SPATIAL AND TEMPORAL INFLUENCE OF METEOROLOGICAL AND SUBSTRATE FACTORS UPON LOGGERHEAD SEA TURTLE NESTS IN SOUTH CAROLINA

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Abstract: Loggerhead nest temperatures were recorded using temperature-humidity data loggers that were emplaced within the center of nests at three nesting beaches in South Carolina. Data loggers were deployed over seasonal quartile periods between June and mid-August with most loggers allocated to the mid two quartiles when the majority of nests were laid. This design allowed a spatial and temporal comparison of nest temperature, incubation duration, sex ratio and overall hatching success. Nest temperatures were cooler at the northern site over the entire season and during the incubation mid third, resulting in a lower percentage of female hatchings being produced (71.73%). Even so, all quartiles for each site produced over 60 percent female hatchlings, and excluding the first quartile, nests ranged from 78% to 96% females. Incubation durations and hatching success were not significantly different between sites. Within sites, only the first quartile nests at Cape Romain displayed significantly longer durations than nests laid at other times. Multiple regressions of thirteen meteorological and substrate attributes on nest temperature at the three nesting beaches were performed. Precipitation was found to be one of the few predictive variables within both Cape Romain and Debidue/Pawleys Island while Air temperature and clutch size contributed the most to nest temperature variation at Edisto. Between beach regressions showed air temperature, color (blue hue) , and sand grain size were the best predictive characteristics.

Introduction: Loggerhead sea turtles (Caretta caretta), a federally threatened species, are the most abundant nesting sea turtle in the southeastern United States. The geographic range of this population spans southern Florida through North Carolina, and experiences 50 - 80 thousand nests per year (Ehrhart et al. 2003). Nest microclimate, which includes the physical conditions of temperature, water content, and relative humidity within the nest cavity, are influenced by a myriad of factors such as latitudinal variation, seasonal temperature changes, shading by vegetation, sand grain size, sand color, clutch size, depth of eggs, and episodic events such as rainfall (Spotila et al. 1996, Godley et al. 2001, Hays et al. 2001). Understanding the characteristics that may contribute to nest microclimate which subsequently influences embryonic outcomes in South Carolina is important because of the relative higher proportion of males produced compared to the more southerly states in the nesting population of the Southeastern U.S.

Site Descriptions: This study took place at three sites (Figure 1) in South Carolina, USA during the 2007 nesting season including; North Inlet, Cape Romain, and the ACE basin. North Inlet and the ACE basin are part of the National Estuarine Research Reserve System (NERRS). Research at North Inlet was conducted at the neighboring Debidue and Pawley's Island beaches, immediately to the north of the inlet. Cape Romain is the location of the largest nesting population of loggerheads in the state with approximately 1000 nests being laid per season. Cape Island is located at the north end of the reserve, and is the site of large scale hatchery operations. The Southern site was at Edisto Beach State Park.

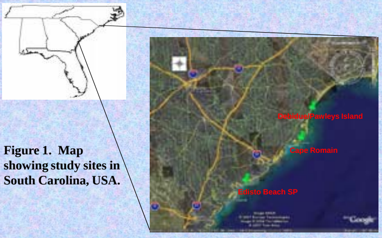


Figure 1. Map showing study sites in South Carolina, USA.

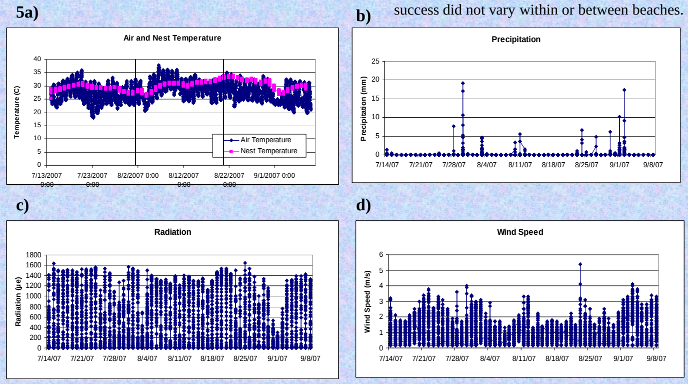
Methodology: The nesting season (May-August) was divided into quarters based on previous nesting data specific to the target sites (Hopkins-Murphy et al., 1999). Most loggers were allocated into the mid two seasonal quarters when nesting activities are highest. At each site temperature/ humidity data loggers from LogTAG were deployed within nests to collect spatial and temporal nest microclimate every 30 minutes. Substrate was collected from each nest within one meter of the egg chamber at 45cm depth (corresponding to average mid-nest depth), and was analyzed for average grain size and sand grain distribution (Folk, 1980) using a shaker sieve series. Sand density (dry) was measured in filled volume film canisters using a benchtop balance and sand color will be determined by digital photography followed by analysis using Image pro plus® software. Meteorological data (temperature, precipitation, wind speed, and solar radiation) was collected every 30 minutes from HOBO® 4-Channel weather stations located at each site. Sex ratios were determined using the temperature model in Georges et al. (1994), which takes into account mean daily temperature and range. Hatching success was determined after completion of hatchling emergence. Data was analyzed using the Kruskal-Wallis nonparametric test in SPSS and regression models were developed for each site and between sites.

Results/Discussion: Edisto and Cape Romain total and mid-third nest temperatures were not significantly different (Figure 2), however when broken down into quartiles, Cape Romain nests are warmer in the last quartile (P<0.05, Figure 3). Overall, total incubation nest temperatures at Debidue and Pawleys Island were cooler (30.3 °C) (Figure 2a) and the mid-third temperatures are significantly cooler than Edisto (P<0.005, Figure 2b). This site, however, is cooler in the second quartile and warmer in the third quartile compared to the other sites (P<0.005, Figure 3). Due to the cooler temperatures, embryonic outcome represented as percent females was lowest at Debidue and Pawleys Island (71.73%) (Table 1, Figure 3). The spread of temperatures during the mid-third can be seen in Figure 4; the northern site is skewed to the left, while the southerly most site can be seen to spread further to the right into the warmer temperatures. Temporally, nest temperatures did not vary throughout the incubation duration at Edisto, and at Cape Romain the first quartile was significantly cooler and the fourth quartile was warmer (P<0.05). Third quartile mid-third temperatures at Debidue and Pawleys Island were significantly warmer than the first two (Figure 3), however no data was collected from this location during the fourth quartile. Although, temperature was not greater, incubation duration was significantly shorter at Cape Romain (P<0.01). Hatching success did not vary within or between beaches.

Table 1. Mean values (standard errors) of characteristics measured. at each study site. Meteorological and substrate factors represent meansduring the middle third of incubation * indicates significance P<0.05.

Meteorological Factors	**Edisto**	**Cape Romain**	**Debidue/Pawleys**
Air Temperature (C)	27.83* (0.16)	29.92* (0.1)	27.05* (0.25)
Total Precip (mm)	103.42* (9.33)	43.52* (3.97)	71.34* (11.41)
Radiation (µE/m2)) †(W/m2)	352.77* (6.51)	257.18*†(2.36)	424.02* (5.59)
Wind Speed (m/s)	0.98* (0.02)	0.62* (0.03)	3.20* (0.06)
Substrate Factors			
Grain Size (mm)	0.62* (0.04)	0.38 (0.01)	0.39 (0.01)
Skewness	-0.312 (0.08)	-0.14(0.05)	-0.34 (.03)
Kurtosis	3.08 (0.14)	3.06 (0.0.12)	3.96 (0.11)
Red	138.96 (0.58)	138.37 (0.59)	143.42* (0.13)
Green	131.36* (0.61)	128.83* (0.77)	136.49* (0.1)
Blue	124.47* (0.68)	118.15* (0.73)	130.98* (0.21)
Density (g/ml)	1.46* (0.02)	1.55 (0.01)	1.54 (0.01)
Nest Factors			
Clutch Size	110.89 (4.28)	112.9 (3.30)	111.59 (4.88)
% Success	71.27 (4.29)	78.15 (2.97)	83.86 (3.90)
Nest Temperature (C)	31.1* (0.17)	30.7 (0.12)	30.3* (0.36)
Sex Ratio (% Female)	88.97 (2.35)	82.83 (1.64)	71.73* (5.11)
Incubation Duration	54.4 (0.69)	52.7* (0.35)	55.2 (0.9)

5a)



Figures 2. Representative data retrieved for the duration of one nest at Edisto Beach SP 7/14-9/8. a) Nest temperature from a central logger and air temperature from a nearby weather station. Vertical lines separate the incubation time into thirds.b) Total daily precipitation, c) Solar radiation,and d) Wind speed.

Measured external characteristics varied temporally and spatially over the incubation duration (Table 1). Representative weather data over the incubation duration of one nest at Edisto can be seen in Figure 5. Only a subset of the 13 meteorological and substrate characteristics measured were significant for within and between site linear regression models (Table 2).

The poorest regression was found when all sites were included, followed by the within site results of Cape Romain. Nest depth was a variable that was not taken into account that may be predictive. The lack of precipitation in the summer of 2007 may have dampened the predictive ability of this attribute, which could lead to lower R^2 values. Using a direct method regression employing all variables, greatly increases R^2 values in the case of Debidue/Pawleys Island (Table 2).

Table 2. Variables that are significant in stepwise linear regression models for within and between beaches and the corresponding R^2 values produced. *0.05>P>0.01 **0.01>P<0.001. R^2 when all variables are forced into a regression are also presented.

Nesting Beach	Significant Variables	R^2 Value produced	R^2 values for forced regression
Edisto	Air Temperature**	0.51	0.64
	Clutch Size **		
Cape Romain	Radiation**	0.25	0.36
	Precipitation*		
Debidue/Pawleys Island	Precipitation**	0.84	0.99
	Red*		
All Sites	Air Temperature**	0.19	0.25
	Blue**		
	Grain Size**		

Historically, Mrosovsky et al. (1984) found that sex ratios from several beaches in South Carolina and Georgia produced nests ranging from 10% female at the cooler ends of the season to 80% female during the center of the season and average sex ratio over 6 years was 56.3%. According to this study 23 years later, all average nest temperatures, except for a few at Debidue/Pawleys Island, were higher than the pivitol temperature of 29.2 ºC (Figure 4), resulting in all quartiles at all sites to be female-skewed (Figure 3). Although the very beginning and end of the season was not captured in this study, percent females averaged 82.9 (SE 1.51) when all sites are combined; 1.5 times greater than the average reported by Mrosovsky. The difference observed could be partially explained by drought conditions, but increasing temperatures along the coast associated with global warming may also contribute.

2a b

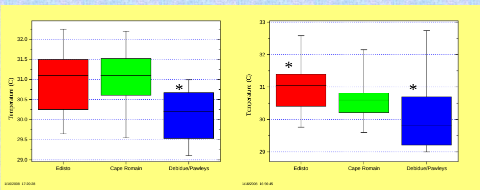


Figure 3. Box and whisker plots representing a) Mean nest temperature over the entire season per site. The Asterick indicates sig. at a P<0.04 level and b) Mean nest temperature during the mid third of incubation duration for all sites. Asterick indicates significance at P<0.002.

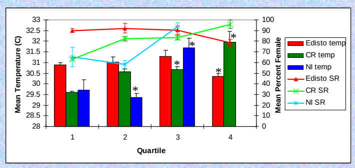


Figure 4. Mean quartile temperatures with error bars for each site and corresponding sex ratio represented as percent females. Asterics represents significance of P<0.025 for temperatures.

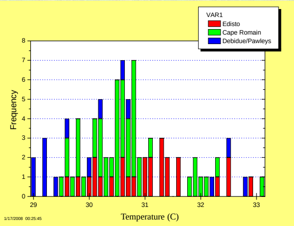


Figure 4. Histogram of nest temperatures during the mid third of incubation indicating the spread of temperatures and the small percentage of females that were produced. Frequencies of different sites are stacked. Note the majority of Debidue and Pawleys Island nests located to the left of the diagram and Edisto nests more to the right.

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