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Earlier nesting by loggerhead sea turtles following sea surface warming

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Abstract

The onset of spring, noted by the timing of wildlife migratory and breeding behaviors, has been occurring earlier over the past few decades. Here, we examine 15 years of loggerhead sea turtle, *Caretta caretta*, nesting patterns along a 40.5 km beach on Florida's Atlantic coast. This small section of beach is considered to be the most important nesting area for this threatened species in the western hemisphere. From 1989 to 2003, the annual number of nests fluctuated between 13 000 and 25 000 without a conspicuous trend; however, based on a regression analysis, the median nesting date became earlier by roughly 10 days. The Julian day of median nesting was significantly correlated with near-shore, May sea surface temperatures that warmed an average of 0.8 °C over this period. This marine example from warm temperate/subtropical waters represents another response of nature to recent climate trends.

Keywords: egg laying, Florida, marine turtle, nesting behavior, sea surface temperature

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Introduction

Corroborative evidence, showing shifts in species' ranges and phenologies as harbingers of climate change, is mounting (Hughes, 2000; Gitay *et al.*, 2002; Root & Schneider, 2002; Walther *et al.*, 2002). For instance, egg-laying in many temperate bird species has been occurring earlier over the past several decades (Archaux, 2003). These changes have been correlated to higher spring temperatures (McCleery & Perrins, 1998; Brown *et al.*, 1999; Wuethrich, 2000). The ramifications of such behavioral shifts may be minor if associated ecosystem properties (e.g., juvenile food supplies) shift synchronously. However, if needed shifts do not occur, ecological repercussions could be dramatic (Grossman, 2004). Though examples of climate-related, temporal shifts of wildlife behavior have largely been terrestrial and from higher latitudes or elevations (Walther, 2001; Gitay *et al.*, 2002; Root & Schneider, 2002), in this study, we examined recent nesting trends of loggerhead sea turtles (*Caretta caretta*).

Loggerhead sea turtles are globally distributed in warm temperate and subtropical oceans. The range of sea surface temperatures (SSTs) that they occupy in the central North Pacific is 15–25 °C (Polovina *et al.*, 2004). Despite the fact that juveniles are known for long-distance dispersal to varied locales (Bolten, 2003), reproductively active females possess a high degree of philopatry denoted by their faithful return to a particular nesting site. The Atlantic beaches of east central Florida are critical nesting grounds for these threatened species (Ehrhart *et al.*, 2003). Thousands of loggerheads nest here annually, mostly concentrated along a <50 km stretch of beach. Moreover, even within this tract, the spatial locations of nests are significantly correlated year to year (Weishampel *et al.*, 2003). In the month after nesting on these beaches, based on satellite telemetry (Caribbean Conservation Corporation & Sea Turtle Survival League, 1999) and tag recovery (Meylan *et al.*, 1983), adult females migrate south hundreds of kilometers to forage in shallow coastal waters around islands in the northern Caribbean and southern Gulf of Mexico. After an inter-nesting period, averaging 2–3 years (ranging from one to nine), reproductively active females swim northward to these nesting beaches (Dodd, 1988; Schroeder *et al.*, 2003). Mating occurs en route several weeks prior to nesting (Nelson, 1988).

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Materials and methods

The study area is a 40.5 km stretch of beach on the east coast of Florida from Sebastian Inlet to the southern boundary of Patrick Air Force Base (Weishampel *et al.*, 2003). Subsuming the Archie Carr National Wildlife Refuge, the beaches on this barrier island attract more nesting loggerhead turtles than anywhere else in the western hemisphere (Ehrhart *et al.*, 2003). Approximately 25% of loggerhead turtle nests in the United States are located here (US Fish and Wildlife Service, 2001).

All nesting events were tallied daily in dawn surveys from 1989 to 2003. Methods conform to the Florida Fish and Wildlife Conservation Commission Index Nesting Beach Survey (INBS) Program that was established in 1989 (Witherington & Koeppel, 2000). These surveys typically run from the beginning of May until the end of August. Because of inconsistencies in the initiation and duration of the surveys, we could not compare the onset and length of nesting seasons. Instead, we examined a window (10 May–30 August) that represented a consistent sampling effort and the majority (98.1%) of recorded annual nesting events. From these data, we calculated the median day of nesting for each year.

Loggerhead oviposition has been shown to commence each spring immediately to the south of the study area on Hutchinson Island when local SSTs reach 23–24 °C. Nesting accelerates with increasing temperatures and photoperiod (William-Walls *et al.*, 1983). To examine the relationship between timing of nesting and ocean temperature, we obtained SST values derived from a NOAA buoy (Station 41009) that monitors marine and meteorological conditions located 37 km east of Cape Canaveral, Florida, about 50 km northeast of the northern end of the study area (National Data Buoy Center, 2003). Monthly water temperature averages over this 15-year period were calculated from 30 min or hourly interval readings taken 1 m below the surface.

Results and discussion

Loggerhead nest numbers were highly variable from year to year (Fig. 1) perhaps reflecting foraging conditions (Hays, 2000; Solow, 2001). When the beach surveys extended outside the 10 May–30 August window, proportionately few additional nests were recorded. Fluctuations in annual nest numbers were not as regular as found with green turtles (*Chelonia mydas*) that nest on this beach at 2–4-year cycles (Nelson, 1988) and produce a pronounced biennial pattern (Weishampel *et al.*, 2003). The probability of green turtle nesting in a given year in Costa Rica has been shown to be a function winter SSTs from the northeastern Caribbean (Solow *et al.*, 2002).

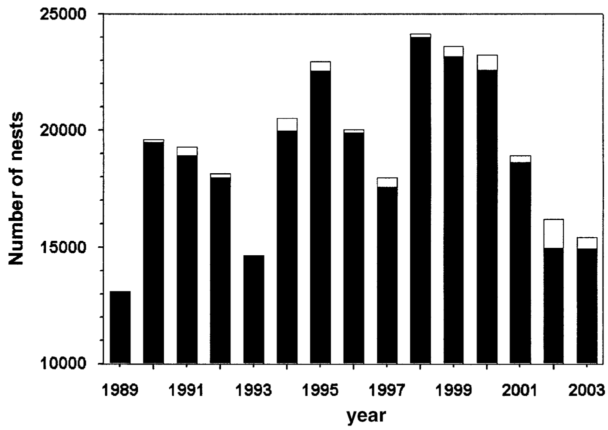

Fig. 1 Loggerhead turtle nest counts from annual surveys 1989–2003. Black bars are nest tallies within the 10 May–30 August window that represents a consistent sampling effort. White extensions represent nests surveyed before and after this period.

From 1989 to 2003, the median date of loggerhead nesting occurred progressively sooner from Julian day 180 to 170 (i.e., 29 June to 19 June) (Fig. 2a). May SSTs over this 15-year period measured by the nearest NOAA buoy were significantly correlated to median nesting date (Fig. 2b). From the linear relationship derived from regression analysis, a 2.0 °C warming in May SST corresponded to a 12-day earlier shift in median nesting date. Being ectothermic, sea turtle physiology and behavior are largely dictated by ambient temperatures (Spotila *et al.*, 1997). As such, nesting season length is generally shorter on higher latitude beaches. Loggerheads lay from one to seven clutches per season; on average clutch numbers are two to four (Dodd, 1988; Schroeder *et al.*, 2003). The interval between clutches ranges between 11 and 20 days with an average interval of 13 days (Nelson, 1988). Warmer spring SSTs, which yield an earlier onset of nesting and a reduction in time between clutches (Nelson, 1988), most likely contributed to this shift in the median nesting date.

During this 15-year period, May SSTs derived from the buoy data warmed on average by 0.8 °C. However, the warming trend over this period was not significant ($r^2 = 0.19$, $P = 0.108$). This suggests that other factors such as the initiation of the northward migration to the nesting beaches may also be contributing to the premature nesting. Cues to begin migration would most likely include warmer SSTs in the foraging areas. The general warming trends found in the buoy point data have been observed in coarser-scale, satellite-derived SSTs for this Atlantic latitudinal zone (Strong *et al.*, 2000). Since the late 1950s, the Caribbean region along loggerhead migratory routes has warmed. Days

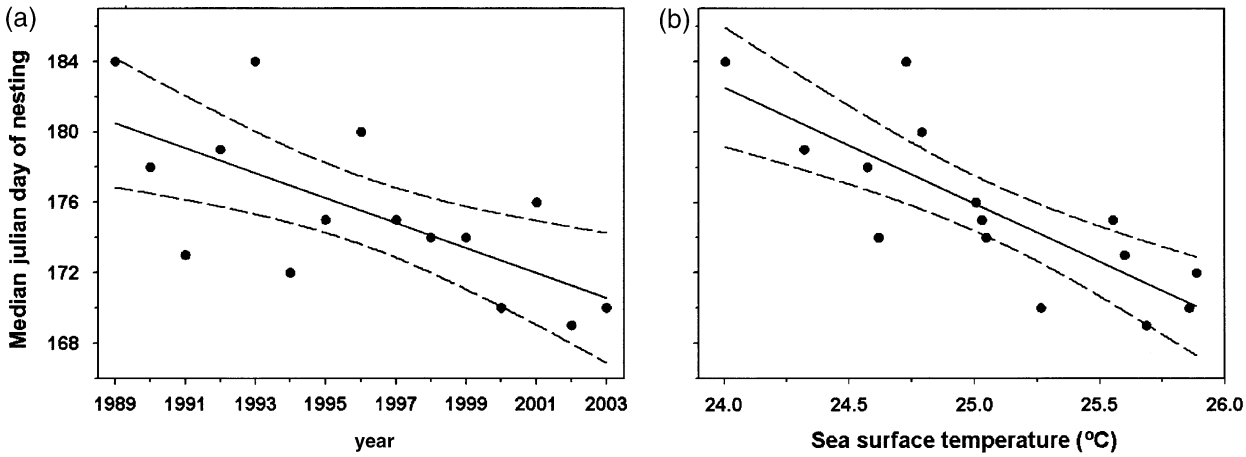

Fig. 2 (a) Temporal change and trend in the annual median nesting date within the 10 May–30 August window ($r^2 = 0.46$, $P = 0.006$) from 1989 to 2003. (b) Relationship between May sea surface temperature derived from a nearby NOAA buoy and annual median nesting date ($r^2 = 0.65$, $P < 0.001$) from 1989 to 2003. Dashed lines represent 95% confidence envelopes.

with temperatures above the 90th and below the 10th percentiles significantly increased and decreased, respectively (Peterson *et al.*, 2002).

To paraphrase Heller (1993), it appears that birds are not the only ones; sea turtles are also laying their eggs sooner. The earlier timing of egg-laying by 10 days is comparable with that found with various avian species (Brown *et al.*, 1999; Crick & Sparks, 1999; Dunn & Winkler, 1999). As with most species-level changes related to climate change, the implications, in terms of species conservation and community- and ecosystem-level interactions, for loggerheads are speculative. This finding leads to numerous follow-up questions that need to be addressed by future studies. These include: Does this earlier nesting affect overall fecundity? Clutch size? Incubation length? Hatching success? Hatchling survivorship? Are the food sources that hatchlings rely on available if turtles hatch earlier? Do cues that produce the earlier migrations, produce synchrony with mating? Are eggs that are laid earlier fertilized similarly to those that are laid later? Because loggerhead turtles (Carthy *et al.*, 2003), like many reptiles and other marine turtles (Hays *et al.*, 2003), show temperature-dependent sex determination (TSD), does earlier nesting affect the sex ratio?

Though perhaps not as dramatic as higher latitudes (Grossman, 2004), subtropical oceans have experienced warming as reflected by coral bleaching events (Winter *et al.*, 1998). This study showed that shifts in behavior of a marine reptile related to environmental warming are also occurring. Though questions remain as to how this will affect this threatened population, given the wide distribution of loggerhead nesting in the Eastern Atlantic (Ehrhart *et al.*, 2003), changes that occur at this restricted, albeit very important, area may be offset by changes, such as an increased length of nesting season at beaches to the north. Hence, a more comprehensive examination of nesting patterns is warranted.

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