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SIMPLE METHOD OF ESTIMATING MEAN INCUBATION TEMPERATURES ON SEA TURTLE BEACHES.—For studies of sex ratios in reptiles, it is important to know incubation temperatures. Soil temperature at nest depth varies over the course of 24 hours. This is true even for marine turtles whose eggs are deposited well below the surface. Therefore, to

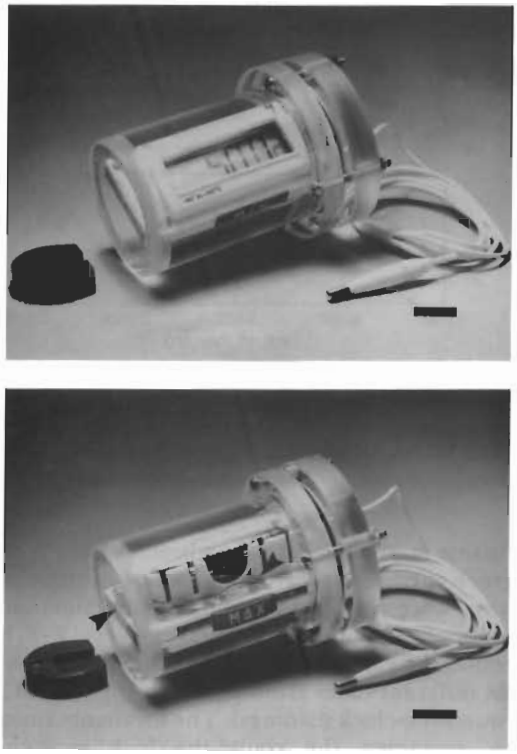

Fig. 1. Maximum-minimum memorizer in its casing. Top shows digital display at front. Bottom shows reed switches (arrows) and battery at back. Scale bar = 1.5 cm. The probe can be uncoiled and buried about 1 m away from the casing.

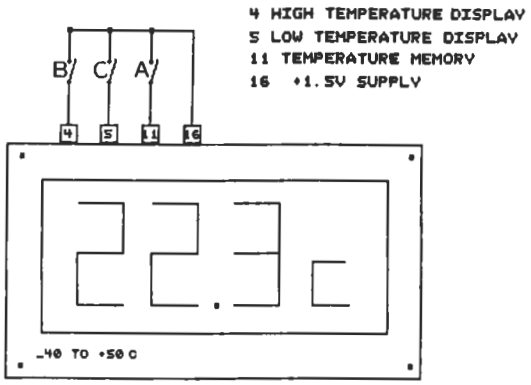

Fig. 2. Wiring diagram. A, B, and C are positions of magnetic switches.

obtain a mean daily temperature, frequent readings are required. A datalogger is one way to provide these, but there are some associated disadvantages. Dependence on a single piece of equipment may be a drawback in isolated places. In more accessible places, there may be a risk of theft. Dataloggers are expensive and may not be suitable where recording sites are far apart, because long leads are then required to connect the thermosensors to the recorder. A way to avoid relying on a datalogger to obtain a daily mean temperature is simply to take measurements manually every few hours. However, such a labor-intensive procedure can seldom be sustained for long periods.

We have developed a compromise procedure that includes sufficient automation to avoid having to take readings frequently but is cheaper than a datalogger and also enables monitoring of widely scattered sites. This consists of a module that memorizes the maximum and minimum temperatures since it was last cleared. For beach temperatures at sea turtle nest depth, the mean of the maximum and the minimum temperatures over a 24-h span is very close to the mean based on frequent readings over the same period.

Methods.—The maximum-minimum memorizer consists of a commercially available thermistor with a digital readout (Radio Shack #277-302, $Can 22.42 in 1992; also #630-1020 can be used) powered by an alkaline AA battery. The module is encased in clear acrylic (Plexiglas) with water-tight seals, and its displays can be activated via magnetic reed switches without opening its case (Fig. 1). The type of magnetic switch is not critical, but those found in security devices for doors and windows are generally suitable. A wiring diagram is provided in Figure 2. The display shows the current temperature. The maximum temperature since the time when the module was cleared is obtained by first activating reed switch A and then reed switch B. The minimum temperature since the time when the module was cleared is obtained by first activating reed switch A and then reed switch C. To clear the memory, a magnet is held over reed switch A while simultaneously activating reed switch B with another magnet and then repeating the process with reed switch C. To avoid unwanted simultaneous activation of reed switches, these should not be mounted too close to each other within the plexiglas case.

Calibration: Different probes do not give exactly the same readings, and each must be calibrated separately against a good quality mercury thermometer (accuracy 0.1 C). Periodic calibration is advised to detect the occasional faulty or erratic system. Although the relationship between readings from the memorizer module and a standard mercury thermometer is close to linear from 23–36 C, slightly different corrections must be made at different temperatures (see Fig. 3, for example). We did not

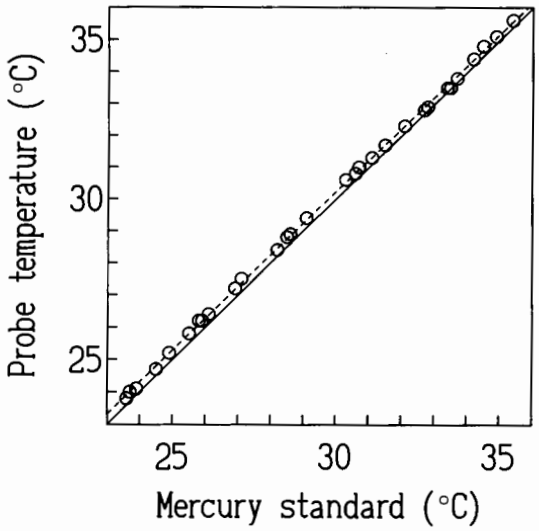

Fig. 3. Calibration curve (circles and dashed line) for an individual module against a good quality mercury thermometer. If no calibration corrections were required, the points would fit on the solid line.

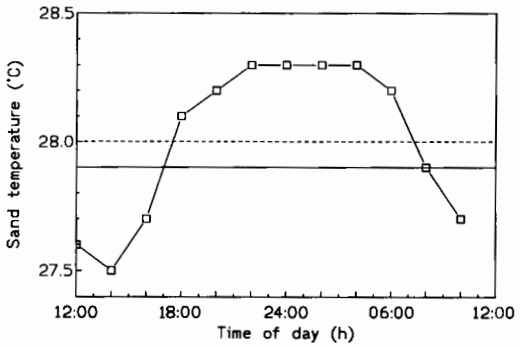

Fig. 4. Squares and solid line show temperatures taken every 2 h at a single site over a day. Dashed line shows the average temperature of all time points. Solid line shows average temperature as determined from the maximum and minimum temperatures.

detect any change in the readings obtained from a thermistor probe kept at constant temperature when the module and its housing were left in icy water or in front of a warm air blower.

Results.—Three sets of data were analyzed to determine how well the mean of the maximum and minimum over 24 h corresponds to the mean based on more frequent readings. First, data from a study of sand temperatures on a hawksbill turtle nesting beach in Antigua were analyzed (Mrosovsky et al., 1992). In that study, sand temperatures were read with a BAT 12 (Sensortek, Inc.) digital thermometer every 2 h from thermocouples previously buried 30 or 60 cm deep in the sand. Twenty separate round-the-clock recordings of this type were analyzed. The average of the maximum and minimum values was slightly lower than the average of the round-the-clock readings. The mean difference between the two methods of determining daily average sand temperature was 0.08 C (range: 0.02–0.22, n = 20). A typical example is shown in Figure 4. Second, in another check using the maximum-minimum memorizer modules themselves, the daily means of sand temperatures at four different 30 cm sites at St. Croix were assessed by the two methods: the values based on readings taken every 2 h over a 24-h period ranged from −0.04 less to +0.03 C more than the means obtained by averaging the maximum and minimum values over the same 24-h period. Third, sand temperatures were studied in Suriname at Matapica; this is a beach where both green turtles and leatherbacks nest. Temperatures were read from the maximum-minimum memorizer modules themselves every 2–3 h round-the-clock at 30 and at 60 cm depth on six different dates from April to Aug. (n = 12 round-the-clock readings). The means obtained by averaging the round-the-clock readings ranged from −0.21 less to +0.21 C more than those obtained by averaging the maximum and minimum values. The mean difference between the two methods was 0.03 C, with the round-the-clock method giving the marginally higher value.

To check on the durability of the casing, five modules were buried in the sand on Buck Island, St. Croix, United States Virgin Islands, for two months. No signs of moisture within the casing were detected. The casing also withstood six months of more or less continuous use in Suriname.

Discussion.—The maximum-minimum memorizer provides two temperatures from which an estimate of mean daily temperatures can be made. Errors in these estimates can be in the order of 0.1–0.2 C (but on average are smaller). These errors are small and are comparable to the accuracy of recording equipment used in other studies of sea turtle ecology. Moreover, the present method overcomes a number of problems with other methods. It provides flexibility in its choice of recording sites, and it is far less time consuming than round-the-clock measures. Some investigators have taken temperatures at a single time of day, one selected on the basis of previous round-the-clock readings to correspond to the daily mean (e.g., Mrosovsky and Provancha, 1989). However, the va-

lidity of that approach depends on relative consistency of weather conditions.

We consider that the maximum-minimum memorizer is valuable for simplifying long-term studies of sea turtle beach temperatures. Provided that the average of the maximum and minimum is validated against other estimates of daily mean temperature, this approach may also be useful for monitoring of nesting sites of other reptiles.

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