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Sex-ratio Predictions of *Eretmochelys imbricata* Nesting Beaches in Nicaragua and the Republic of Seychelles

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Abstract

The hawksbill sea turtle (Eretmochelys imbricata) occurs in tropical oceans throughout the world and is known for inhabiting coral reef environments. It is harvested for its "tortoise shell" which is used to make jewelry, and this species is considered "endangered" throughout its range. The hawksbill possesses temperature-dependent sex determination (TSD) in which temperatures during the middle third of incubation period determine the sex of the hatchling. The significance of understanding TSD is clear in a conservational sense, offering the possibility to monitor and optimize sex ratios in order to enhance the recovery of this endangered species. The current study addresses hatchling sex ratios produced by hawksbill turtles on major nesting beaches in the Republic of the Seychelles and in the Pearl Cays off the Caribbean coast of Nicaragua. Beach temperatures at nest depth and nest temperatures were monitored and used to predict sex ratios during the 2007-2008 nesting seasons. The average temperatures from the warmest and coolest sites were used to estimate the potential range of hatchling sex ratios from each site. The beach temperature data suggest that both of these major nesting locations may produce male biases. However, nest temperature data from a limited subsample of nests from Nicaragua suggest that nests in specific locations may produce female biases. These data will be used to evaluate and develop a conservation strategy for these endangered populations of the hawksbill turtle.

Introduction

The hawksbill (Figure 1) is a small to medium-sized sea turtle that has become endangered due to extensive harvesting for the "tortoise shell" trade (Mortimer, 2005). The turtle nests mostly in tropical regions of the Atlantic and Pacific Oceans and is often associated with coral reefs (Edelman, 2004).

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Figure 1. Hawksbill sea turtles are endangered due in part to the "tortoise shell" trade.

Sea turtles have temperature-dependent sex determination (TSD) in which incubation temperature determines the sex of the hatchling (Wibbels, 2003). This type of sex determination has the potential to produce highly biased sex ratios. Therefore, TSD has significant implications for the ecology and conservation of sea turtles. For example, extreme sex ratios could alter the reproductive output of an endangered population and thus affect its survival status. The significance of understanding TSD is clear in a conservational sense, serving as a method for predicting and optimizing sex ratios in endangered species to restore populations (Wibbels, Hillis-Starr & Phillips, 1999).

Hawksbills possess a male-female (MF) pattern of temperature-dependent sex determination in which warmer incubation temperatures produce females while cooler incubation temperatures produce males (Figure 2). A transitional range of temperatures (TRT) exists between the maximum temperature which produces 100% male hatchlings (28.5 °C) and the minimum temperature which produces 100% female hatchlings (30.3 °C) (Mrosovsky *et al.*, 1992). The pivotal temperature of 29.2 °C produces a 1:1 sex ratio (Wibbels, 2003; Mrosovsky *et al.*, 1992).

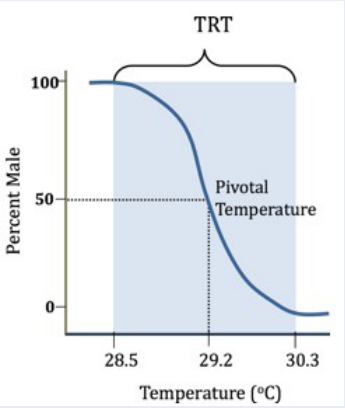

Figure 2. General pattern of TSD in the hawksbill sea turtle.

The current study addresses hatchling sex ratios in hawksbill turtles on major nesting beaches in the Pearl Cays off the Caribbean coast of Nicaragua (Figure 3) and in the Republic of Seychelles (Figure 4). Nesting beach temperatures and nest temperatures are evaluated in order to provide insight on the hatchling sex ratio produced on these nesting beaches. Such information is a prerequisite to developing effective conservation strategies for the recovery of these populations.

Figure 3. A representative island of the Pearl Cays in Nicaragua, where hawksbill nesting occurs.

Figure 4. An aerial view of the D'Arros and St. Joseph hawksbill nesting beaches in the Seychelles.

Materials and Methods

Small, battery-powered HOBO data loggers (Figure 5) from Onset Computer Corporation were used to record sand temperatures in beaches of Nicaragua and the Seychelles. The data loggers were programmed in the laboratory at the University of Alabama at Birmingham to record temperatures every 1 to 3 hours. They were heat-sealed in plastic bags with a container of desiccant. The microprocessor and temperature probe accurately recorded temperatures to approximately ±0.3 °C. The data loggers were placed in sand at a depth to approximate the center of a nest in areas that were representative of hawksbill nesting or in the center of the egg mass while the female turtle was nesting. In the Seychelles, 10 sites were examined in D'Arros Island, St. Joseph Atoll, and Bird Island in various habitat types. Approximately 6 data loggers were deployed at each site. In Nicaragua 9 sites, each with 1 to 10 data loggers, were monitored. Data loggers were also used to monitor 8 hawksbill nest temperatures in several locations in Nicaragua. Once the data loggers were collected,

they were sent back to the University of Alabama at Birmingham and downloaded using BoxCar Pro 3.51. Temperature analysis was done using Microsoft Excel. The average temperature corresponding to the middle third (20 days) of each lay week for the warmest and coolest sites were used for the Seychelles and Nicaragua beaches to predict sex ratios of the hatchlings.

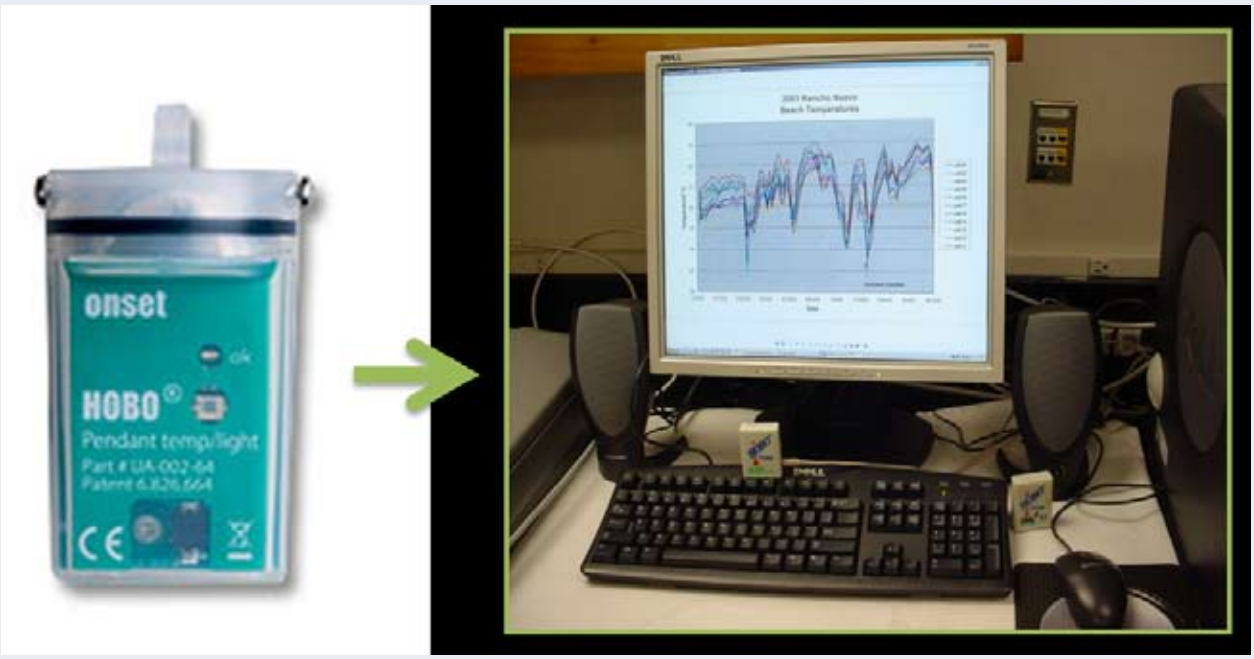

Figure 5. A data logger with a microprocessor and temperature probe. Data were analyzed using Microsoft Excel.

Results and Discussion

The results indicate that the sand temperature was frequently below the pivotal temperature of 29.2 °C (i.e. male-producing temperatures) for each nesting beach in Nicaragua and the Seychelles (Figures 6 and 7; Mrosovsky *et al.*, 1992). Peak nesting was estimated to occur during the months of October-January in the Seychelles and from June to September in Nicaragua. Based on these sand temperatures, Tables 1-4 show predicted sex ratios for nests laid each week during the peak portion of the nesting season (based on average temperature during the middle third of the incubation period). Overall, the observed average sand temperatures clearly indicate a strong male bias, with most lay dates indicating 100% male-producing temperatures (Tables 1-4). Water Beach, the warmest monitored beach in Nicaragua, produced one female-biased middle-third incubation period corresponding to a lay week of 08/10/08 (Table 1). Bird Island Site 1, the warmest monitored site in the Seychelles,

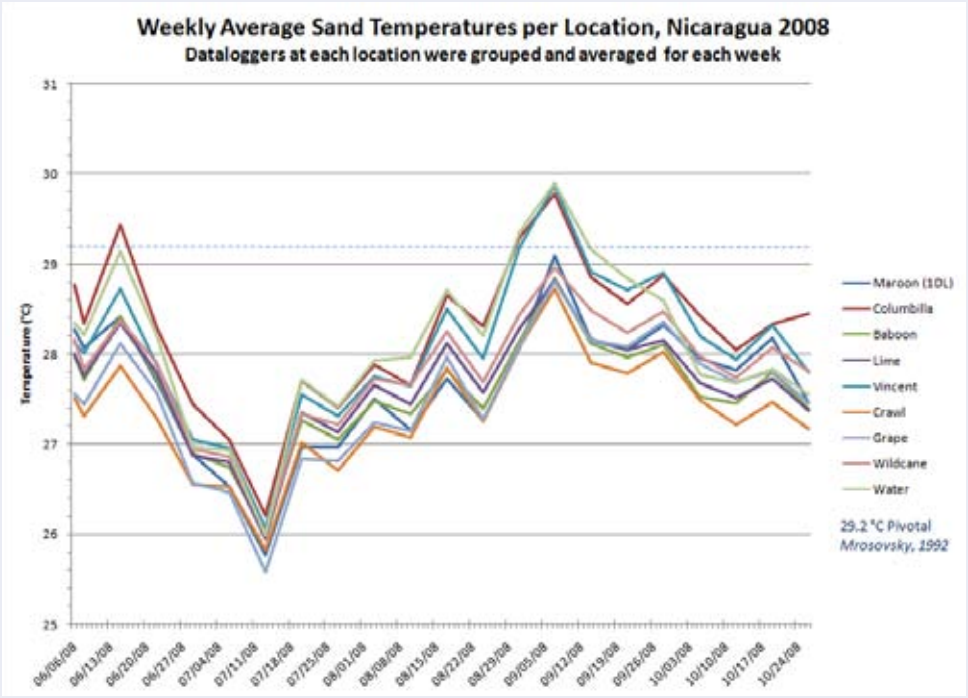

Figure 6. Average temperature of sites in Nicaragua (pivotal temperature is shown by dashed line).

produced a general male bias, with the 12/16/07, 12/23/07, and 12/30/07 lay weeks indicating 100% male-producing temperatures (Table 3). The coolest monitored beaches in both locations predict 100% male-producing temperatures during the entire duration of the peak nesting season (Tables 2 and 4).

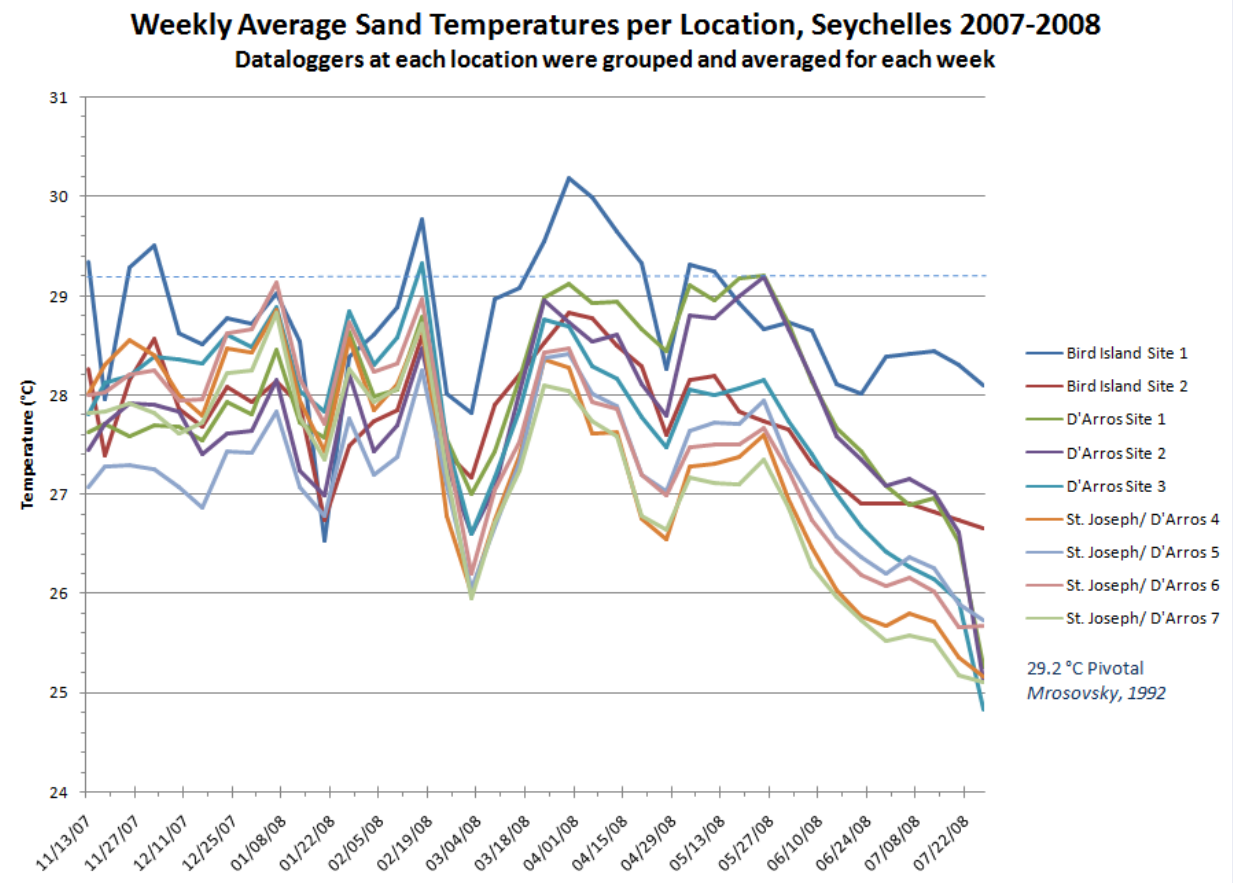

Figure 7. Average temperatures of sites in Seychelles (pivotal temperature is shown by dashed line).

Table 1. Sex-ratio predictions at Water Beach, the warmest monitored site in Nicaragua.

Lay Week	Middle Third	Temperature	Bias
06/08/08	06/28/08-07/17/08	26.730	100% male
06/15/08	07/05/08-07/24/08	26.779	100% male
06/22/08	07/12/08-07/31/08	26.970	100% male
06/29/08	07/19/08-08/07/08	27.584	100% male
07/06/08	07/26/08-08/14/08	27.730	100% male
07/13/08	08/02/08-08/21/08	28.128	100% male
07/20/08	08/09/08-08/28/08	28.225	100% male
07/27/08	08/16/08-09/04/08	28.681	male-bias
08/03/08	08/23/08-09/11/08	29.037	male-bias
08/10/08	08/30/08-09/18/08	29.540	female-bias
08/17/08	09/06/08-09/25/08	29.270	pivotal
08/24/08	09/13/08-10/02/08	28.975	male-bias
08/31/08	09/20/08-10/09/08	28.443	100% male
09/07/08	09/27/08-10/16/08	28.115	100% male
09/14/08	10/04/08-10/23/08	27.814	100% male
09/21/08	10/11/08-10/30/08	27.719	100% male
09/28/08	10/18/08-11/06/08	27.390	100% male

Table 2. Sex-ratio predictions at Crawl Beach, the coolest monitored site in Nicaragua.

Lay Week	Middle Third	Temperature	Bias
06/08/08	06/28/08-07/17/08	26.3737	100% male
06/15/08	07/05/08-07/24/08	26.3978	100% male
06/22/08	07/12/08-07/31/08	26.4713	100% male
06/29/08	07/19/08-08/07/08	26.9088	100% male
07/06/08	07/26/08-08/14/08	26.9872	100% male
07/13/08	08/02/08-08/21/08	27.3051	100% male
07/20/08	08/09/08-08/28/08	27.3627	100% male
07/27/08	08/16/08-09/04/08	27.6760	100% male
08/03/08	08/23/08-09/11/08	27.9206	100% male
08/10/08	08/30/08-09/18/08	28.3008	100% male
08/17/08	09/06/08-09/25/08	28.1029	100% male
08/24/08	09/13/08-10/02/08	27.9762	100% male
08/31/08	09/20/08-10/09/08	27.7831	100% male
09/07/08	09/27/08-10/16/08	27.6652	100% male
09/14/08	10/04/08-10/23/08	27.4770	100% male
09/21/08	10/11/08-10/30/08	27.3233	100% male
09/28/08	10/18/08-11/06/08	26.9984	100% male

Table 3. Sex-ratio predictions at Bird Island 1, the warmest monitored site in Seychelles.

Lay Week	Middle Third	Temperature	Bias
11/18/07	12/08/07-12/27/07	28.649	male-bias
11/25/07	12/15/07-01/03/08	28.694	male-bias
12/02/07	12/22/07-01/10/08	28.860	male-bias
12/09/07	12/29/07-01/17/08	28.856	male-bias
12/16/07	01/05/08-01/24/08	28.160	100% male
12/23/07	01/12/08-01/31/08	27.753	100% male
12/30/07	01/19/08-02/07/08	27.703	100% male
01/06/08	01/26/08-02/14/08	28.502	male-bias
01/13/08	02/02/08-02/21/08	28.999	male-bias
01/20/08	02/09/08-02/28/08	29.116	male-bias
01/27/08	02/16/08-03/06/08	28.583	male-bias

Table 4. Sex-ratio predictions at St. John/D'Arros 7, the coolest monitored site in Seychelles.

Lay Week	Middle Third	Temperature	Bias
11/18/07	12/08/07-12/27/07	27.667	100% male
11/25/07	12/15/07-01/03/08	27.796	100% male
12/02/07	12/22/07-01/10/08	27.930	100% male
12/09/07	12/29/07-01/17/08	27.844	100% male
12/16/07	01/05/08-01/24/08	27.627	100% male
12/23/07	01/12/08-01/31/08	27.428	100% male

12/30/07	01/19/08-02/07/08	27.459	100% male
01/06/08	01/26/08-02/14/08	27.502	100% male
01/13/08	02/02/08-02/21/08	27.457	100% male
01/20/08	02/09/08-02/28/08	26.813	100% male
01/27/08	02/16/08-03/06/08	25.659	100% male

In summary, the sand results show an overall male-biased hatchling sex ratio for the hawksbill sea turtle in both Nicaragua and the Seychelles for the 2007-2008 nesting season (Table 1-4). This bias is unusual since many sea turtle populations have been reported as having a female bias (Wibbels, 2003). For example, Godfrey et al. reported a >90% female bias in Brazil (1999). The beaches in the Seychelles and Nicaragua may be important for the recovery of the hawksbill population by producing a majority of males.

The sand temperature data are by far the most comprehensive data set collected in the current study. However, it is of particular interest that the temperature data from a sample of nests from Nicaragua (Figure 8) suggest that warmer temperatures are possible, with some nests predicted to produce female biases. These biases contrast the more comprehensive dataset collected from sand temperatures at nest depth which reported mostly male-producing temperatures. We are currently investigating the basis for this variation, but it may relate to factors such as specific locations and timing of the nests that were sampled. Hawksbill turtles are well known for selecting a wide variety of locations on a nesting beach ranging from those that are on open beach (i.e. direct sunlight) to those that are well up on the beach in the shaded vegetation zone. We are currently working with our collaborators to address this question. Regardless, the temperature data collected during the current study provide insight on hatchling sex ratios which can be used to evaluate and optimize current conservation strategies for these endangered populations of hawksbill turtles.

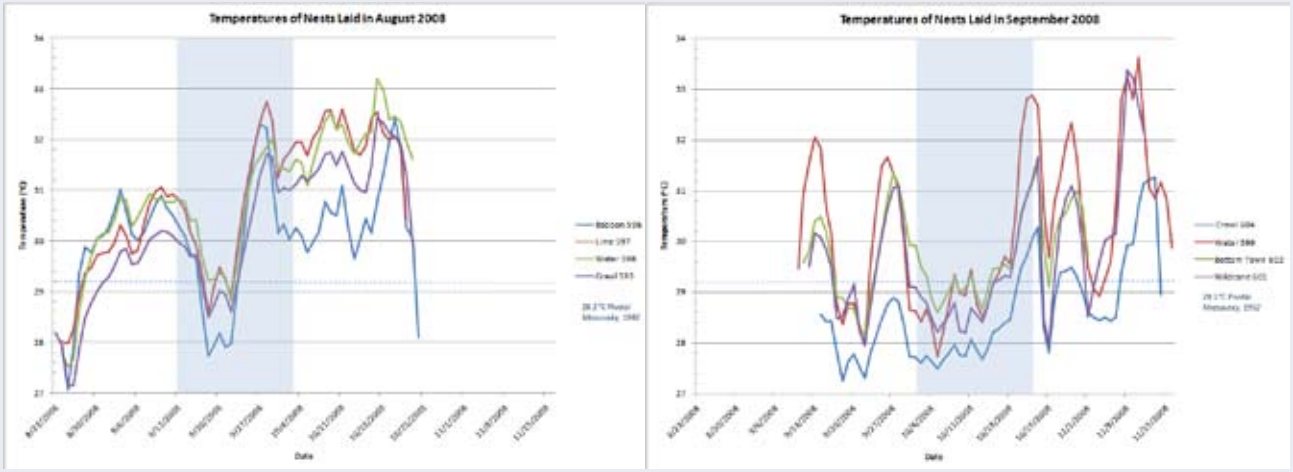

Figure 8. Average nest temperatures in Nicaragua. Shaded area represents temperature-sensitive period of TSD. Pivotal temperature is shown by dashed line.

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