The Temperature Inside the Nests of the Diamondback Terrapin, Malaclemys terrapin, and Its Relationship with the Air Temperature of the Nesting Site.

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Abstract

The diamondback terrapin (Malaclemys terrapin), the official state reptile of Maryland, is an estuarine turtle found along the eastern and Gulf coasts of the United States. The diamondback terrapin may experience risks due to increasing global temperatures because they display temperature-dependent sex determination (TSD). Terrapins, through TSD, produce more female offspring than male offspring if their nest temperatures are relatively warm, leading to ecological issues should global temperatures get too high. This study used temperatures from several individual field, monitored nests, along with air temperatures at the nesting site, recorded in the summer of 2018, to select a predictive model with the R software package rstanarm. The model was then used to predict the average nest temperature in the same nesting site using air temperatures that were recorded during the summer of 2019. This prediction was then compared to temperatures recorded from five nests within the nesting site in 2019 to evaluate its predictive capabilities. A regression spline mixed model (RSMM) was selected for having the lowest leave-one-out information criterion at 50905.95 LOOIC, with a standard error of 0.64 LOOIC. The prediction of average nest temperature developed by the RSMM was given a predictive interval of 95%. We found that the actual temperature of the average nest in 2019 had a prediction coverage of 92.97% from the prediction model, with a root squared mean error of 1.89oC and a predictive mean absolute error of 2.10oC. Benefits of the study involve the ability to predict the future diamondback terrapin nest temperatures within a specific nesting site so long as future air temperatures within that site are known.

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Diamondback Terrapin, *Malaclemys terrapin*:

- It is the official reptile of Maryland.
- Estuarine turtle, part of the Emydidae family.
- Practices temperature-dependent sex determination (TSD).
  - Sex of hatchling determined by temperature of embryo during temperature-sensitive period.
  - Happens in approximate middle of incubation.

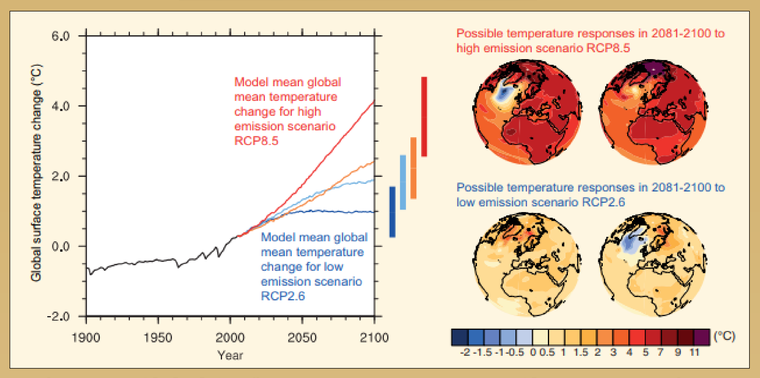

Figure 1: Global Surface Mean Temperature Change over Time under different Scenarios

The Problem:

- At a constant incubation temperature of 29.3°C, 50% males and females are produced.
- Rising surface air temperatures create cause for concern that terrapin populations will become female-biased.

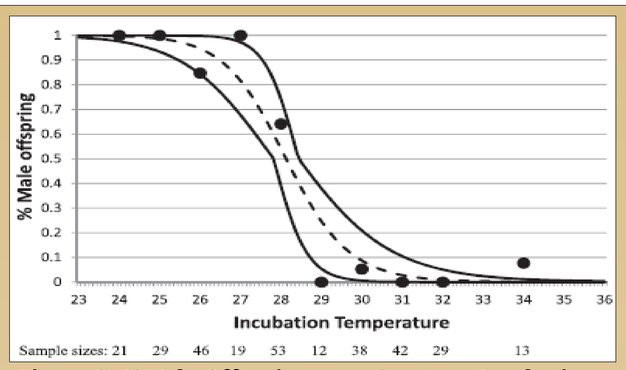

Figure 2: % Male Offspring over Constant Incubation Temperature for Development Period

The Solution:

- Surface air temperatures are easily measured, finding a predictive relationship between surface air and nest temperatures could provide estimates of nest temperatures without having to disturb them.
- This study evaluated the relationship between nest temperature and surface air temperature at the nesting site in order to create a predictive model for their relationship.

Study Location:

- Nesting sites located at Naval Air Station Patuxent River (NAS PAX).
- Consisted of high beach zones, coastal grasslands, and maritime forests.

Figure 3: Diamondback Terrapin Nesting Site Location, NAS PAX.

2018 Nest Data:

- The model was created by finding relationship between nest temperatures and nesting site air temperatures measured in summer 2018.
- From June 5th to October 1st, temperatures were recorded and aggregated to hourly data.
- Eight nests were used.

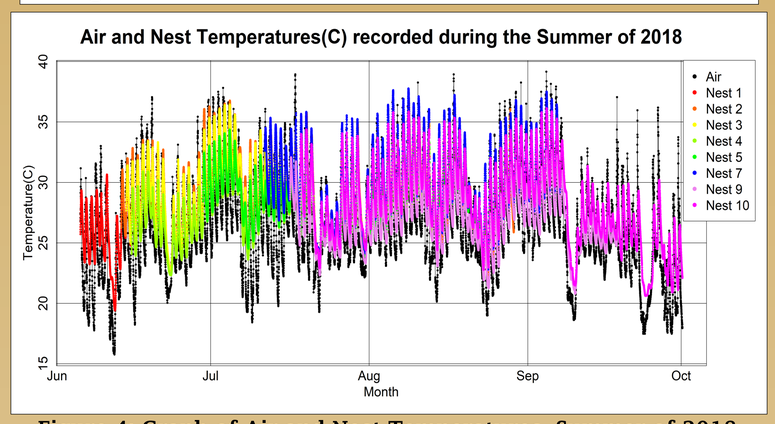

Figure 4: Graph of Air and Nest Temperatures, Summer of 2018

2019 Nest Data:

- A learning algorithm was developed to determine average nest temperature to nesting site air temperatures from summer 2019.
- From June 17th to July 31st, temperatures were recorded and aggregated to hourly data.
- Five nests were used.

The Model:

- A regression spline mixed model (RSMM) was chosen for predicting nest temperature.
- Hierarchical model for nest characteristics / microhabitat influence on temperature.
- Spline for non-linear response of nest temperature to environment.
- One-hour lag was introduced to accommodate for thermal inertia of sand.
- Bayesian model was conducted using R package rstanarm.
- Prediction and 95% interval for site level average provided for 2019.

Results:

- The average 2019 nest prediction from the model has a prediction coverage of 93%.
- Nest 15 had the greatest amount of predictive coverage at 98.7%, at a root mean squared error (RSME) and predictive mean absolute error (PMAE) of 1.89°C and 1.58°C respectively.
- Nest 13 had the least amount of predictive coverage at 83.62%, at a RSME and PMAE of 3.01°C and 2.59°C respectively.

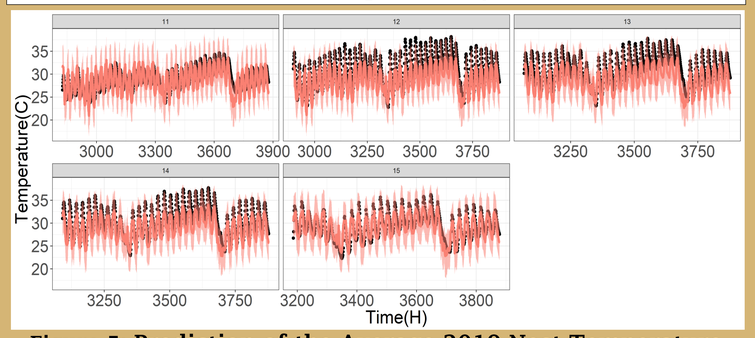

Figure 5: Prediction of the Average 2019 Nest Temperature developed by the RSMM (red) in comparison with Nest Temperatures recorded in the field (black) over Time

RSMM Prediction Results			
Nest	RMSE (C)	PMAE (C)	Coverage %
11	2.235	1.911	96.863
12	2.791	2.388	89.388
13	3.011	2.586	83.621
14	2.299	1.926	96.827
15	1.888	1.579	98.699
Average	2.493	2.095	92.969

Table 1: RSMM Prediction Results and Errors

Conclusions:

- The average diamondback terrapins' nest temperature can be predicted with a prediction coverage of 93% and a predictive absolute mean error of 2.1°C.
- However, air temperature of the nesting site is not the only factor that determines nest temperature behavior, and steps should be taken to determine how other physical characteristics of nests impact their temperature.
- From this study, it is possible to create accurate incubation studies and predictions into the effects of air temperature on the terrapin's average nest.
- The accuracy of the prediction may be improved by using the complete nesting cycle for the summer of 2019, increasing the amount of introduced lag on nest temperatures, using multiple years of nesting data to make the RSMM instead of one, or using an entirely different model to make the prediction.