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# Water temperature and internesting intervals for loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) sea turtles

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## Abstract

Temperature loggers were attached to the carapace of green turtles (*Chelonia mydas*) at Ascension Island and Cyprus and to loggerhead turtles (*Caretta caretta*) at Cyprus, in order to record the ambient temperature experienced by individuals during the internesting interval, i.e. the period between consecutive clutches being laid. Internesting intervals were relatively short (10–14 days) and mean ambient temperatures relatively warm (27–28°C), compared to previous observations for these species nesting in Japan, although a single internesting interval versus temperature relationship described all the data for these two species from the different areas. The implication is that water temperature has both a common and a profound effect on the length of the internesting interval for these two species: internesting intervals are shorter when the water is warmer. © 2002 Elsevier Science Ltd. All rights reserved.

## 1. Introduction

Assessing how animals respond to spatio-temporal patterns in ambient temperature, and the ecological implications of these responses, are important to our understanding of life-history strategies. For sea turtles, there has been extensive work over the last two decades showing that sex is determined by temperature, with eggs incubating under warmer conditions producing female hatchlings and vice versa. Interestingly, the pivotal temperature (i.e. that producing a 50:50 sex ratio) is very close to 29°C for widely separated populations and even for different species of sea turtle (Mrosovsky, 1994). Temperature also influences the duration of incubation, with warmer nests hatching quicker than cooler ones and again this relationship between temperature and incubation period is very similar across different populations and species (e.g. Kaska et al., 1998). The implication is that nest temperature has common effects both between different populations and between different species.

Our understanding of the impact of temperature at other times during the lives of sea turtles is far more fragmentary, mainly due to the fact that it has traditionally been very difficult to record the behaviour of individuals at sea, where they spend most of their time. For at least two hard-shelled species, the green turtle (*Chelonia mydas*) and loggerhead turtle (*Caretta caretta*), it would be predicted that the metabolic rate will generally increase with ambient temperature since these species are essentially ectothermic, being able to raise their body temperature, at most, only a few degrees above ambient levels whilst in the water (Sato et al., 1995). Such thermally driven variations in metabolic rate might, in turn, have ecological implications. For example, for loggerhead and green turtles in Japan, the length of the internesting interval (i.e. the period between consecutive nesting emergences within a season) has recently been shown to be strongly coupled to water temperature, with this interval decreasing when the water is warmer (Sato et al., 1998). The implication of this relationship is that the rate at which eggs develop within a female prior to oviposition increases with temperature, and since eggs tend to be laid when the embryos have developed to a specific stage (Miller,

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1997), at warmer temperatures a female is able to re-nest sooner.

At Ascension Island (equatorial Atlantic), where green turtles nest, and at Cyprus (Mediterranean), where both green and loggerhead turtles nest, internesting intervals are relatively short (10–14 days) (Mortimer and Carr, 1987; Broderick and Godley, 1996). If the relationship between water temperature and the length of the internesting interval is common across different populations, then we would predict that water temperatures encountered by turtles at these two rookeries will be warmer than those in Japan. Here, we test this prediction by attaching temperature loggers to nesting females at both sites.

## 2. Materials and methods

We used time depth recorders (TDRs) to quantify the ambient temperature and depth of turtles during the internesting interval. Nesting turtles were located while ashore and once egg laying was complete TDRs were attached to the carapace with quick setting epoxy resin. When individuals returned to nest, subsequently, the TDRs were removed and the internesting interval recorded, i.e. the period between TDR attachment and the next nesting emergence. Three models of TDR were used: Wildlife Computers Mk 6 (Wildlife Computers, Redmond, WA, USA); Vemco Minilog TX (Vemco Ltd., Shad Bay, Nova Scotia, Canada); Lotek LTD-100 (LOTEK Marine Technologies, St. John's, Newfoundland, Canada). These units were relatively small (weights in air 125, 23, and 16 g, respectively) compared to the size of the turtles (many 10s of kg) and recorded temperature at intervals of between 150 s and 1 h depending on the model. Deployments were made on green turtles nesting on Long Beach, Ascension Island (7°57'S, 14°22'W) in March and April 1998 and on Alagadi Beach on the northern shore of Cyprus (35°33'N, 33°47'E) in June and July 2000, and on loggerhead turtles nesting on Alagadi Beach in June and July 1999. Information on the ambient water temperature and length of the internesting interval for loggerhead and green turtles nesting in Japan (again collected with TDRs) was taken from Table 2 in Sato et al. (1998).

## 3. Results

Temperature and depth were recorded successfully for three green turtles at Ascension Island, eight green turtles over a total of nine internesting intervals at Cyprus (i.e. two internesting intervals were recorded for one individual) and two loggerhead turtles at Cyprus, giving a total sample size of water temperature for 14

interesting intervals. This is a large sample size given the logistical problems of working with sea turtles.

Interesting intervals at Ascension Island and Cyprus were between 10 and 14 days. When superimposed on the previously published information for loggerhead and green turtles in Japan (Sato et al., 1998), it is evident that the water temperatures experienced by turtles in Cyprus and Ascension Island were relatively warm and the internesting intervals relatively short (Fig. 1). When comparing the five different populations and species (i.e. green turtles at Ascension Island, Cyprus and Japan; loggerhead turtles at Cyprus and Japan), there was no significant difference between the mean residual values from the fitted line (one-way ANOVA,  $P = 0.95$ ) suggesting that a single relationship described the entire dataset.

All turtles spent the vast majority of their time at shallow depths, generally <25 m. At both Ascension Island and Cyprus, depth selection by the turtles had little impact on the ambient temperature recorded. At Ascension Island the temperature at different depths was always close to 28°C, while at Cyprus there was more thermal variation with depth, with a slight decrease (about 1°C) in the mean temperature between the surface and 15–20 m (Fig. 2).

## 4. Discussion

Although studies on the free-living thermal ecology of marine reptiles have been sparse, as might be expected,

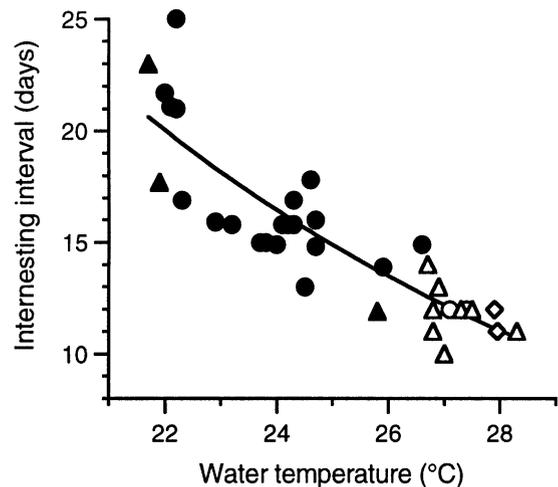


Fig. 1. The relationship between water temperature and the length of the internesting interval for green turtles in Japan ( $\blacktriangle$ ), Ascension Island ( $\diamond$ ) and Cyprus ( $\triangle$ ) and for loggerhead turtles in Japan ( $\bullet$ ) and Cyprus ( $\circ$ ).  $\text{Log}(\text{interesting interval in days}) = 2.25 - 0.043 \text{ Temperature } (^{\circ}\text{C})$ . ( $F_{1,36} = 129$ ,  $r^2 = 0.78$ ,  $p < 0.001$ ).

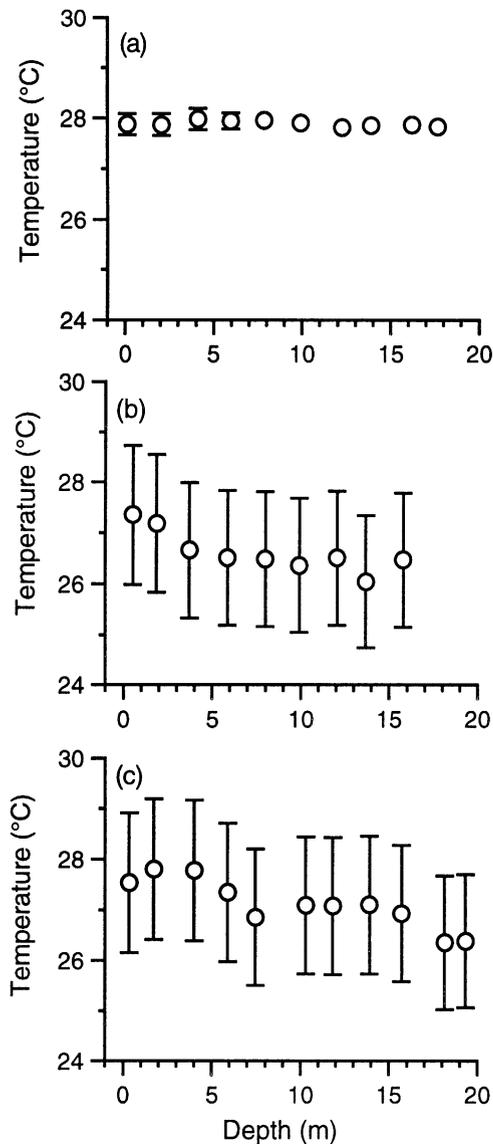


Fig. 2. The mean temperature recorded at different depths for: (a) green turtles at Ascension Island, (b) green turtles at Cyprus, and (c) loggerhead turtles at Cyprus. The mean temperature was determined between the surface and 1 m and then for subsequent 2 m depth intervals. Error bars are  $\pm 1$  SD and so represent the thermal variation at each depth.

ambient temperature is known to have wide-ranging and important impacts. For example, for marine iguanas (*Amblyrhynchus cristatus*) in the Galapagos Islands, the generally cold water may constrain the amount of time that individuals can spend foraging, with periodic on-shore basking being required to rewarm (Buttemer and Dawson, 1993). While marine iguanas may be studied by direct observation, since they forage close to land and

come ashore every few hours, marine turtles are far more aquatic, usually only coming ashore to nest and hence they present a more difficult group for study. However, as the use of satellite transmitters and logging equipment on marine turtles increases, so our knowledge of their behaviour whilst at sea continues to expand (e.g. Hochscheid et al., 1999; Nichols et al., 2000). Given the dependence of body temperature on water temperature in green and loggerhead turtles (Sato et al., 1998), it is not surprising that water temperature has a strong impact on the length of the internesting interval. The results presented here, when combined with previously published information, suggest that there may be a general relationship between water temperature and internesting interval for loggerhead and green turtles that applies across species and populations. As such, water temperature may have a strong influence on the length of time a female takes to lay her full complement of clutches within a season and hence her residence time at the nesting grounds.

At both Ascension Island and Cyprus, there appeared to be little potential for behavioural thermoregulation since the ambient temperature varied little with depth. Under certain conditions turtles might be able to increase their body temperature by basking at the surface. For example, Sapsford and Van der Riet (1979) found that when an immature captive green turtle floated at the surface while it was sunny, the body temperature increased by several degrees, but when the individual floated under overcast conditions there was no such effect. However, in general it appears that marine turtles spend little time actually floating at the surface either during the internesting interval, while migrating or while at foraging grounds (Renaud and Carpenter, 1994; Gitschlag, 1996; Hays et al., 1999). Even in Japan where water temperature during the internesting interval is low, dropping to 22–24°C, surface basking rarely occurs (Sato et al., 1995). Thus, while behavioural thermoregulation through microhabitat selection occurs widely in terrestrial reptiles (e.g. Christian and Bedford, 1995), for free-swimming green and loggerhead turtles, body temperature is likely to be driven largely by the ambient water temperature.

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