

hatchlings in open air beach hatcheries (Kamarruddin, 1996). Ideally, the sex ratio of hatchlings emerging from *in-situ* nests needs to be determined for as many nesting beaches as possible and non-sacrificial methods should be developed. The data obtained will help provide guidelines regarding hatchling sex ratios which should be produced from hatchery programs.

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Sand Temperatures of Green Turtle Nesting Beaches in the Hawaiian Archipelago

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Sea turtles possess temperature-dependent sex determination or TSD in which the incubation temperature of the egg determines the sex of the hatchling (reviewed by Wibbels *et al.*, 1993; Mrosovsky, 1994). Previous studies of sea turtles indicate that TSD can produce highly biased hatchling sex ratios on some nesting beaches (Mrosovsky and Provanca, 1989; 1992; Marcovaldi *et al.*, 1997; Hanson *et al.*, 1998). As such, hatchling sex ratios are of conservational interest (Mrosovsky and Yntema, 1980; Morreale *et al.*, 1982). However, there are a number of logistical difficulties associated with studying hatchling sex ratios in sea turtle populations, including the inability to sex hatchlings based on external morphology.

Traditionally, hatchlings have been sexed by gonadal histology which requires the dissection of hatchlings (Yntema and Mrosovsky, 1980). More recent studies have employed alternative methods in an attempt to predict sex ratios without killing hatchlings (Mrosovsky and Provanca, 1992; Godfrey *et al.*, 1996; Marcovaldi *et al.*, 1997; Hanson *et al.*, 1998). These methods include the estimation of sex ratios based on sand temperatures on the nesting beaches.

In the current study, sand temperatures (at nest depth) were examined over three consecutive nesting seasons on two nesting islands for the Hawaiian green turtle, *Chelonia mydas*, at French Frigate Shoals.

Methods and Materials

The French Frigate Shoals is an atoll located approximately 800 km northwest of Oahu in the Hawaiian Archipelago (latitude 23° 52' N, longitude 166° 17' W). Over 90% of Hawaiian green turtle nesting occurs on the French Frigate Shoals (Balazs, 1976; 1980). Nesting at French Frigate Shoals occurs on six small islands (Balazs, 1980), with the majority occurring on East Island.

Sand temperatures were monitored on East Island and Tern Island. Sand temperatures were monitored with Hobo temperature data loggers and Optic Stowaway data loggers (Onset Computer Corp., Pocasset, MA, USA). Prior to use each season, the data loggers were calibrated in laboratory incubators. The data loggers were deployed on both East Island and Tern Island during 1995, 1996, and 1997. Data loggers were programmed to record temperature every 3.2 hr. On East Island, data loggers were distributed throughout the island in locations which historically had the greatest nesting activity (Balazs, 1980). On East Island, the data loggers were distributed evenly along the sand beach extending from the south sea wall at a distance from the water where the majority of nesting activity occurs. All data loggers were buried in the sand at a depth of approximately 45 cm, which approximates the depth of the center of the egg clutch in a Hawaiian green turtle nest (Balazs, 1980). At this depth, the maximal daily fluctuation in temperature was typically 0.2°C or less (average maximal daily temperature fluctuation = $0.11^{\circ}\text{C} \pm 0.4$, mean \pm SE). The number of data loggers deployed each year was: 1995, East Island N=8, Tern Island N=4; 1996, East Island N=7, Tern Island N=4; 1997, East Island N=4, Tern Island, N=6.

A previous six year study on Tern Island indicated that nesting normally begins in mid May, with the majority of nesting (approx. 65 to 70%) occurring during June and July (Niethammer *et al.*, 1997). Nesting then declines in August and ends in September (Niethammer *et al.*, 1997). That study also indicated that the average duration of incubation for eggs (yearly averages) on Tern Island ranged from 62.5 to 70.5 days (Niethammer *et al.*, 1997). Considering that the temperature sensitive period of sex determination occurs during the approximate middle third of the incubation period (Yntema and Mrosovsky, 1982; reviewed by Wibbels *et al.*, 1991), mid June through mid September would represent the approximate time period during which temperature would affect the sex of the majority of hatchlings. During each year of the current study, data loggers were deployed during early June and recovered no sooner than early September. Thus, the data collected during this study included the time period during which sand temperature influenced sex determination in the majority of hatchlings produced during the 1995, 1996, and 1997 nesting seasons.

Results and Discussion

During the mid June through mid September periods of 1995 through 1997, the sand temperatures recorded on East Island and Tern Island were in the range of approximately 25 to 29°C. In general, these temperatures appear cool in

relation to sex determining temperatures. In sea turtles, relatively warm incubation temperatures (approx. 31°C or above) produce all females, whereas cooler incubation temperatures (approx. 27°C or below) produce all males (reviewed by Mrosovsky, 1994). The "pivotal temperature" is the temperature which produces an approximate 1:1 sex ratio (Mrosovsky and Pieau, 1991). Although pivotal temperatures can vary, previous studies suggest they normally range between approximately 28.5 to 30.0°C in sea turtles, including green turtles studied in Suriname and Costa Rica (Morreale *et al.*, 1982; Mrosovsky *et al.*, 1984; Standora and Spotila, 1985; Spotila *et al.*, 1987; Godfrey *et al.*, 1996). The pivotal temperature for Hawaiian green turtles is unknown. If the pivotal for Hawaiian green turtles is similar to that of green turtles in Suriname and Costa Rica, then the majority of temperatures recorded in the current study would be below the pivotal. This would suggest that male biased hatchling sex ratios were produced during 1995, 1996, and 1997 on East Island and Tern Island.

However, there are at least two alternative hypotheses. It is plausible that temperatures within the nests may be slightly higher than adjacent sand temperatures due to metabolic heating. Further, it is also possible that the pivotal temperature for Hawaiian green turtles may be relatively low in comparison to those estimated for other green turtle populations. That is, the pivotal temperature for the Hawaiian green turtle may have evolved relative to the nesting beach temperatures at French Frigate Shoals. Either of these scenarios could facilitate the production of unbiased or even female-biased sex ratios at the temperatures observed in the current study. Thus, the results of the current study show the need for future studies addressing the incubation temperatures within nests at French Frigate Shoals and addressing the pivotal temperature in Hawaiian green turtles.

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Incubation Temperatures in Kemp's Ridley Nests during the 1998 Nesting Season

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Sea turtles possess temperature-dependent sex determination or TSD (Mrosovsky, 1994), in which the incubation temperature of the egg determines the sex of the hatchling. This type of sex determination has the potential of producing highly biased sex ratios. A variety of past studies have suggested that in some cases (e.g. strong male biases), such biases could decrease the effectiveness of sea turtle nesting beach conservation programs (Mrosovsky and Yntema, 1980; Morreale et al., 1982; Mrosovsky, 1983; Wibbels et al., 1989). Therefore, it is advantageous to monitor hatchling sex ratios in nesting beach programs.

There are a number of logistical difficulties associated with studying hatchling sex ratios in sea turtle populations, not the least of which is the inability to sex hatchlings based on external morphology. Traditionally, hatchlings have been sexed by gonadal histology which requires the sacrifice of hatchlings (Yntema and Mrosovsky, 1980). Recent studies have employed alternative methods in an attempt to predict sex ratios without killing hatchlings (Mrosovsky and Provancha, 1992; Godfrey et al., 1996; Marcovaldi et al., 1997; Hanson et al., 1998). These methods include the estimation of sex ratios based on incubation temperatures in the nests.

In the current study incubation temperatures were examined in Kemp's ridley nests during the 1998 nesting season. The recovery program for this severely endangered sea turtle is coordinated by Instituto Nacional de la Pesca (Marquez-Tamaulipas, Mexico).

Methods and Materials

Sand temperatures and nest temperatures were monitored with Hobo temperature data loggers and Optic Stowaway data loggers (Onset Computer Corp., Pocomsett, MA). These are relatively small units that can be programmed to record temperatures at a variety of time intervals. They contain a thermistor probe, and at the temperatures common in sea turtle nests, are precise to approximately 0.3°C or better. They are programmed to record temperature by temporarily connecting them to a personal computer loaded with the appropriate software. After they have acquired the temperature data, the units are reconnected to a personal computer to download data. The data loggers were calibrated in custom incubators which maintain a constant internal temperature of $\pm 0.2^\circ\text{C}$.

Data loggers were used to monitor sand and nest temperatures in egg corrals at Rancho Nuevo, Tepehuajes,



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