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Temperature Monitoring Manual

Guidelines for Monitoring Sand and Incubation Temperatures on Sea Turtle Nesting Beaches

Julianne Baker Gallegos, Marianne Fish & Carlos Drews

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Cite as:
Baker-Gallegos J., M.R. Fish & C. Drews. 2009. Temperature monitoring manual. Guidelines for Monitoring Sand and Incubation Temperatures on Sea Turtle Nesting Beaches. WWF report, San José, pp. 20.

Cover Photo:
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ISBN: 978-9968-825-44-3

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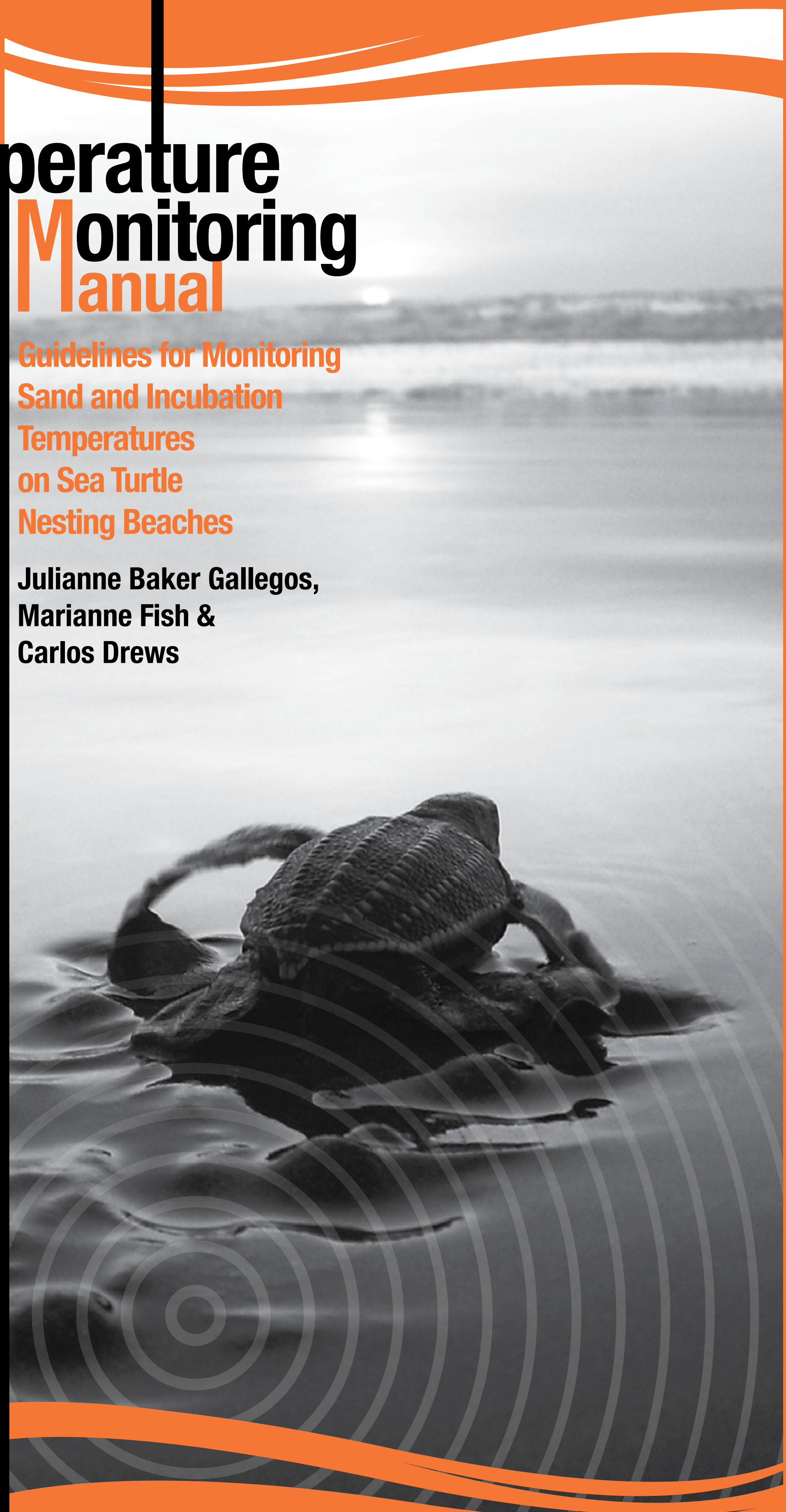
Summary

Current estimates predict a 1.8 to 4°C increase in global temperatures within the next century. One of the ways in which higher temperatures may affect sea turtles is during embryonic development. Successful incubation of turtle nests is possible within specific thermal limits and the sex ratio of hatchlings from a nest is determined by the temperature at which the nest is incubated. There is some concern that an increase in nesting beach temperatures could bias sex ratios significantly towards females. If temperatures are extremely high, the implications may be much more serious, leading to high nest mortality in some locations. High egg loss could lead to a decrease in population size, increasing the vulnerability of sea turtles to extinction.

There are many gaps in our knowledge of how temperature changes resulting from climate change will affect sea turtle populations. Nest temperatures are subject to several factors, including, but not limited to, nest location within a beach, extent of shading and nest depth, and may vary not only among beaches but also within a beach. By monitoring beach and nest temperatures over time and in different locations and relating these to nesting success and sex ratios, it is possible to fill some of the gaps in our knowledge of current nesting conditions, allowing us to make better predictions about the potential impacts of climate change.

The main objective of this manual is to provide guidelines on how to establish a temperature monitoring project on a nesting beach with the aim of describing the current thermal conditions. By collecting and analysing the thermal conditions on beaches, projects will be better placed to incorporate temperature data into management decisions, including the actions to be taken if temperatures exceed the maximum temperatures at which hatchlings can develop. It is hoped that through this manual we can promote collaborative regional data collection efforts to fill crucial knowledge gaps. Understanding the thermal conditions at nesting beaches at a regional level will help in assessing the potential impacts of increasing temperatures on regional sea turtle nesting populations.



Introduction

Climate change, temperature and sea turtles

The most recent IPCC assessment [1] reports an unequivocal and unprecedented rate of warming that is highly related to the way humans use and produce energy. Current estimates predict a 1.8 to 4°C increase in global temperatures within the next century [1]. It is conceivable that these changes could have substantial effects on natural ecosystems and their ability to support wildlife and human communities with the wide range of services they require to survive. The IPCC has assessed that 20 to 30 percent of species assessed may be at increased risk of extinction if current temperatures increase by 1.5 to 2.5°C [1]. This forecast is particularly alarming when considering that the most conservative projections estimate an increase of 1.8°C by 2100 (and more so for maximum predicted changes of 4°C). Changes in ecosystems can affect all wildlife populations, including sea turtles.

Marine turtles depend on both the coastal and oceanic realms for reproduction and feeding [2]. Climate change has the potential to affect sea turtles in numerous ways through altered thermal conditions in these habitats [3]. Increasing surface air temperature patterns may also affect weather patterns, including precipitation. Research in Central America found a positive correlation between northern and equatorial Atlantic and Pacific Ocean sea surface temperatures and increased ambient temperature and intensified precipitation [4].

One of the ways in which increasing temperatures may affect sea turtles is during embryonic development. Successful incubation of turtle nests is possible between specific thermal limits and is impeded below 25 °C and above 35 °C (33°C in leatherbacks; [5, 6]). Like many reptiles, and some invertebrates, sea turtles have temperature-dependent sex determination (TSD); the sex ratio of hatchlings from a nest is determined by the temperature at which the nest is incubated [2, 7]. There is a known thermosensitive period during the middle third of embryonic development during which the incubation temperature will determine the gender of the hatchlings. Temperatures higher than the "pivotal temperature" produce females and lower temperatures produce males. At the pivotal temperature, a 1:1 sex ratio is produced [8] and it would appear the pivotal temperature lies between 28°C and 30°C for most sea turtle species studied to date [5, 9-11].

As temperatures rise, a concern is that sex ratios will become increasingly female-biased. Female-biased sex ratios have been reported for marine turtles in numerous locations. Wibbels *et al.* [12] found a strong female bias among hawksbill (*Eretmochelys imbricata*) hatchlings at Buck Island and, in 1999, a study in Bahia with the same species estimated more than 90% of hatchlings were female [13]. Strong female biases have also been shown in loggerheads (*Caretta caretta*) [14-16] and flatbacks (*Natator depressus*) [17]. Sex ratios may vary within a season [18] and from year to year on the same beach. Different nesting locations of the same species can also produce very different sex ratios. Binckley *et al.* [19] found sex ratios of leatherback turtles (*Dermochelys coriacea*) at Playa Grande, Costa Rica, ranged from 74.3 - 100% female, between 1993 and 1995. When compared to data for Suriname, these ratios were far more female-biased than any of the reports for the last 25 years [19].

A number of studies have been carried out to try and ascertain changes in hatchling sex ratios over time. Hays *et al* [20] used the relationship between air and nest temperature on Ascension Island to predict nest temperatures for the past 150 years. A progressive warming of the sand in the islands was observed and they determined that there was a yield of 99.4 % females for the nests surveyed during 1998 and 1999. Research in Pasture Bay, Antigua demonstrated air temperatures have increased by 0.7 °C in the past 35 years. This study indicated not only a higher percentage of *E. imbricata* females, but also an all-time low for male production in 2003 [21]. The predicted relationship between changes in nest temperature and hatchling sex ratios has also been examined. Hawkes *et al* [22] concluded that a 1°C increase in temperatures in North Carolina would lead to an ultra-feminization of hatchlings and a 3°C increase could provoke extreme levels of mortality [22].

While the precise consequences of increasing temperatures are not well understood, there are likely to be negative impacts on turtles. Although adult sex ratios are unknown, and may naturally be female-biased, there is some concern that the projected increase in temperatures associated with climate change has the potential to markedly reduce the available numbers of male turtle offspring and distort population sex ratios more dramatically. It is possible that low numbers of males would be a meaningful restriction for females, through reduced fertilization capacity and a loss of genetic variation, thereby lowering a population's capacity to adapt and augmenting its chance of extinction [23]. Hence, TSD has become a critical element in determining whether climate change is a threat for species that exhibit this characteristic. In addition, if temperatures are extremely high, the implications may be much more serious, leading up to complete nest loss due to egg protein denaturization. High egg mortality could lead to a decrease in population size, increasing the vulnerability of these already endangered species to stochastic effects [20], and, ultimately, to extinction.

The risk from rising temperatures will depend to some extent on sea turtles' ability to adapt either behaviourally or evolutionarily. Females may alter their behaviour, for example by nesting in areas shaded by vegetation cover that may provide cooler incubation conditions and therefore a greater proportion of males [24-26]. Alternatives are shifting to different nesting beaches with cooler conditions or shifting timing of nesting to cooler months [27]. Although sea turtles have adapted to many changes in climate in the past, it has been suggested that they may be unable to evolve as rapidly as is necessary to counteract the effects of climate change as we are seeing it today [28]. Drastically reduced populations and non-climatic anthropogenic threats have put them in probably unprecedented, disadvantageous circumstances to adapt to climate-related habitat changes.

Temperature Monitoring

There are many gaps in our knowledge of how temperature changes will likely affect sea turtle populations. Nest temperatures are subject to several factors including, but not limited to, nest location within a beach, extent of shading and nest depth and may vary not only among beaches, but also *within* beaches [9]. Some of the key gaps in our knowledge of how climate change will affect sea turtle populations in the future relate to the effect temperature will have on aspects of reproduction and the reaction of sea turtles to those changes. The importance, therefore, of expanding our awareness of the conditions currently faced on both local and regional scales cannot be emphasized enough.

Implementation of temperature-monitoring projects region-wide would be a useful step in obtaining data that will demonstrate more clearly what the impact of climate change will be on beaches and sea turtles. By monitoring beach and nest temperatures over time it is possible to determine to what extent beach temperatures are changing. Through measurement of temperatures at different beaches, we can gain a better understanding of the range used by sea turtles at present and use this information to model which areas may be suitable in the future. One of the key questions when considering future temperature changes is what the effect on sex ratios will be. Current beach temperatures can be used to predict sex ratios, and may be used to reveal the extent to which beaches in the region are predominantly 'female- or male-producing'.

At a local management level, adequate monitoring of beach temperatures enables visualization of differences in vulnerability to overheating within the nesting area, and management can be designed accordingly. Knowledge of temperature ranges within the nesting area can facilitate the design and implementation of adaptation measures, such as, for example, reforestation to provide shading to open beach areas.

This manual is expected to be one of many tools that will eventually contribute to a better understanding of the effects climate change may have on sea turtle populations. It is our hope that it will be a useful tool for any sea turtle program interested in having a better understanding of incubation temperatures at nesting beaches. While this manual by no means presumes to be the final word in temperature monitoring for sea turtle nesting beaches, it is a guide for conservation projects interested in incorporating temperature monitoring into their research agendas. We also hope that the information obtained through the implementation of standardized, temperature monitoring work can be used in a collaborative, regional effort to try and fill some of the gaps in our knowledge of temperature effects on sea turtle populations and to implement a regional, early-warning system for temperature impacts on sea turtles.

Objectives

Main Objective:

To provide a standardized data collection method to the wider sea turtle community to facilitate data collection, local management design, data sharing and analysis

Specific Objectives:

- Provide guidelines on how to establish a temperature monitoring project on a nesting beach with the aim of describing the thermal conditions of the beach
- Standardize the methodology for the collection of temperature data
- Provide guidelines on how to establish a temperature monitoring project in hatcheries
- Promote collaborative regional data collection efforts to fill crucial knowledge gaps and to establish a regional early-warning system for temperature impacts on marine turtles
- Discuss uses of temperature monitoring data, in particular i) filling gaps in our knowledge of climate change impacts on sea turtles and ii) to help design management responses to changing temperatures
- Present a case study of implementation of a temperature monitoring project
- Provide supplemental sources of temperature data

Understanding the study area

Beach temperature may vary widely both among and within beaches due to variation in sand characteristics and beach topography. Before implementing a temperature-monitoring project, it is useful to have basic information describing the physical characteristics of the study beach as these may strongly influence the temperature in any particular area and may help to explain observed thermal patterns across the beach. These data are also useful for creating detailed temperature maps for nesting beaches.

Beach characteristics

1) **Extent of study area.** The first step should be to determine the extent of the beach area to be studied. The geographical limits of the area to be studied should be marked on existing maps or recorded using a GPS (Global Positioning System) unit. The coordinates of the area should be added to a map (e.g. using free-ware mapping tools such as "MapTool" at seaturtle.org: www.seaturtle.org/maptool).

2) **Beach width.** The width of the beach is the horizontal distance measured at right angles to the shoreline from low water to the landward limit of the beach, for example the dune base. Temperatures have been shown to increase with distance from the shoreline at some beaches [29]. Width measurements can also be used with slope measurements to calculate beach elevation and to develop detailed beach profiles. Width may vary along the beach and should be recorded at various locations along its length. The beach can be divided into sections and then for each section a transect should be taken perpendicular to the shoreline (Fig. 1). The number of sections and spacing will depend on the length of the beach and area of interest but the full range of beach conditions present should be represented. Each transect can then be divided into three zones: berm, border and vegetation zones (Fig. 1 inset). Measurements for beach width should be taken at various time intervals to define changes over time in the average nesting area available, as well as the maximum and minimum beach widths. Measurements should be taken during ordinary high and low tides.

3) **Beach slope.** Measuring beach slope provides useful three-dimensional data, which can be used to calculate beach elevation and produce a graphic rendition of beach shape. Beach slope can be measured very simply using two sticks, or PVC pipes and a tape measure or rope of fixed length. Slope can be measured along the same transects as above, running perpendicular to the sea from a reference marker at the back of the beach. Starting at the reference marker, ensure poles are vertical (use a small level or fishing weight on a line). The person holding the second pole should move it to the required distance or change in slope (Fig. 2a), being careful not to walk along the profile line. Measure and record the distance between the first and second pole either for fixed distance poles (z) (Fig. 2b), or the horizontal distance, x, using a tape measure. The observer lines up his/her eye with the top of the lower pole and the horizon and then measures the distance, y, from the top of the upper pole to eye level. Move down the next section so the upper pole is now where the lower pole was for the previous measurement and continue down the beach. Slope can be calulated as y/x or the angle of the slope can be found using angle=inv tan (y/x), e.g. if the poles are 2 m apart and the distance y is 35 cm, the slope is 0.175 or 17.5% and the angle is 10°. Average slope can be calculated for each profile and for the whole beach.

4) **Sand characteristics:** Sand temperature at nest depth is determined by the rate at which heat is exchanged between the sand and the sand surface and the transmission of heat within the sand, which occurs primarily via conduction through solids (sand grains) and water [30]. The colour, particle size and moisture content of sand can all affect the extent and rate at which heat is tranferred.

- **Albedo.** Sand temperature is generally higher on darker beaches [31] as darker sand has a lower albedo than lighter sand. Albedo is a measure of how much solar energy is reflected by an object. Albedo is either expressed as a percentage or a number ranging from 0 to 1, black objects have an albedo of 0 (no light is reflected) and white objects have an albedo of 1 (all light is reflected). Sand albedo usually ranges from approximately 0.2 - 0.3. Albedo can be measured using a standard photographic lightmeter (such as Sekonic Dual Spot FL-778, Tokyo, Japan). Measurements

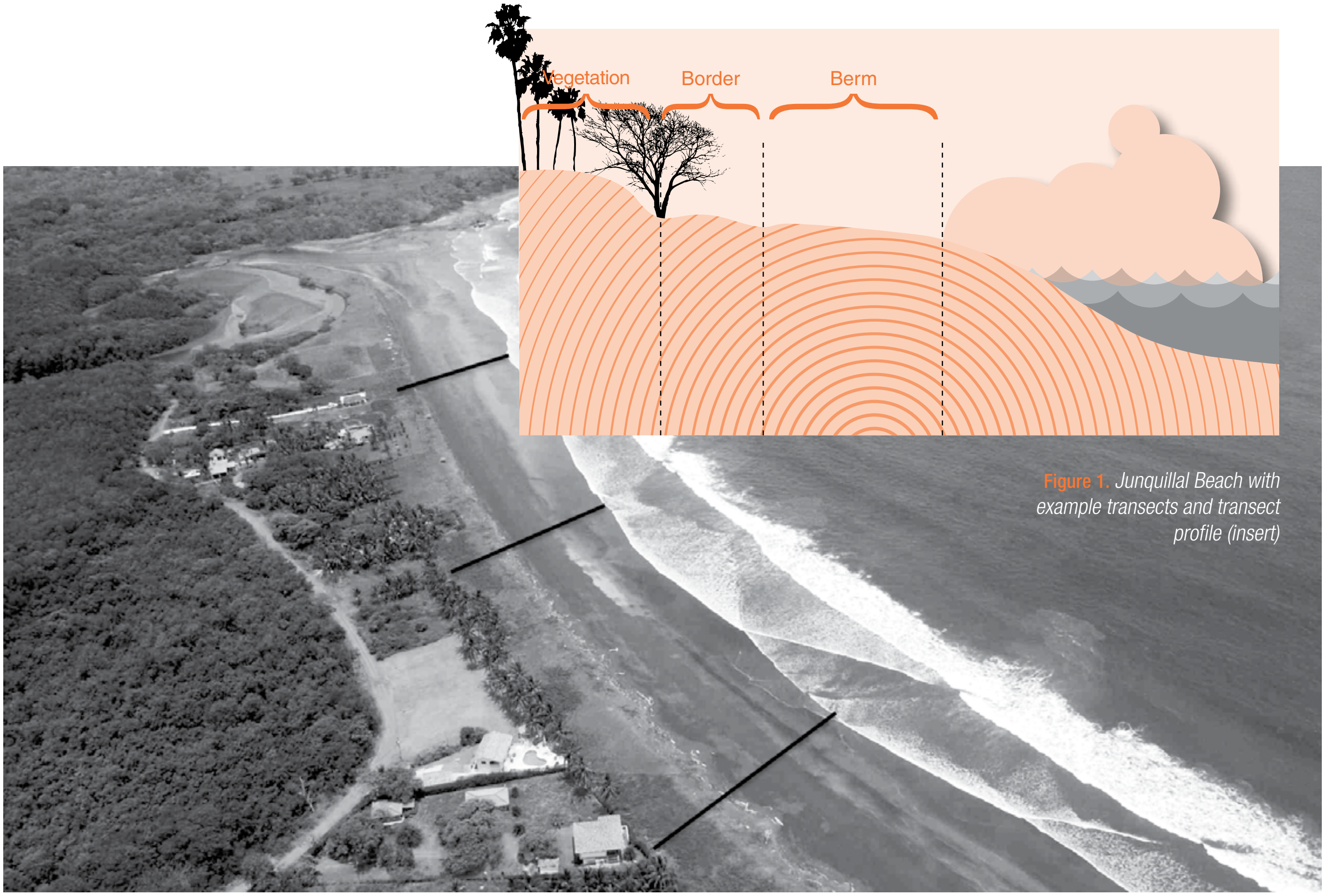


Figure 1. *Junquillal Beach with example transects and transect profile (insert)*

should be taken under clear sunny skies and on a smoothed-over sand surface. Solar radiation from the sand (L_s) is measured at visible wavelengths and compared to the solar radiation reflected from a photographic grey card of known albedo (18%) measured under the same conditions (L_G). It is important to cast no shadow on the area measured and to hold the light meter in a vertical position approximately 25 cm above the surface to standardize measurements between sand and card. At least five pairs of readings (sand then gray card) should be taken and means obtained. The spectral range of the equipment is only relative to visible wavelengths (350 nm to 800 nm) [31]. According to this, albedo (ρ) may be determined as follows:

$$\rho_{350\text{-}800} = (L_S)/(L_G) \times 18\%$$

- **Sand composition.** Sand grain size can affect temperature at nest depth as thermal conducitvity increases with particle size [30]. Sand grain size can be measured by collecting sand samples (approx. 200 g) along each sector and within each area down to a depth of 10 cm and then either turned into a lab for granulometric analysis or measured using a set of sieves. When using sieves, a sand sample of known weight is passed through a set of sieves of known mesh sizes. The sieves are arranged in downward decreasing mesh diameters. The sieves are shaken for a fixed period of time (several minutes). The weight of sediment remaining on each sieve is measured and converted into a percentage of the total sediment sample. This method is quick and sufficiently accurate for most purposes.

- **Moisture**. Sand temperature depends largely on the relative proportions of water, air and solids within it [30]. Thermal conduction is much higher in water films than in air-filled pores so sands with a higher water content exhibit greater thermal conductivity [30]. The moisture content of sand can be measured by taking a sample of known weight (usually 500 g), drying it and weighing it again. Total percentage moisture content can then be calculated as

$$\left(1 - \frac{dryweight}{wetweight}\right) \times 100$$

The sample can be dried in the oven or in a frying pan and is considered dry when a near constant weight is reached, i.e. further heating does not cause a further decrease in weight.

5) **Shading.** Vegetation or infrastructure near the beach limits the amount of solar radiation reaching the sand surface and can therefore affect sand temperatures [32]. For each area that is to be monitored, amount of shading should be quantified as far as possible. Shading will depend on the amount of time the sand is protected from direct sunlight and may vary from 100% shading (sand permanently protected from direct sunlight) to 0% shading (sand completely exposed to direct sunlight through the day) and may be calculated from the number of hours per day that sand is exposed to direct sunlight. For instance, if a certain patch is hit by the sun´s rays in the afternoon (12 noon to 5 pm), this would be a total of 5/12 hours (considering there are 12 hours of light), approximately equal to 42% sun exposure or 58% shading. For the purpose of this manual, we recommend using three sectors in terms of beach width: 1) vegetation, the area that is completely shaded by ground-dwelling shrubs or under complete shade from a tall tree

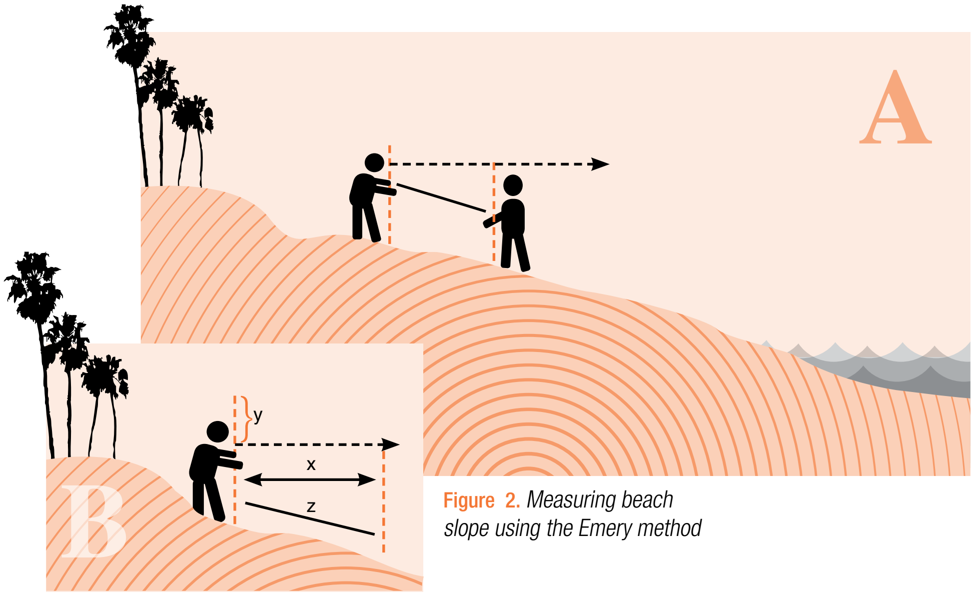


Figure 2. *Measuring beach slope using the Emery method*

or shrub; 2) border, as that area that is partially shaded, whether 10% or 90% shading; 3) berm, the area that is usually exposed to direct sunlight, yet is not reached by the average high tide line.

Nesting data

There are numerous ways in which sand temperature can affect nests and egg development and collection of temperature data for a beach enables examination of the relationships between observed temperatures and some key nesting features:

- Areas of peak nesting density. Examination of nesting location in relation to temperature may shed light on whether females select a particular thermal environment for nesting [33].

- Hatching success. Successful incubation of eggs is temperature-dependent and examination of hatching success in relation to temperature provides insight into the thermal tolerance of turtles at a particular beach and the role temperature is playing in overall hatchling production.

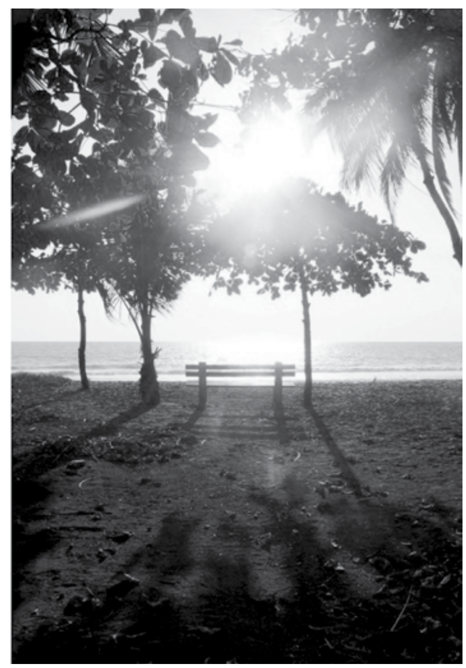
- Incubation duration. Higher sand temperatures can increase hatchling metabolic rate and therefore growth rate and can also decrease incubation time. Warmer nests incubate for a shorter time [34]. Incubation temperature also influences the size and phenotype of hatchlings, with higher temperatures producing smaller hatchlings [35].

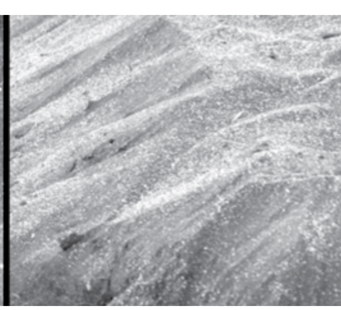
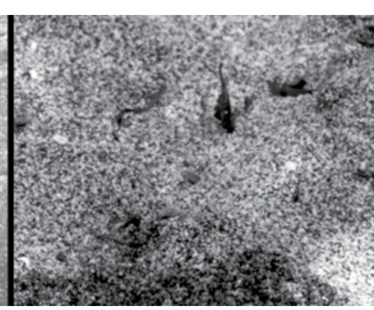
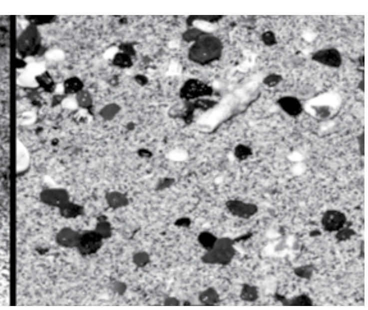
Information about other aspects of nesting can provide useful information for setting up the monitoring project. Nest depth varies among species and locations and therefore average nest depth for an individual beach should be found so that dataloggers can be placed at the appropriate depth. In addition, nest temperatures are influenced not only by sand temperature but also by metabolic heat generated by the eggs during incubation. Metabolic heating of the nest chamber results in nest temperatures higher than the surrounding sand [21, 36-38]. It is particularly important to consider metabolic heating when inferring sex ratios from sand temperatures at nest depth as metabolic heating can raise the temperature during the sensitive period by ~ 1 °C. In general, the extent of metabolic heating varies with clutch size [37] as larger numbers of eggs generate more heat and and eggs at the side of the nest are cooler than those in the middle [38].

Temperature monitoring: data collection & methods

1) Locations

Once the study area has been characterized (as detailed above) temperature-monitoring locations must be determined. The number and location of these will vary depending on: 1) the total area of the beach, 2) logical division of beach into study areas and 3) available budget for temperature-monitoring dataloggers. Ideally, the temperature monitoring locations should be broadly representative of the total available nesting area. Beaches are naturally dynamic habitats with marked seasonal variations in conditions. In order to obtain meaningful data on thermal conditions at a beach it is therefore recommended that loggers are deployed for at least a year. Including both nesting and non-nesting periods is useful, as this may yield information about temperature relationships to onset of nesting and therefore facilitate better predictions about how sea turtles might shift timing of nesting with climate change or may



otherwise help explain why turtles nest when they nest. Likewise, monitoring temperatures at beaches not currently used for nesting may reveal temperature differences.

The method described here seeks to create a thermal profile for the length and width of the beach. The latter is very important since this data will reflect the effect shading, beach width etc. is having on nesting temperatures. For each designated beach sector in which dataloggers are to be placed, three dataloggers are needed: 1) to be located at the uppermost end of the beach (completely shaded by coastal vegetation, if present); 2) to be located under partial shading (a spot directly in line with 1 but partially exposed to direct sunlight); and 3) to be located under complete exposure (a spot also in line with 1 and 2 but completely exposed to direct sunlight).

2) Equipment

- Thick walled PVC tubes (1.5 m x 2.5 cm) (1 per datalogger to be deployed)
- Rope (10 mm diameter)
- Laptop or desktop PC, running at least Windows 97
- Dataloggers (e.g. HOBO U 10 Family)
- Datalogger software
- Plastic bag sealer (e.g. Midwest Pacific Hand Bag Sealer)
- Thick plastic bags (e.g. Kapak SealPAK pouches ¼ pint size)
- Cordless power drill
- Cable ties
- A GPS
- Compass
- Measuring tape (25m minimum)

3) Temperature logger deployment

Preparing the dataloggers

All dataloggers must be programmed for deployment through the manufacturers software (e.g. HOBOware Lite software). The software enables start and end times and measurement interval to be scheduled and should be coordinated for all loggers so that data is comparable. The interval used will depend on the logger memory, deployment duration and available time. Once programmed, label the logger with a unique identifier prior to waterproofing.

If possible, waterproof dataloggers should be obtained. However, if these are not available, loggers can be prepared for use in wet or damp conditions as follows. Firstly, place each datalogger in a sealable plastic pouch with a small amount of dessicant (e.g. silica gel) and seal the plastic pouch at least twice using a commercially available machine (dataloggers can be damaged by contact with humidity and/or water). Use a cable tie to attach the datalogger pouch to a PVC pipe.

Dataloggers should be mounted on PVC poles for easy deployment and collection. Prepare the poles as follows:

- Poles (1.5 m long and 2.5 cm diameter) should be sharpened at one end by either sawing a pointed end section or by sanding the end to a point
- Using a cordless power drill, make two holes, one at the top of the pole to attach a label, and one at target nest depth, assuming that the pole will be 25 cm below the sand surface. Make a hole in the datalogger packet using a hole punch and attach the datalogger to the PVC tube with a cable tie
- Record datalogger number or code
- Once the loggers are ready to be deployed, a hole at least 1.25 m deep should be excavated at the locations where each PVC tube will be placed
- In order to facilitate retrieval, each tube can be tied to a wooden marker or to another monitoring pole located further down the beach
- Mark logger locations. This can be done using triangulation (Fig. 3) by measuring the distance (Fig. 3a) or the angle (Fig. 3b) to at least two permanent markers, e.g. trees, buildings, etc. If loggers run along a transect, distance from a permanent marker in the back beach area should be recorded. A position taken with a hand-held GPS is not accurate enough to ensure that the logger can be easily found later.

4) Monitoring

It is useful to designate someone to check on all sites periodically (ideally, on a weekly basis) in case of loss to tidal erosion and animal or human activities. Constant monitoring clearly requires that someone is always on-site who is familiar with the project's purpose and methods. These limitations can be handled by building capacity amongst local community members who are interested in the project.

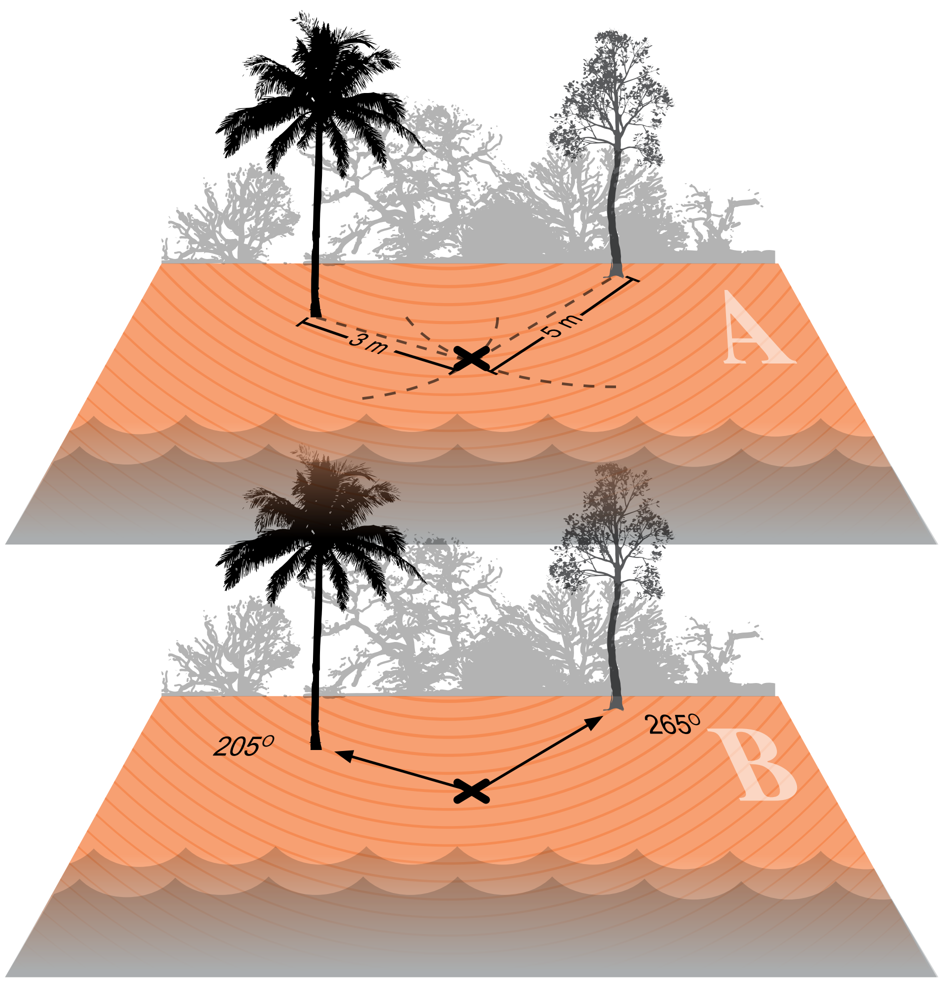


Figure 3. *Triangulation of datalogger positions X, using a) distance or b) compass bearing from at least two fixed locations*

Equipment retrieval is one of the most challenging aspects of the project. In our experience, wooden markers are the most useful way to locate equipment. However, they should be secured and buried deeply to avoid loss to extreme weather events and high tides. Nonetheless, markers can be lost. Thus, triangulation with fixed vegetation or landmarks should always be carried out. Although this may add extra hours to the initial work, it is a worthwhile effort in order to be able to retrieve all of the equipment.

5) Artificial incubation: ex-situ monitoring

When working with hatcheries, it is useful to monitor temperatures for comparison with natural beach conditions. In addition, monitoring temperatures throughout the incubation cycle allows an inference about sex ratios in hatchlings produced in the hatchery. Thermal conditions for incubation should ideally: 1) be within the known limits for incubation and 2) consider the influence of temperatures on sex ratio production. In some cases, manipulation of incubation temperatures may be a goal of the project. In these cases it is important to measure the effects of measures such as shading to understand their effect on nest temperatures.

The same equipment and methods should be employed to monitor temperatures in the hatchery as on the beach, to allow for comparison. At least three dataloggers should be deployed in the hatchery: 1) towards the seaward front of the hatchery, 2) in the middle of it and 3) in the landward sector of the hatchery (see Fig.4).

If sex ratio estimates are required for ex-situ nests and sufficient equipment is available, ideally dataloggers would be deployed within each relocated nest in order to incorporate temperature increases from metabolic heating. Alternatively, or in addition, thermocouples can be used to monitor nest temperatures on a daily basis. Thermocouples and dataloggers should be calibrated if both methods are used in the same project.

6) Data analysis

Data collected can be used to develop profiles of average temperature for beach width, beach length or both (Fig. 5), which in turn can be used to visualize temperature differences over the study area. To obtain a thermal profile of the beach, average temperature along with standard deviation should be calculated for each beach sector or transect.

Case study: Junquillal Beach, Costa Rica

In January 2008, a WWF intern (Julianne Baker Gallegos) trialled the methods detailed above at Junquillal Beach, Guanacaste, on the Costa Rican Pacific Coast. An initial trip to the site was spent getting to know the beach, the community and the local staff. Initially, the intern was to set up the project and leave it ready for the local team to continue starting September 2008. However, after this first meeting it became clear that the temperature-monitoring project would require a full-time, or at least a consistent part-time, supervisor.

In the following months the project was designed and equipment was ordered. Thirty dataloggers were purchased. Once the dataloggers were ready to be deployed, and the equipment was working properly, the dataloggers were attached to "anchors" that would hold them in place in the beach. It took an entire day to prepare the "anchors" for the loggers (cutting 6 m-long tubes into 1.5 m-long portions, sharpening them and making holes to attach the dataloggers and identifications). The dataloggers were placed in thick plastic bags and sealed to protect them

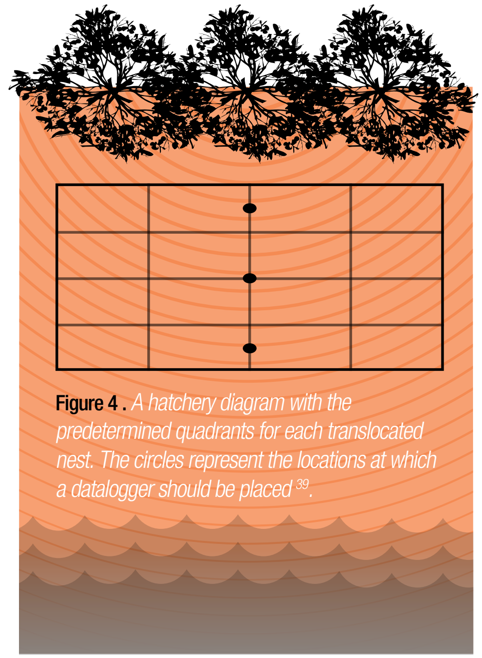


Figure 4 . *A hatchery diagram with the predetermined quadrants for each translocated nest. The circles represent the locations at which a datalogger should be placed [39].*

from humidity. The following day, three people worked together to dig 1.5 m-deep holes to bury the equipment. The anchor poles were connected by chords, to aid removal, and the actual burying involved making channels between markers for these chords, as well as marking local vegetation to aid triangulation. A total of 24 hours of human labor were needed to complete the deployment process.

The dataloggers were set to run for a 6-month period (battery life was over a year). However, a week after they were buried, the PVC tubes were exposed by high tides. A few days later, two of the tubes were pulled out by visitors. Three days were therefore dedicated to sawing up to 25 cm from all exposed tubes and reburying the equipment to ensure it would not be exposed again. The chords that had been buried 5 cm below ground level and had been exposed were also reburied 25 cm below ground.

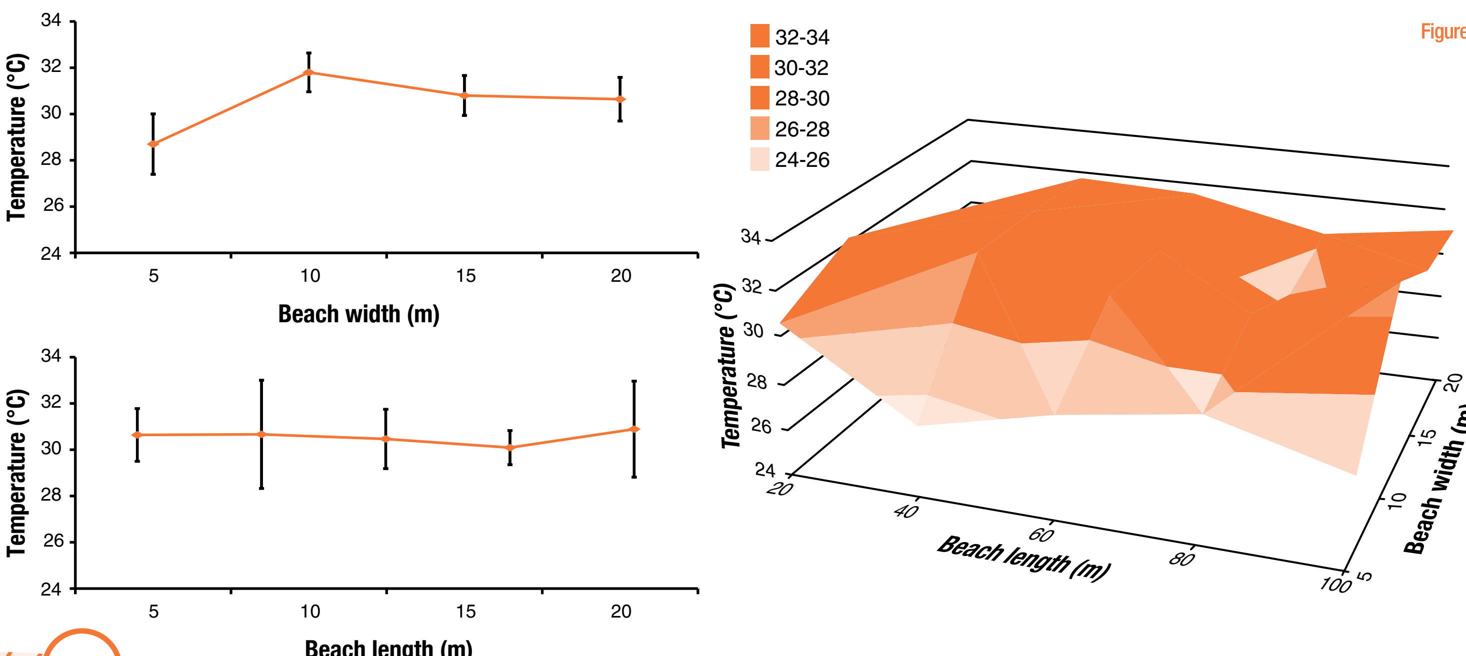


Figure 5

Dataloggers were removed after six months, during the last weekend of June 2008. Although everyone contributed to try and mark each site, efforts were not sufficient and datalogger retrieval was much more difficult than originally foreseen. Over 30 hours of human labor were dedicated to the recovery of the dataloggers, but seven were never found. The difficulty of retrieval was due to three main reasons: 1) most of the wooden markers had been lost, limiting triangulation in the cases in which little or no permanent vegetation was available to triangulate; 2) the beach had been altered much more than foreseen (in terms of erosion, sand deposits, vegetation spreading and debris accumulation); and 3) retrieval efforts were limited to two people.

Alongside monitoring the thermal conditions of the beach overall, two experiments were set up to examine:

1) The effect of shading on sand temperature
2) The relationship between ambient temperature and sand temperature at nest depth

a) Shading

The set up described above covered areas fully exposed to sunlight, partially exposed and completely shaded but the data loggers were all placed in a line perpendicular to the shoreline. An additional experiment was set up to compare temperatures between shaded and exposed areas whilst controlling for distance from the water. Ten pairs of dataloggers were buried along the beach at 60 cm depth. The two loggers of each pair were placed at the same distance from the shoreline, with one logger of each pair buried in direct sunlight and the other in shade, close to the first. The logger pairs were distributed along the beach, always looking for conditions of shade next to direct sunlight. This paired experimental design was used as it cancelled out differences in local conditions between sites, focusing rather on the differences between temperature values within each logger pair. Once the new dataloggers arrived, three days (with a total of 12 hours of human labor) were dedicated to the identification of sites with adequate shading and to the burial of the equipment at nest depth.

Unshaded sites were on average 2.25 °C warmer at nest depth than shaded sites and there was a significant difference in temperature between shaded and unshaded sites (paired t-test of averages $t=5.86$, $df=8$, $p<0.001$) [32]. Average temperature in shaded areas was 29.2 °C (±0.005), as compared to 31.5 °C (±0.006) in unshaded areas.

b) Ambient temperature and sand temperature

A set of six dataloggers was deployed within the hatchery to examine the correlation between ambient temperature and sand temperatures at nest depth. Three dataloggers were buried at average nest depth (60 cm), while three other dataloggers were placed in a half-open box 1 m above ground. Measurements were taken every 30 seconds over 10 days.

Above ground temperatures oscillated between 22 and 34 °C, with an average of 27.11 ºC (± 0.02). Below ground temperatures at nest depth ranged from 29 to 29.7°C, with an average of 29.4 (± 0.001). Daily oscillations below ground were much smaller than for above ground temperatures. When comparing above ground and nest depth temperatures, the maximum correlation was found with a lag period of 2 days, but this result is based on limited time data and the correlation was weak ($r=0.42$, $p<0.05$) [32].

Lessons learned

When beginning the temperature monitoring project, suggestions are to:

- consider weather conditions and begin deployment before extreme weather conditions can affect access to the designated area and/or the equipment;
- make sure all the components required to set the dataloggers and to retrieve information are ordered/purchased simultaneously;
- closely monitor the loggers to make sure they do not become exposed or are taken from the site;
- bury pipes at least 25 cm from the surface, to hinder the exposure of the pipes by tides or people;
- very good triangulation is needed to make sure the equipment can be found. While the wooden marks seemed to be the best way to retrieve the equipment, these were also the most vulnerable to high tides and a vast majority were lost within the first month. Triangulation to permanent markers in the back beach area is therefore recommended.

The dataloggers in semi-enclosed condition and placed 1 m above ground.

Appendix A: Additional Temperature Data Sources

I. Local meteorological stations

The first place to search for local temperature time series is in local stations. These stations will more than likely have data for areas within a short distance of the beach in question, hence generating the least error when extrapolating data for beach temperatures. In this case, the internet, local municipalities and other research projects (both publicly and privately funded) taking place in the area are alternatives worth exploring.

II. Governmental institutions

Many remote sea turtle nesting sites will not have local stations. In this case, some countries have meteorological institutions, which generally have an ample enough array of temperature data nation wide. If the institution provides several options, the best choice is the site that has the most similar characteristics to the nesting beach. Some of the characteristics to consider are: altitude, latitude, longitude, distance from the actual beach, humidity levels and weather patterns in the area. A time series for the last 2 or 3 decades is recommended in order to have sufficient data not influenced by climatic phenomena such as El Niño or La Niña events.

III. Satellite data sets

If neither of the above options offer sufficient data to build the desired temperature trend for the nesting beach, lower resolution data are available that can be used. Some of the largest datasets worldwide from remote sensing stations (many times with data corroborated *in-situ*) can be found at the following websites:

1) Ocean Biology Processing Group (OBPG), NASA Goddard Space Flight Center, United States of America
http://oceancolor.gsfc.nasa.gov/

2) Earth Observatory (EO), National Aeronautics and Space Administration (NASA),
United States of America
http://earthobservatory.nasa.gov/GlobalMaps/

3) Computational and Information Systems Laboratory, National Center for Atmospheric Research,
United States of America
http://dss.ucar.edu/

4) National Oceanographic Data Center, National Oceanic & Atmospheric Administration (NOAA),
United States of America
http://www.nodc.noaa.gov/dsdt/oisst/

Complete lists of data sets can be found at:

National Oceanographic Data Center, National Oceanic & Atmospheric Administration (NOAA),
United States of America
http://www.nodc.noaa.gov/General/temperature.html

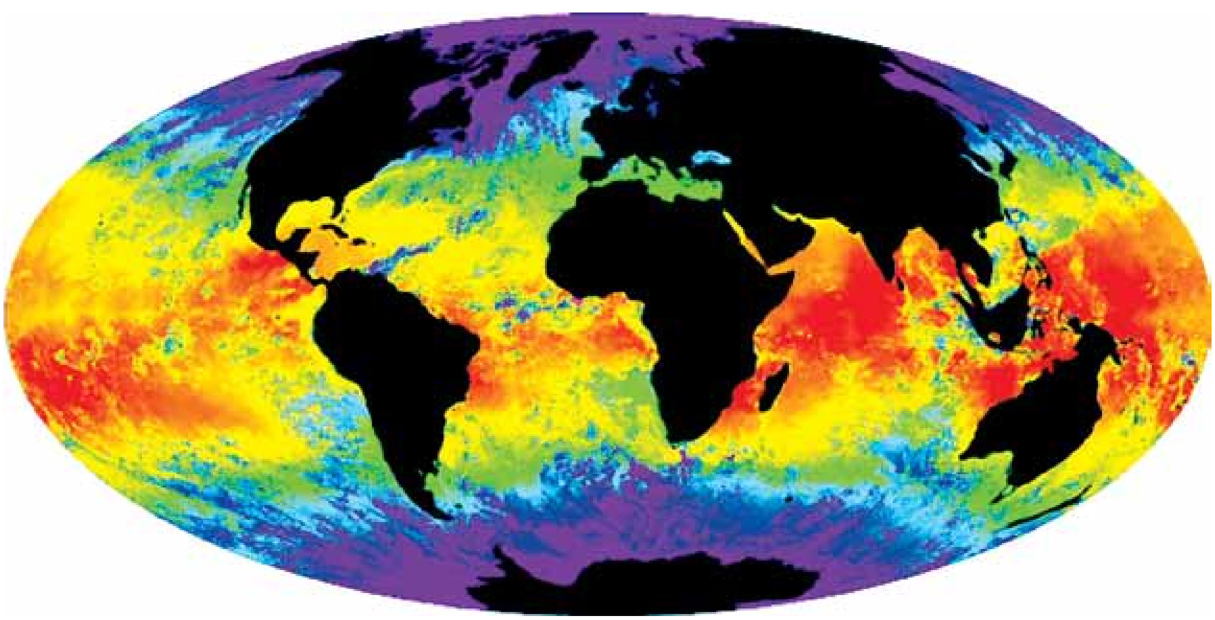


Figure 6. *This image shows sea surface temperatures worldwide as recorded by the NASA Goddard Space Flight Center's satellite MODIS. The metadata used to build this image was taken on April 18th, 2000.*

References

1. Pachauri, R. K., and Reisinger, A. (2007) Climate Change 2007: Synthesis Report. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK

2. Spotila, J. R. (2004) Sea turtles: A complete guide to their biology, behavior, and conservation, Johns Hopkins University Press and Oakwood Arts, Baltimore and London

3. Hawkes, L. A., Broderick, A. C., Godfrey, M. H., and Godley, B. J. (2009) Climate change and marine turtles. Endangered Species Research 7, 137-154

4. Aguilar, E., Peterson, T. C., Ramírez Obando, P., Frutos, R., Retana, J. A., Solera, M., Soley, J., González García, I., Araujo, R. M., Rosa Santos, A., Valle, V. E., Brunet, M., Aguilar, L., Álvarez, L., Bautista, M., Castañón, C., Herrera, L., Ruano, E., Sinay, J. J., Sánchez, E., Hernández Oviedo, G. I., Obed, F., Salgado, J. E., Vásquez, J. I., Baca, M., Gutiérrez, M., Centella, C., Espinosa, J., Martínez, D., Olmedo, B., Ojeda Espinoza, C. R., Núñez, R., Haylock, M., Benavides, H., and Mayorga.R. (2005) Changes in precipitation and temperature extremes in Central America and northern South America, 1961-2003. Journal of Geophysical Research 110

5. Ugalde, A. (1986) La temperatura como factor determinante del sexo en la tortuga lora Lepidochelys olivacea Eschscholtz. Graduate thesis in Biology with emphasis in Ecology. In Department of Biology, Universidad de Costa Rica

6. Ackerman, R. A. (1997) The nest environment and the embryonic development of sea turtles. In The biology of sea turtles (Lutz, P. L., and Musick, J. A., eds) Vol. 1 pp. 83–106, CRC Press, Boca Raton, FL

7. Mrosovsky, N. (1988) Pivotal temperatures for loggerhead turtles from northern and southern nesting beaches. Canadian Journal of Zoology-Revue Canadienne De Zoologie 66, 661-669

8. Yntema, C. L., and Mrosovsky, N. (1980) Sexual differentation in hatchling loggerhead sea turtles (Caretta caretta) incubated at controlled temperatures. Herpetologica. 36, 33-36

9. Davenport, J. (1997) Temperature and the life-history strategies of sea turtles. Journal of Thermal Biology 22, 479-488

10. Hays, G. C. (2004) Good news for sea turtles. Trends in Ecology & Evolution 19, 349-351

11. Mrosovsky, N., Bass, A., Corliss, L., Richardson, J. I., and Richardson, T. H. (1992) Pivotal and beach temperatures for hawksbill turtles nesting in Antigua. Canadian Journal of Zoology-Revue Canadienne De Zoologie 70, 1920-1925

12. Wibbels, T. R., Hillis-Starr, Z. M., and Phillips, B. (1999) Female-biased sex ratios of hatchling hawksbill sea turtles from a Caribbean nesting beach. Journal of Herpetology 33, 142-144

13. Godfrey, M. H., D'Amato, A. F., Marcovaldi, M. A., and Mrosovsky, N. (1999) Pivotal temperature and predicted sex ratios for hatchling hawksbill turtles from Brazil. Canadian Journal of Zoology-Revue Canadienne De Zoologie 77, 1465-1473

14. Chu, C. T., Booth, D. T., and Limpus, C. J. (2008) Estimating the sex ratio of loggerhead turtle hatchlings at Mon Repos rookery (Australia) from nest temperatures. Australian Journal of Zoology 56, 57-64

15. Mrosovsky, N., and Provancha, J. A. (1989) Sex ratio of loggerhead sea turtles hatching on a Florida beach. Canadian Journal of Zoology-Revue Canadienne De Zoologie 67, 2533-2539

16. Oz, M., Erdogan, A., Kaska, Y., Dusen, S., Aslan, A., Sert, H., Yavuz, M., and Tunc, M. R. (2004) Nest temperatures and sex-ratio estimates of loggerhead turtles at Patara beach on the southwestern coast of Turkey. Canadian Journal of Zoology-Revue Canadienne De Zoologie 82, 94-101

17. Blamires, S. J., and Guinea, M. L. (1997) Implications of nest site selection on egg predation at the sea turtle rookery at Fog Bay. In Marine turtle conservation and managment in northern Australia., Northern Territory University, Darwin

18. Mrosovsky, N., Dutton, P. H., and Whitmore, C. P. (1984) Sex ratios of two species of sea turtle nesting in Suriname. Canadian Journal of Zoology-Revue Canadienne De Zoologie 62, 2227-2239

19. Binckley, C. A., Spotila, J. R., Wilson, K. S., and Paladino, F. V. (1998) Sex determination and sex ratios of Pacific leatherback turtles, Dermochelys coriacea. Copeia 2, 291-300

20. Hays, G. C., Broderick, A. C., Glen, F., and Godley, B. J. (2003) Climate change and sea turtles: a 150-year reconstruction of incubation temperatures at a major marine turtle rookery. Global Change Biology 9, 642-646

21. Glen, F., and Mrosovsky, N. (2004) Antigua revisited: the impact of climate change on sand and nest temperatures at a hawksbill turtle (Eretmochelys imbricata) nesting beach. Global Change Biology 10, 2036-2045

22. Hawkes, L. A., Broderick, A. C., Godfrey, M. H., and Godley, B. J. (2007) Investigating the potential impacts of climate change on a marine turtle population. Global Change Biology 13, 923-932

23. Hoekert, W. E. J., Neuféglise, H., Schouten, A. D., and Menken, S. B. J. (2002) Multiple paternity and female-biased mutation at a microsatellite locus in the olive ridley sea turtle (Lepidochelys olivacea). Heredity 89, 107-113

24. Janzen, F. J. (1994) Vegetational cover predicts the sex ratio of hatchling turtles in natural nests. Ecology 75, 1593-1599

25. Kamel, S. J., and Mrosovsky, N. (2006) Deforestation: Risk of sex ratio distortion in hawksbill sea turtles. Ecological Applications 16, 923-931

26. Standora, E. A., and Spotila, J. R. (1985) Temperature dependent sex determination in sea turtles. Copeia 3, 711-722

27. Weishampel, J. F., Bagley, D. A., Ehrhart, K. M., and Rodenbeck, B. L. (2003) Spatiotemporal patterns of annual sea turtle nesting behaviors along an East Central Florida beach. Biological Conservation 110, 295-303

28. Janzen, F. J. (1994) Climate-Change and Temperature-Dependent Sex Determination in Reptiles. Proceedings of the National Academy of Sciences of the United States of America 91, 7487-7490

29. Rees, A. F., and Margaritoulis, D. (2004) Beach temperatures, incubation durations and estimated hatchling sex ratio for loggerhead sea turtle nests in southern Kyparissia Bay, Greece. Testudo 6, 23-36

30. Schaetzl, R. J., and Anderson, S. (2005) Soils: Genesis and Geomorphology, Cambridge University Press, Cambridge, UK

31. Hays, G. C., Ashworth, J. S., Barnsley, M. J., Broderick, A. C., Emery, D. R., Godley, B. J., Henwood, A., and Jones, E. L. (2001) The importance of sand albedo for the thermal conditions on sea turtle nesting beaches. Oikos 93, 87-94

32. Baker Gallegos, J., Fuchs, E., and Fonseca, A. (2009) Analysis of temperature data from Ostional and Junquillal beaches. WWF-LAC Marine and Species Program, San José, Costa Rica

33. Stoneburner, D. L., and Richardson, J. I. (1981) Observations on the role of temperature in loggerhead turtle nest site selection. Copeia 1981, 238-241

34. Matsuzawa, Y., Sato, K., Sakamoto, W., and Bjorndal, K. A. (2002) Seasonal fluctuations in sand temperature: effects on the incubation period and mortality of loggerhead sea turtle (Caretta caretta) pre-emergent hatchlings in Minabe, Japan. *Marine Biology* 140, 639-646

35. Glen, F., Broderick, A. C., Godley, B. J., and Hays, G. C. (2003) Incubation environment affects phenotype of naturally incubated green turtle hatchlings. Journal of the Marine Biological Association of the United Kingdom 83, 1183-1186

36. Broderick, A., Godley, B., and Hays, G. C. (2001) Metabolic heating and the prediction of sex ratios for green turtles (Chelonia mydas). Physiological and Biochemical Zoology 74 161-170

37. Booth, D. T., and Astill, K. (2001) Incubation temperature, energy expenditure and hatchling size in the green turtle (Chelonia mydas), a species with temperature-sensitive sex determination. Australian Journal of Zoology 49, 389-396

38. Godfrey, M. H. (1997) Sex ratios of sea turtle hatchlings: direct and indirect estimates. In Graduate Department of Zoology, PhD thesis, Graduate Department of Zoology, University of Toronto

39. Chacón, D., Sánchez, J., Calvo, J. J., and Ash, J. (2007) Manual para el manejo y la conservación de las tortugas marinas en Costa Rica; con énfasis en la operación de proyectos en playa y viveros. Sistema Nacional de Áreas de Conservación (SINAC), Ministerio de Ambiente y Energía (MINAE). Gobierno de Costa Rica. . p. 103, San José

Acknowledgements

Many thanks to Thane Wibbels for advice during the development of this project and to Lucy Hawkes for comments on an earlier draft. The production of this manual was funded by Hewlett-Packard. The editing, lay-out and printing of this report was supported by the John D. and Catherine T. MacArthur Foundation.

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