow hatchery was associated with an increase in the daily range of temperatures of 1°C at 30 cm depth and 0.5°C at 60 cm. The irrigation, however, was necessary to maintain thermal similarity to natural areas, and changes of this amount in range are not likely to have a marked effect on the sex ratio.

Table 1. Percent of sand by weight in different grain sizes.

Sand Grain Size mm	Yellow Hatchery	North Beach	South Beach	White Hatchery
> 1.0	1.0	2.6	0.1	1.3
0.5-1.0	39.2	42.6	12.0	10.2
0.25-0.5	59.0	53.6	74.6	63.2
0.125-0.25	0.8	1.2	13.1	20.8
0.062-0.125	0	0	0.2	4.2
<0.062	0	0	0	0.3

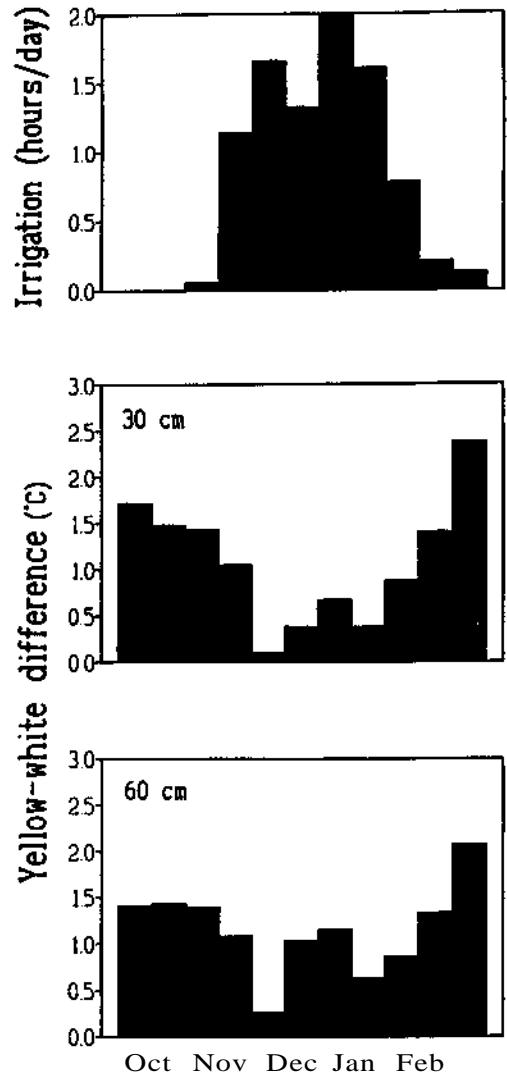


Figure 3. Mean duration of irrigation in the yellow hatchery over the season and differences between mean temperature in the yellow and the white (non-irrigated) hatcheries.

Georges et al. (1994) determined that temperature fluctuations may impact turtle sex ratios by altering the proportion of development occurring at particular temperatures. Because more embryonic development occurs at higher temperature, an increase in range, even if mean temperature remains unaltered, is equivalent to incubating the eggs at a slightly higher temperature. This effect, however, is greatest for shallow-nesting species where daily fluctuations are great, rather than for deep-nesting species like sea turtles (Georges et al., 1994).

In the case of the yellow hatchery, the increase in range of about 1°C (from about 2-3°C) is likely to augment the constant temperature equivalent by only about 0.2°C (Georges et al., 1994). It should, however, be noted that the temperature changes in the experiments of Georges et al. (1994) approximately followed the form of sine waves, which did not exactly match the temperature changes produced by irrigation in the yellow hatchery. Nevertheless, if the pivotal temperature for Brazilian loggerheads is similar to that for

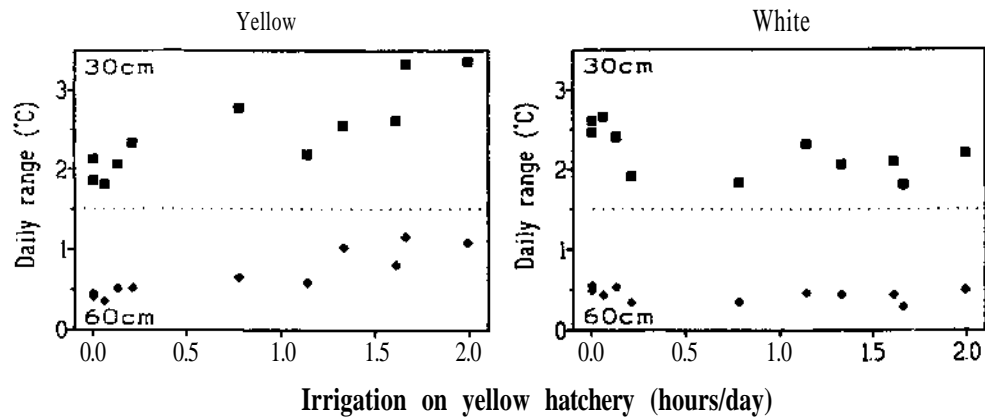


Figure 4. Daily temperature ranges in the yellow and white hatcheries as a function of duration of irrigation in the yellow hatchery. Ranges are positively correlated with irrigation in the yellow hatchery (30 cm, $r = .85$; 60 cm, $r = .91$; $p < .001$ in both cases). Temperature ranges in the white (non-irrigated) hatchery and in the yellow-sand north beach area (data not graphed) showed non-significant negative correlations with irrigation in the yellow hatchery, indicating that changes in weather were not responsible for the significant positive correlations obtained in the yellow hatchery.

loggerheads elsewhere (approximately 29°C; Marcovaldi et al., 1997), an increase in the constant temperature equivalent in the yellow hatchery would have little effect on sex ratio since the temperature was 30°C or above for most of the season (Fig. 1).

The present study, as well as indicating that the hatcheries at Praia do Forte are unlikely to be introducing much bias into sex ratios, provides data on a number of other factors that potentially have thermal effects. The most obvious of these is sand type. The greatest temperature difference found in this study, that between the yellow and white hatchery (Fig. 2), is probably attributable to the color and quality of the sand, though because these open-air hatcheries were placed near buildings and associated trees, and located in places convenient for protecting the eggs rather than for a scientifically designed experiment, differences in complicated and varying patterns of shade cannot be ruled out. However, the north and south beach areas, which differed in sand color, also registered different temperatures, with the whiter and finer sand on the south beach having cooler temperatures.

Also, comparisons of sand temperature between other turtle beaches suggest that whitish calcareous sand tends to be cooler than darker sand with more silica (Limpus et al., 1983; Mrosovsky et al., 1992). Hays et al. (1995) found that sand temperatures and albedo (the ratio of the amount of light reflected by a surface to the amount of incident light) were negatively correlated on 12 beaches on Ascension Island; the darkest beach was 4.2°C warmer than the lightest. Much of the variance in temperature was accounted for by albedo ($r^2 = 0.95$), indicating that other factors such as slope and exposure to winds were of little thermal importance. An even better way to study the influence of sand type on temperature is to transport sand from different areas to a single uniform place and make comparisons under exactly the same environmental conditions. This has been done with pale whitish aragonite sand from the Bahamas and darker more siliceous sand from Florida. A preliminary report

indicated that nests of loggerhead turtles incubated in the aragonite sand were about 2°C cooler than those placed in siliceous sand (Shaw et al., 1995).

The lack of temperature differences attributable to shade from palm trees found in this study is not too surprising if one considers information from other research on the effect of shade. In Florida, on a beach running in a north-south direction, shade from tall beach-front buildings was associated with lowering of temperatures of only about 1°C on average (Mrosovsky et al., 1995). The shade from such buildings is much more extensive and persistent than that produced by groves of coconut palms. This is not to say that palm trees are without any influence on beach temperatures in Brazil, but given natural variation between sites, it might take larger samples to detect such effects.

Although we do not believe that use of open-air hatcheries such as those at Praia do Forte has large effects on sex ratios, two cautions are in order. First, small effects, cumulated over many years as a result of entrenched hatchery procedures, could introduce biases in the sex ratio. Second, one needs to be alert for other ways in which use of hatcheries might affect sea turtles. For example, it might seem appropriate to employ white dune sand more often in hatcheries, because hatchling survival rates are higher (D'Amato and Durst, 1994) and watering is not necessary. But whether or not imprinting on beach characteristics — if that exists as part of the mechanism for natal homing — would be affected by sand type, is unknown. Another possibility is that handling of the eggs during relocation might affect sex ratios, but this seems unlikely because the movement of the eggs occurs well in advance of the period of development when sex is determined. Aspects of hatchery sand to be considered include moisture content (especially in the irrigated hatchery), grain size, and the effects of prolonged watering (rainfall or irrigation) on the sand. Therefore, TAMAR will continue to seek ways to optimize hatchery procedures. The organization is addressing these issues at present by experiments in one hatchery using sand from the south beach

which does not require irrigation and comes from an area of concentrated natural nesting. TAMAR's long-term strategy is to leave as many nests as possible *in situ*, or to relocate nests onto safer areas of the beach rather than into hatcheries. Currently about 70% of nests managed by TAMAR are left on the beach, and all nests on oceanic islands are left in natural conditions (Baptistotte, 1995). But for nests that are at high risk, use of open-air hatcheries will be continued. The practice of maintaining a number of smallish open-air hatcheries, with sand type similar to that on local beaches along the 1000 km of coast monitored by TAMAR, rather than a few central ones, provides further insurance against introducing sex ratio biases.

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