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THERMAL EFFECTS OF CONDOMINIUMS ON A TURTLE BEACH IN FLORIDA

N. Mrosovsky,[a] Craig Lavin[b] & Matthew H. Godfrey[a]

[a]Department of Zoology, University of Toronto, Toronto, Ontario, M5S 1A1 Canada

[b]Department of Biological Sciences, Florida Atlantic University, Boca Raton, FL 33431, USA

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Abstract

Beach temperatures at the depth of nests were studied at the loggerhead turtle Caretta caretta *rookery at Boca Raton, Florida. The sand at 30 and 60 cm depth in areas shaded by condominiums averaged about 1°C cooler than that in adjacent areas unshaded by buildings. With particularly large condominiums, differences were as large as 2°C. Longer incubation durations of nests laid close to buildings were consistent with such sites being cooler. In the heat of midsummer, when temperatures on this beach were almost always well above the pivotal level, the shade from condominiums probably did not alter the sex ratio of the hatchlings. However, at the cooler start of the season, shade reduced temperatures to below the pivotal level, presumably increasing the number of males produced at this time.*

Keywords: condominium, incubation, loggerhead, nest site, sea turtle, sex ratio, temperature.

INTRODUCTION

Turtles use beaches for procreation. People use beaches for recreation. Are these two compatible? Attention has focussed on 'photopollution' (Verheijen, 1985) from human activities. For instance, because the seafinding orientation of hatchlings depends on visual cues (reviews in Mrosovsky & Kingsmill, 1985; Salmon *et al.*, 1992), lights from highways and condominiums can be disruptive; delay in reaching the water increases vulnerability to terrestrial predators. Efforts have been made to discover what wavelengths affect turtles the least (Witherington & Bjorndal, 1991) and to promote lighting ordinances and public education about the need to reduce illumination (Raymond, 1984). However, little attention has been given to the possibility of thermal pollution from buildings.

It is known that sexual differentiation in sea turtles, like that of many other reptiles, depends on the temperature prevailing during incubation of the egg (review in Raynaud & Pieau, 1985). In sea turtles, at higher temperatures the embryos develop into females. at lower temperatures into males. In between these high and low levels is a transitional range of temperature within which either sex can be produced. Somewhere around the middle of this transitional range is the pivotal temperature at which 50% of each sex is produced (see Mrosovsky & Pieau, 1991, for definitions). It is plausible that condominiums, by shading the beach for part of the day (Fig. 1), could push sand temperatures down toward or lower than the masculine end of the transitional range of temperatures.

We investigated this possibility by comparing beach temperatures at sites in front of condominiums to those in undeveloped areas; average temperatures over 24 h periods were taken. An attempt was also made to obtain an index of temperature differences over longer periods by studying incubation durations.

METHODS

The study area was at Boca Raton, Florida; it extended from Red Reef Park to about a few km south of Palmetto Park Road. The beach here runs approximately north–south and has numerous condominiums behind it, but also includes enough undeveloped areas to provide control sites. Loggerhead turtles *Caretta caretta* commonly nest on this stretch of the coast from early May to early October. Sand temperatures were measured during two field visits, one late in the turtle season in 1991 and the other early in the season in 1992. Slightly different recording methods were used on the two occasions.

Late season temperatures, 1991

Single transects were selected in front of each condominium (n = 6) and at the nearest undeveloped space available by each building, usually adjacent to the condominium (n = 6). At each transect, three sites were selected for temperature measurement: one site high on the beach near the condominium, one site at mid-beach, and one site low on the beach, a metre or two above the recent high tide lines. All sites were within the zone where loggerheads laid their nests. In 1988 this beach was renourished with sand dredged up from offshore. Proximity of control and condominium sites minimized differences in sand quality and width of beach.

At each site a wooden dowel was buried with two

Fig. 1. Shadows cast by condominiums, late afternoon, 1991, Boca Raton, Florida. Note clump of nests, protected by wire cages, in the shadow.

thermocouples attached, one at 30 cm, the other at 60 cm, depth. After allowing at least 14 h for equilibration, temperatures were read approximately every 3 h over a 24 h period. Times for reading temperatures were *c.* 0100, 0400, 0700, 1000, 1300, 1600, 1900 and 2200 h. When daytime readings were taken, a note was made of whether the condominiums screened the sun from the thermocouple site. The readings were taken over two different 24 h periods between 13 and 18 July 1991, three condominium and three control transects being studied over a given 24 h period.

Temperatures were taken with a BAT-12 digital thermometer (Sensortek, Clifton, NJ) with the same particular recorder being used in any one 24 h period. Probes and recorders were calibrated against a Sybron-Taylor (Arden, NC) mercury thermometer, the latter with certified calibration. Small correction factors (not $>0{\cdot}1°C$) were applied when necessary. On eight occasions single readings were lost because of faulty connections; six of the lost readings were for 60 cm thermocouples. For lost readings, values were assigned by interpolation or extrapolation from adjacent time points. Because sand temperatures change slowly, it made virtually no difference whether assigned values were included or averages of the other values were taken. In any case, missing values represented $<1{\cdot}4\%$ of the total number of readings.

Early season temperatures, 1992

The main difference in procedure was that instead of measuring temperatures every 3 h around the clock we used thermistor devices that memorized the maximum and minimum temperatures since the time when last cleared. The use of this method to assess mean temperature depends on the finding that the mean of the maximum and the minimum temperatures over a 24 h span in the sand on a turtle beach closely approximates ($<0{\cdot}1°C$ difference on average) the mean calculated from numerous around-the-clock readings. The validation of this point and full description of the device is provided by Godfrey and Mrosovsky (1994). The use of these maximum–minimum memorizers made it possible to avoid working on the beach all through the night.

Each thermistor was calibrated as in the previous year. At least 18 h were allowed for equilibration after burying the probes. Between 22 May and 6 June 1993, data were obtained for 10 condominium and 10 nearby transects (i.e. the sample size was larger than for the late season work in 1991, and not exactly the same sites were studied). On any day on which readings were taken at a condominium transect, readings were also taken from a nearby control transect. As in 1991, there were three sites in each transect (high, mid and low beach) and two depths (30 and 60 cm). Thus there were 20 transects with six temperature probes in each transect.

Incubation durations

Early in the morning every day in June and July 1992, one of us walked along the beach for approx. 1 km, starting at Palmetto Park Road and going south. Nests laid on known dates and previously marked by the

Boca Raton Sea Turtle Conservation Program were inspected for hatchlings. During June, before any emergences, nearly all nests on this stretch of beach were assigned to one of two groups, control and condominium. Control group nests were those laid in areas not shaded by buildings. Condominium group nests received afternoon shade from buildings. Four visits to the beach at approximately 3-week intervals confirmed that 78% of the nests in the condominium sample were shaded by 1530 h, and the other 22% became shaded by 1630 h. A few nests that were on the edge of shadow between condominiums and open areas were excluded from either group, because they did not remain predictably in the shadow as the afternoon wore on. No data were obtained from any nest laid after 4 July because Hurricane Andrew washed away nest markers. A few nests laid too near the water had been moved up the beach to above the high tide.

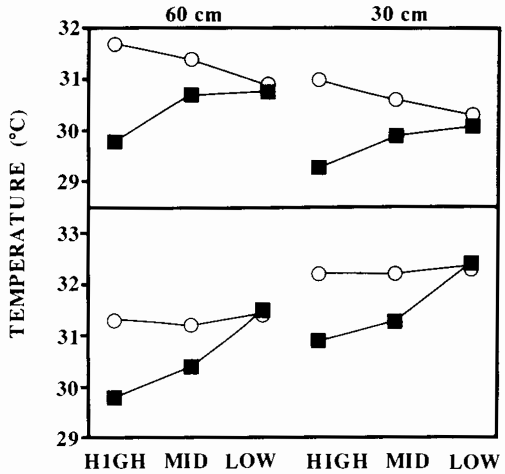

Fig. 3. Examples of temperatures (means over 24 h) from two transects extensively shaded by condominiums (■) compared to those for two nearby transects in unshaded areas (○), July 1991.

Analyses

Only one-tailed t-tests (unpaired) were used, since predictions were made about the direction of effects; $p < 0{\cdot}05$ was accepted as significant.

RESULTS

Late season temperatures

The effect of shade from condominiums depended on the position of the nest on the beach. For sites high up on the beach, relatively near to the buildings, the sand was close to 1°C cooler than in comparable areas in front of dunes ($p < 0{\cdot}001$ for 60 cm, $p = 0{\cdot}03$ for 30 cm, Fig. 2). For sites farther away from the buildings (mid and low beach), the differences were not significant. This is to be expected because, on a beach oriented in a north–south direction, the shadows from buildings do not reach the lower beach until later in the afternoon. Therefore, not all sites between a condominium and the sea are cooler.

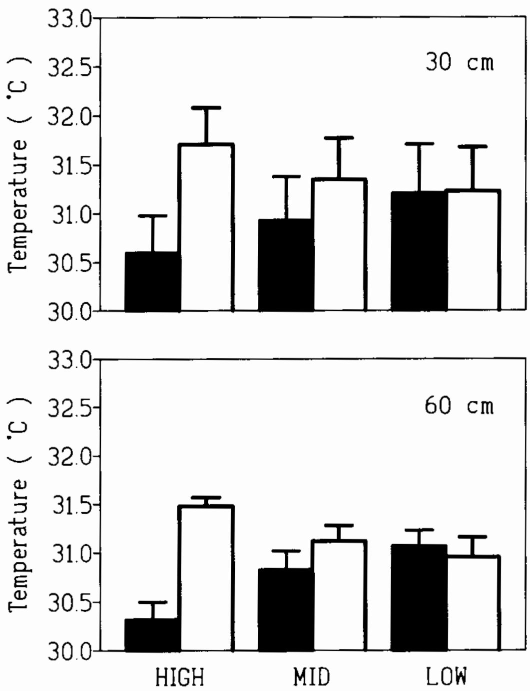

Fig. 2. Means ± SEM of mean temperatures over 24 h for high, mid and low beach sites, July 1991. ■, transects in front of condominiums (n = 6); □, transects without buildings (n = 6).

The 1°C difference between the means for the high beach sites in Fig. 2 does not reveal the full extent of the cooling effect that condominiums can have on the beach. Each building is different and casts shadows for different durations, depending on height, width, and nearness to the water, etc. In front of some condominiums the temperature was almost 2°C lower than in nearby control sites. Figure 3 shows examples from two transects that were extensively shaded by buildings compared to two adjacent unshaded transects. In one case (top) the 30 cm readings are lower than those at 60 cm, while in another case (bottom) they are higher. This reflects different weather conditions. There were heavy rains on the days preceding collection of data from some transects (top) and generally sunny conditions preceding collection of data from other transects (bottom). Sand temperatures at 30 cm depth are more susceptible to these changes than those lower down. Although loggerheads do not lay their eggs as deep as 60 cm, recordings from this depth are in some ways better indicators of average temperature in circumstances when a given site cannot be monitored continuously for many days. In any case, the cooling effect of condominiums is evident both at 30 cm and at 60 cm.

Early season temperatures

The data for the measurements made early in the season showed that at this time of year also the sand high up on the beach near condominiums is about 1°C cooler on average than in adjacent transects without buildings ($p < 0{\cdot}001$ at both depths, Fig. 4). On the mid and low beach, differences between condominium and natural sites did not reach significance ($p > 0{\cdot}05$ at both depths).

The actual temperatures were lower in May–June than later in the season (compare Figs 2 and 4); the values for control areas at both times were close to those

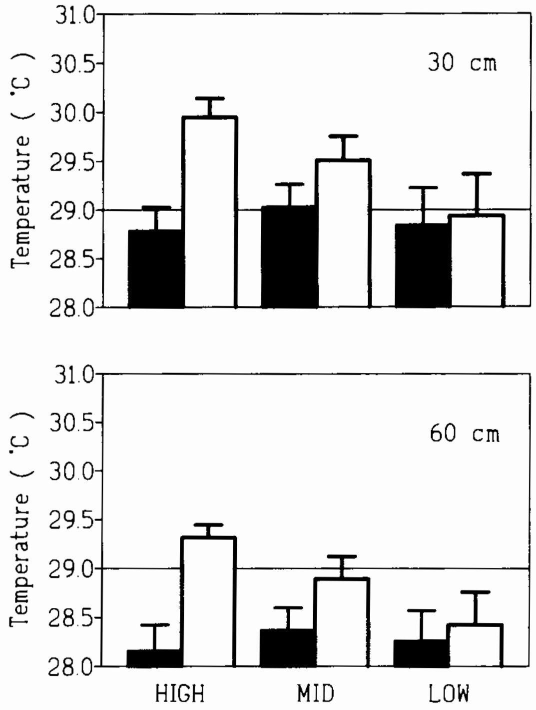

Fig. 4. Means ± SEM of mean temperatures over 24 h for high, mid and low beach sites, May–June 1992. ■, transects in front of condominiums (n = 10), □, transects without buildings (n = 10). Horizontal lines shows pivotal temperature for loggerhead turtles in the USA (Mrosovsky, 1988).

typical for recent years at loggerhead rookeries a little farther up the coast at Cape Canaveral (Mrosovsky & Provancha, 1992).

Incubation durations

There was a trend for incubation durations to be longer in nests laid in the shade of condominiums (Fig. 5). When all the nests in the sample are considered, this trend fell short of significance (p = 0·12). However, because of seasonal changes in incubation duration and the unbalanced sample in May, an overall comparison may be misleading. If nests for June are considered, or for June plus the few nests laid early in July, then condominium nests do have longer incubation durations, 2.85 days extra for June (p = 0·006), and 2·61 days for June and July considered together (p = 0·009).

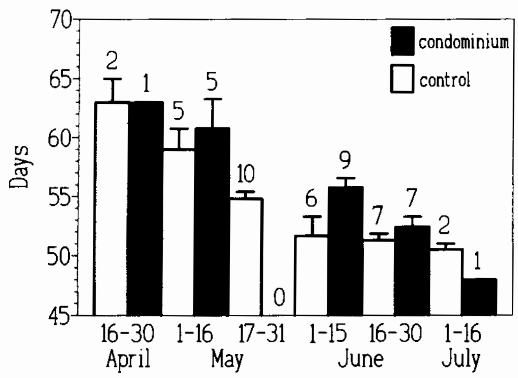

Fig. 5. Means ± SEM of incubation durations (laying to emergence) for 1992 sample, plotted in half month bins. Numbers above bars are n values. Dates are for laying.

DISCUSSION

The incubation durations are consistent with the direct measurements on temperature. From laboratory data, a rough rule of thumb was derived for sea turtle eggs: a 1°C lowering of temperature results in a 5 days' lengthening of the time from laying to hatching (Mrosovsky & Yntema, 1980). However, the size of the effect depends on the absolute temperature levels and becomes smaller at levels close to 30°C; at higher temperatures a 1°C difference may barely affect incubation durations. More extensive data for loggerhead turtles (Mrosovsky, 1988) show that incubation duration at 30·4°C is 50·5 days (n = 50) and at 29·5°C is 53·3 days (n = 77); this is equivalent to 1°C adding 3 days onto incubation duration. Assuming that the time from hatching to emergence is the same in shaded and sunny areas, a similar 3-day lengthening for a 1°C drop in field conditions might be expected. However in the present case, sand temperatures were nearer 31 than 30°C for much of incubation (Fig. 2); therefore the effect would be reduced. Moreover, once metabolic warming begins, the temperature of the actual nests would be still higher. Therefore, the values of the 2–3 days found for June nests (Fig. 5) are in line with what might be expected if nest temperatures at these sites were about 1°C cooler. Collecting data on incubation durations may be the simplest way in some circumstances to discover if shade from buildings is reducing nest temperatures, but fairly large samples and attention to seasonal changes would be needed.

It has to be emphasized that the present results are for particular sites, weather conditions, parts of the season, and for a particular beach running approximately north–south. Moreover each condominium is different. Therefore the present data should be taken as no more than an indication of what might occur on other beaches in other circumstances. Nevertheless, it is safe to say that condominiums tend to reduce beach temperatures, that these effects are in the order of 1°C, and at some sites can be as large as about 2°C.

Could such differences affect sex ratio? In the later part of the season, the mean sand temperatures were mostly in the 30–31°C range. This is well above the 29°C pivotal level for loggerhead turtles in the USA, and close to the upper (female) end of the transitional range of temperatures. Therefore, whether the nests were laid in the shade of buildings or not, the sand would still have been warm enough to produce mostly, perhaps all, females. In support of this inference is the fact that in midsummer at Cape Canaveral beach temperatures are usually close to 31°C and nearly all the loggerhead hatchlings produced there are female (Mrosovsky & Provancha, 1989, 1992).

However in the early part of the season, shade from buildings probably does influence sex ratio. The cooling effect of condominiums in May–June reduced the mean sand temperature on the upper beach to below the pivotal temperature of loggerhead turtles on this coast (Fig. 4). The average pivotal temperatures of the few loggerhead clutches studied so far is 29·0°C, but some clutches can have pivotals as high as 29·7°C (Mrosovsky, 1988). For such clutches, the cooling by condominiums might be effective in altering sex ratio at times later than the start of the nesting season. However, clutches with pivotals well above 29·0°C are probably rare because at Cape Canaveral, where mid-season sand temperatures are around 31·0°C, almost exclusively females are produced (Mrosovsky & Provancha, 1989, 1992). Therefore, it is likely that the main effects of condominiums in eastern Florida are restricted to early parts of the season, perhaps increasing the number of males produced at that time. On loggerhead beaches further north where it is cooler, the sand temperatures are presumably close to pivotal level for more of the season than they are in Florida. If our results can be generalized, buildings on northern beaches probably cause greater changes in sex ratio than in Florida.

Should the temperature effects found on this Florida beach studied here be considered harmful or desirable? There are two difficulties in answering this question. The first is that there is insufficient information on the thermal profiles of these beaches before condominiums were built. A. K. Craig (pers. comm.) estimates that 100 years ago the vegetation seldom reached a height of more than 5 m, and most of the taller plants were on the landward side of the beach ridge. Closer to the beach itself the plant associations were dominated by saw palmettos *Serenoa repens* (Austin *et al.*, 1977). It seems likely, therefore, that the shade from today's condominiums is far more extensive than that formerly provided by natural vegetation (also compare Figs 1 and 6).

However, cooling produced by increased shade from buildings must be considered in the context of other unnatural changes on these beaches. Photographs from the turn of the century, provided by A. K. Craig, show heavy accumulations of sargassum on some Florida beaches. Today it is a common practice to clear away sargassum. It has not been investigated whether sargassum accumulations, if left alone, would last long enough to influence beach temperatures before disintegrating or being washed away. Perhaps the reflectance and thermal characteristics of unraked beaches would be different. The practice of nourishing beaches by adding sand from offshore is another factor that needs evaluating. Although no obvious differences in sand temperatures of nourished and unnourished areas have been detected yet (Broadwell, 1991), the matter requires more extensive study.

The second problem is that it is not known whether having pivotal temperatures so far above beach temperatures, and the consequent large biases in hatchling production toward females (>90% in Florida, Mrosovsky & Provancha, 1992), is a natural and desirable state of affairs for this turtle population. If it is, then the shadows cast by buildings and the consequent cooling effects can be considered as thermal pollution. If, however, present female biases represent some demographic distortion – one that could become more severe should global warming become significant — then condominiums could be considered as part of a thermal solution rather than as thermal pollution. A major gap in knowledge, of practical as well as theoretical importance, is the lack of reliable information on equilibrium natural sex ratios in undisturbed populations of reptiles whose sexual differentiation depends on temperature (see discussion in Mrosovsky & Provancha, 1992; Mrosovsky, 1994).

Because it is clear that buildings have the potential to influence sex ratio, surveys are needed of the

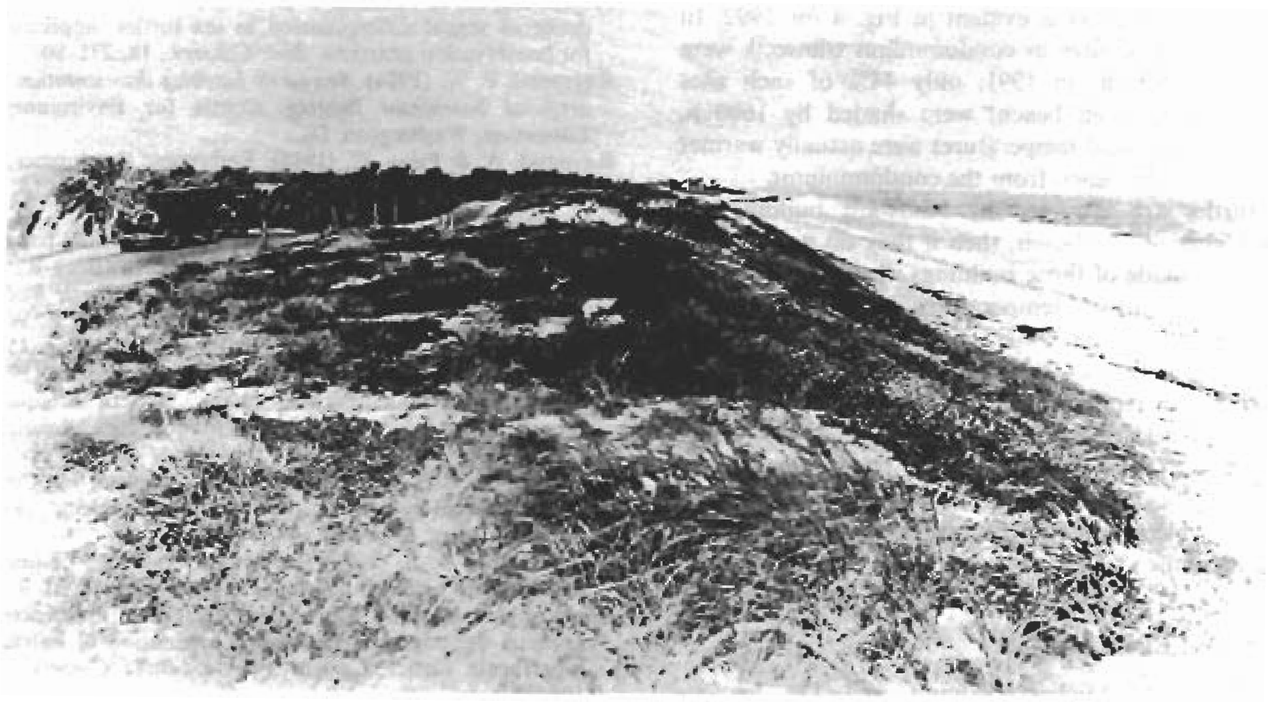

Fig. 6. The beachscape near Lake Boca Raton looking north, as it was in the late 1920s. Photograph kindly provided by the Boca Raton Historical Society from their archives.

percentage of beaches at the principal loggerhead turtle rookeries that receive shade from buildings, and how many turtles nest in this shade. It might be thought that turtles would avoid large unnatural objects on the beach, especially when these produce light (Witherington, 1992). However, nearly every one concerned with the sea turtle program in the Boca Raton area has noticed that sometimes there are clusters of nests near condominiums, with lesser nesting density in adjacent areas (e.g. Fig. 1). This is also our impression. Systematic studies by Salmon *et al.* (1994) are in progress.

Light from condominiums in Florida during the summer, the turtle nesting season, is very variable. In some condominiums many units are empty and shuttered, so that the light may often be insufficient to deter turtles. Possibly in such cases condominiums are a supernormal releaser for stimuli naturally provided by land masses and vegetation. It may be adaptive to nest near vegetation since its presence denotes places that have escaped high tides. It also provides cues that help the hatchlings orient toward the sea. Whatever the case, if impressions of nesting aggregations in front of condominiums are substantiated, they should be able to tell us something about nest site selection.

If nest site selection is influenced by condominiums, then their effects on sex ratio may be more complex than simply providing additional shade. Figures 2, 3, and 4 show trends for control transects to be cooler nearer the sea, presumably because the water table is nearer the surface at these sites. This trend is absent or reversed in condominium transects. In such areas, there are two cooling influences: from the water table, pronounced on the lower beach, and from the shade of condominiums, especially on the upper beach. It would be expected therefore that shade from buildings would reduce thermal gradients between the low and high beach. This reduction is evident in Fig. 4 for 1992. In that year 80% of sites in condominium transects were shaded by 1600 h. In 1991, only 44% of such sites (mostly on the high beach) were shaded by 1600 h, and if anything sand temperatures were actually warmer farther down the beach from the condominiums.

If turtles are attracted by landward buildings to move higher up the beach, then if they do not actually nest in the shade of those buildings, their eggs could be exposed to warmer temperatures than if they had nested closer to the water. To assess the effects of condominiums on sex ratio not only requires information on beach temperatures but also an understanding of nest site selection on these beaches, and on former or more natural nesting habitats. The present paper outlines some of these considerations and makes a start on the problem by documenting the cooling effects of condominiums.

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