Bay County Box Turtle Project

Introduction

Hurricane Michael, a category 5 hurricane that hit Florida in 2018, caused significant environmental disturbance, mainly through the loss of tree canopy. The cleanup efforts, which involved heavy machinery to remove storm debris, further exacerbated the impact. These machines destroyed habitats, leaving turtles without homes, seeking shelter during the winter, and, in many cases, costing them their lives. Although some data were available starting in 1994, systematic monitoring started after the hurricane with the goal of improving scientific understanding of box turtles and enhancing their survival within their communities. Additionally, researchers aimed to use box turtles as an indicator to monitor the recovery of Bay County's natural elements and neighborhoods.

The Bay County box turtle project is a collaborative effort led by credible biologists operating in areas such as Lower Grand Lagoon, Cove, and College Point. They rely on the contribution of local citizens who have been engaged through education about the project's objective and trained in the proper methods of tagging box turtles:

1. Encounter a turtle in its natural habitat.
2. Measure (straight carapace length, temperature of the environment at the time, sex, habitat the turtle was found in…etc) and give a name and tag number.
3. Release at the exact location where it was found.
4. Collected data entered into the database.

The Bay County Box Turtle Project is under the US Fish and Wildlife service and is focused on protecting and monitoring box turtles and their habitats in Bay County, Florida. The data collection process for this project includes a survey and turtle mapper that creates a data layer to track turtle population and habitat condition. It uses box turtles as an indicator to assess the health of green space in the area from the impact of Hurricane Michael[1].

Box turtles are ecological generalists, thriving in a variety of habitats and feeding on a diverse range of food items due to their carnivorous diet. Because of Florida's humid climate, they require shelter to endure the intense summer heat and cold winters. The turtles favor damp environments with tree canopy cover, ground level moisture, and low-lying vegetation, which provide essential hiding spots during the day.

Given the citizen science nature of this project, we wanted to engage and inform the public participants who contributed to the research, to provide an overarching view of the data that they have been helping collect.

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[1] [Commodore Productions], *"Bay County Box Turtle Project- Citizen Science Lecture Series Presentation"*, [52:38], published [2022], [https://www.youtube.com/watch?v=9vIOLkW-7vU].

We aim to analyze the health, habitat use, and movement patterns of box turtles in Bay County, Florida, to better understand ecological recovery following Hurricane Michael. Specifically, we will examine how movement behavior, categorized as stationary or non-stationary, and air temperature (°F) relate to their overall health.

Background

Our initial data consisted of 3,928 observations, representing 1,055 distinct box turtles identified by their tag numbers. However, since we aim to use a multilevel model that accounts for multiple measurements of the same turtle, thus we narrowed our observation to only look at box turtles that were recaptured/tagged[2]. As a result our final dataset consists of 2,269 observations corresponding to 476 unique tag numbers. We also removed all observations with missing straight carapace length measurements, since this is our response variable. There were 1661 captures with this missing data, leaving us with a total of 608 observations of 441 individual turtles in our final dataset. This cleaned dataset was used in our modeling, tables, and graphs.

Among various variables such as habitat, status (alive or dead), shell height, maximum carapace width and eye color we focused our analysis on straight carapace length (measured in millimeters), the number of years before and after the hurricane, air temperature (°F), and stationarity, using the unique tag numbers of the box turtles as a basis.

A turtle's straight carapace, or outer shell, length can be used as an indicator of the turtle's health. It refers to how long a turtle's shell is when measured in a straight line from the front (near its neck) to the back (near its tail), without following the shell's curve. The length of each turtle, measured in millimeters, was recorded for each capture. Size acts as a proxy for turtle well-being, as turtles that are thriving in their habitat will likely have access to abundant food sources, allowing them to grow more than turtles in worse conditions. In Table 1, we can see that our data reflects the paper on "How Big Do Box Turtles Get?": box turtles remain small creatures throughout their lives, averaging 127 to 178 millimeters once fully mature. Depending on its subspecies, for example, the Eastern box turtle reaches a maximum length of between 102 and 152 millimeters, while the Gulf Coast box turtle can grow to 216 millimeters long.[3]

[2] U.S. Fish and Wildlife Service. *National Wildlife Refuges [GIS data]*. Accessed December 5, 2024. https://gis-fws.opendata.arcgis.com/maps/88488e1d686e422b908007d3e8864cac/about.
[3] Pet Care Advisors. *How Big Do Box Turtles Get?* Accessed December 5, 2024. https://petcareadvisors.com/reptiles/how-big-do-box-turtles-get/.

Older turtles, however, are more likely to be larger than younger turtles[4]. We account for this difference by using the number of years after the hurricane in our model calculations. Including the number of years after the hurricane in our model helps to capture how time-related changes, such as habitat alteration, may have impacted the size of turtles.

Table 1: Box Turtle Shell Lengths from Final Dataset (608 Observations)

Category	Shell Length (mm)
Smallest Shell Recorded	15 mm
25% of the Smallest Shells	153.8 mm
Typical Shell Size (Average)	164 mm
75% of the Bigger Shells	182 mm
Largest Shell Recorded	232 mm

Another way to estimate turtle health is by looking at their behavior. Turtles that are content in their current environment will likely stay in place, while those that are not satisfied will try to find a better location. At capture time, turtles were either moving in a particular direction or stationary (Table 2). Turtles observed moving in a clear cardinal direction (east, west, north, south) or an unknown/other direction are classified as non-stationary, while those found in the same location are classified as stationary.

Table 2: Turtle Movement Behavior at Capture from Final Dataset (608 Observations)

Behaviour	Count
Stationary (Stayed in the same location)	223
Non-Stationary (Moving in a direction or unknown)	385

Methods

The data we are working with helps us develop a multilevel regression model. As shown in Figure 1, we can observe variability in the counts of distinct turtles, the different years they

[4] Kirkpatrick, Robert L., and Christopher D. McAlister. "Home Range and Habitat Use of Florida Box Turtles (*Terrapene carolina bauri*) in the Florida Keys." *Journal of Herpetology* 56, no. 4 (2022): 403-410. https://doi.org/10.1670/20-071.

were captured/tagged, the movement behaviour they were found in, and air temperature. While a regular regression model assumes that all turtles are identical regardless of their context, a multilevel model provides the flexibility to account for the influence of these factors on the outcome of our analysis.

Initially, we aimed to investigate changes in the straight carapace length that could be associated with or influenced by the year, whether turtles are getting larger, smaller or staying the same across different years.

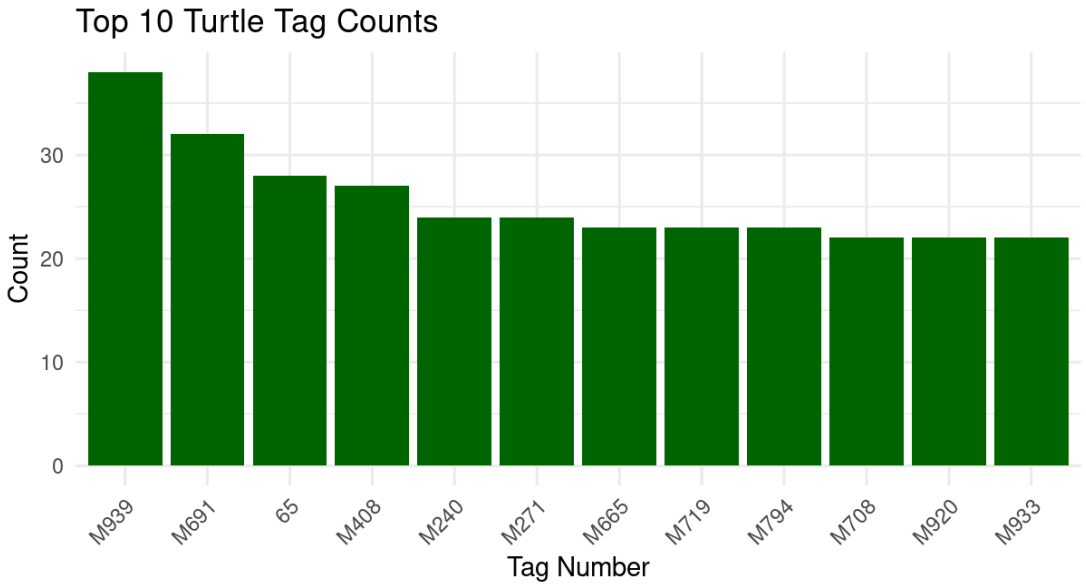

Figure 1:Count Data supporting multi-level model

Figure 2 shows us the monitoring of turtles began after Hurricane Michael in 2018, providing an opportunity to assess its impact on turtles health over time. We can see a clear starting point for the data collection post hurricane, allowing us to evaluate changes in turtle characteristics in the aftermath. In our model we adjusted the year so that 2018 is that starting point (so that it is easier to compare changes before and after 2018).

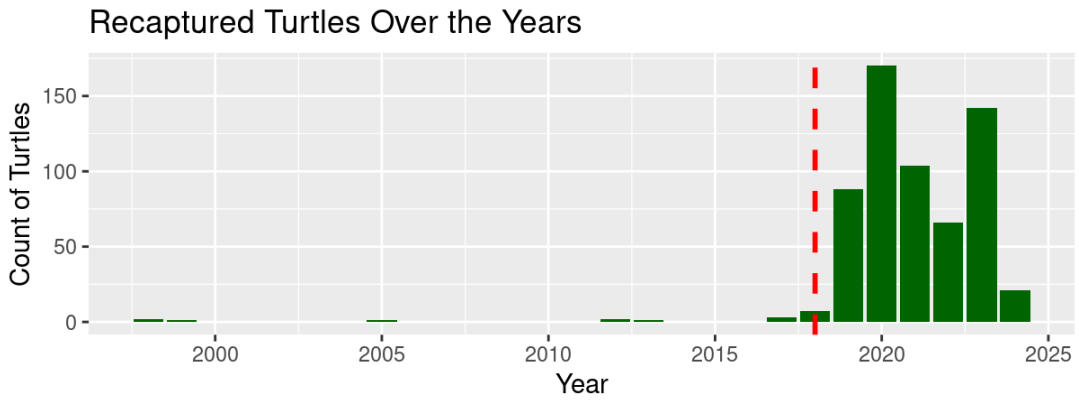

Figure 2: Count of recaptured turtles across different years, highlighting the increase in monitoring efforts starting after Hurricane Michael in 2018. The year variable in our statistical model is represented by the difference in years post-hurricane, with significance indicated by a t-value greater than 2.

Figure 3 provides a better illustration into how the straight carapace length (mm) of box turtles changes over time. The varied size trajectories of individual turtles, with some showing an increase in carapace length over the years, while others exhibit stagnation or a decrease. Interestingly, even within a single turtle's trajectory, we observe fluctuation, size, and stagnation–highlighting not only the varying size patterns among turtles but also the dynamic nature of their development over time.

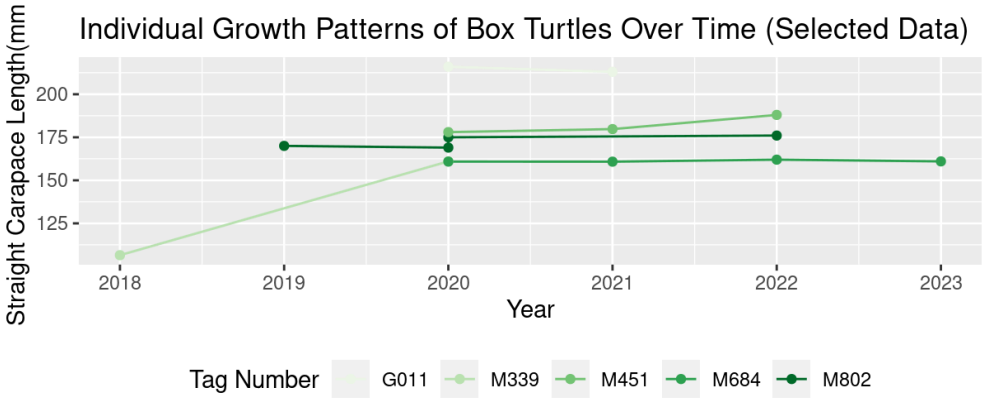

Figure 3: Straight carapace length trajectories for a selected sample of five tagged box turtles, observed across different years. Each line corresponds to an individual turtle. This plot illustrates variability in growth patterns among turtles.

Since the goal of the survey our dataset comes from is to assess the environmental recovery after Hurricane Michael, we want to look at the habitat that the turtles were found in as an indicator of how well the box turtle population is doing. Many of the entries in this dataset include a description of the turtles' habitats. Figure 4 shows that the majority of turtles were found in open green areas, followed by on the road or sidewalk, in brushy cover,in a body of water, and others. This graph only includes habitats with more than one entry.

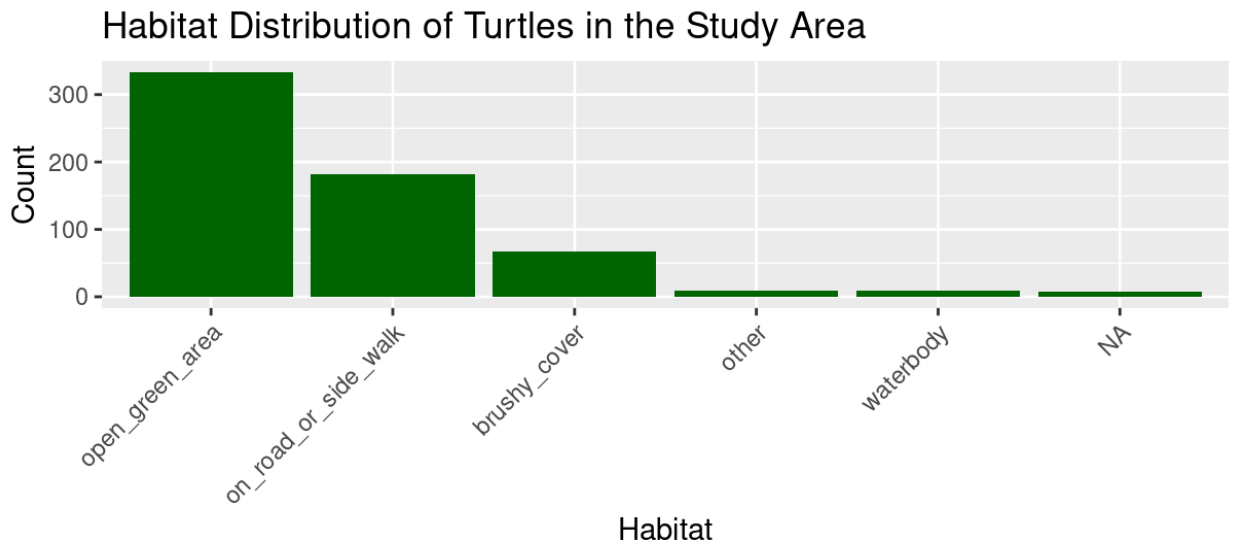

Figure 4: Count of Turtles by Habitat Type

When we didn't observe any significant results, instead we expanded our analysis to include the stationarity of the tagged turtles instead. This variable helps assess whether the turtles are well adapted to their environment. Figure 5 shows us that there isn't much variation in straight carapace length for stationary and non–stationary box turtles. Regardless of their movement behaviour, the turtles might have similar carapace lengths.

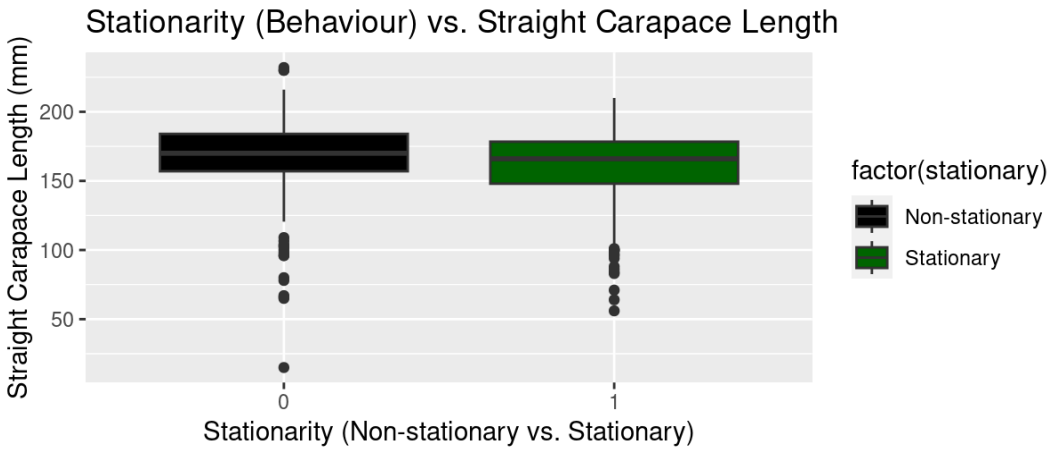

Figure 5: The distribution of straight carapace length (mm) for stationary and non-stationary turtles seem to be close to each other, although non-stationary seems to have a higher straight carapace length (mm). Stationarity is significant with a t-value > 2

It's also important to understand that air temperature influences both the individual turtles health and the broader ecological conditions, making it a vital factor in assessing

ecological recovery[5]. In Figure 6 we look at varying levels of air temperature affecting the captured and tagged turtles. The patterns observed mirror those seen in Figure 3, which illustrates individual size changes over time. As air temperature increases, some turtles show growth in carapace length, while others experience stagnation or even a decrease in size.

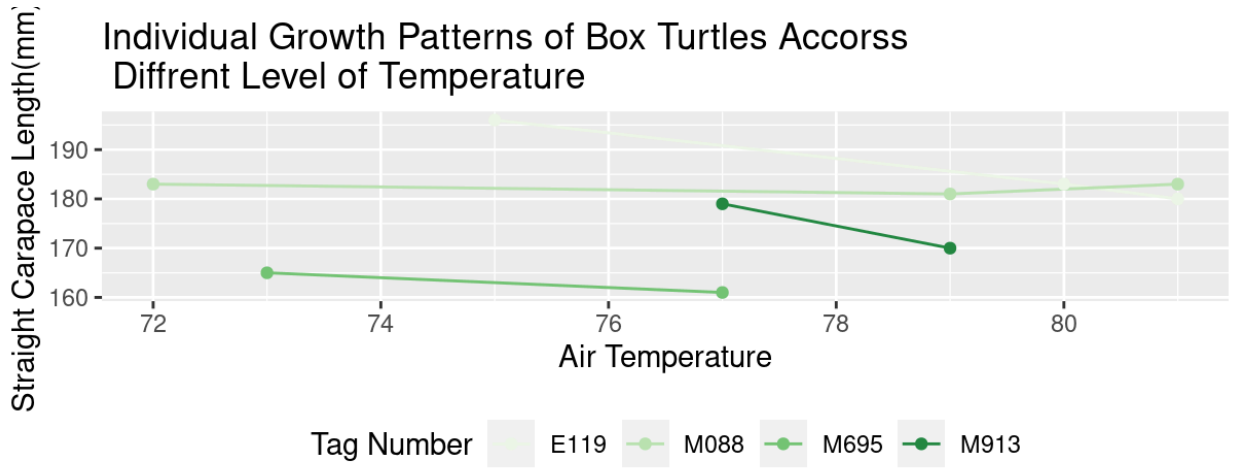

Figure 6: Straight carapace length trajectories for a selected sample of four tagged box turtles, observed across different levels of Tempreature. Each line corresponds to an individual turtle. This plot illustrates change in size among turtles (growth, decrease, stagnant). With significance indicated by t-value greater than 2

We squared the shell size measurements in our analysis to better capture patterns in the data and improve the accuracy of our model. This helps account for the way size changes might vary more dramatically in larger turtles. The straight carapace length of each turtle is influenced by two factors: the starting value/ base value of shell length (which would be different for each turtle) and the number of years that have passed since Hurricane Michael. This would include a random variation that can affect the shell length. We explain why the starting value/ base value are different for different turtles by looking at air temperature and whether the turtle is stationary or moving, including a random variation that affects the relationship between air temperature and stationarity.

Results

Based on our model, we determined that the number of years after Hurricane Michael, the air temperature at capture/tagged time, and the stationarity of the turtle are all significant predictors ($t >= 1.96$) of straight carapace length. As air temperature at capture/tagged time rises, we expect the turtle's squared straight carapace length to be longer as well, about $52.3mm^2$ longer for each one digit increase in temperature. Similarly, turtles caught later (in comparison to Hurricane Michael) are expected to be $484.9mm^2$ per year larger than turtles caught earlier. Turtles that were stationary at capture/tagged time, however, are expected to be $866.08mm^2$ smaller than turtles that were moving when captured/tagged. The differences

[5] U.S. Geological Survey. *Predicting Vulnerability of Southeastern Sea Turtles to Climate Change*. Accessed December 5, 2024. https://www.usgs.gov/centers/wetland-and-aquatic-research-center/science/predicting-vulnerability-southeastern-sea.

between turtles are larger than the differences between each turtle's captures/tagged. That being said, these findings shouldn't be interpreted as causal relationships. For instance, larger turtles may be more easily detected when moving, or changes in movement pattern could relate to other unmeasured factors. In addition, his researchers are more likely to sample during certain times of the day or year.

Conclusion/Discussion

Box turtles in Bay County, Florida suffered habitat loss after Hurricane Michael in 2018. Box turtles are good indicators of ecological health, so researchers began studying them to see how the Bay County area was recovering from the hurricane. We used turtle size, specifically straight carapace length, to determine recovery progress. Since the turtles we're looking at were recaptured/tagged and measured multiple times over the years, we used a multilevel model to account for both turtle-to-turtle differences, which have a variation in straight carapace length of 618mm, and individual turtles' capture-to-capture differences, which have a variation in length of 101.9mm. Based on the results of our multilevel model, we determined that stationarity, air temperature, and year are all important factors in box turtle size. These results lead to further questions about how researchers can help improve both box turtle recovery and overall ecological recovery in the Bay County area.

The implication of these findings tells us that the environment and temperature significantly influence the size of turtles. We can see the long term changes in their development since the hurricane. Although we initially assumed that stationary turtles would be well adapted to their environment, resulting in larger shell length, we instead found that mobile turtles experience better growth in size .

Because our data were collected by multiple researchers in a survey format, there were many observations that had missing data. Many variables like air temperature and straight carapace length were not recorded at every capture/tagged. Excluding the missing data makes our dataset much smaller than it started out, which in turn makes any conclusions we draw more limited. Thus, when we draw conclusions about the size of turtles in the Bay County area, we must note that we removed a substantial amount of missing data.

Addition to this habitat was divided into more than 10 categories, but to simplify our model interpretation we combined similar categories such as "open yard" and "on road or sidewalk"- which resulted in a more manageable set of 5 categories. We wonder if the lack of significance might be because these more specific categories limited the information available for the model, and whether a broader classification could provide more meaningful insights.

In future research, it would be valuable to explore the interaction between air temperature and stationarity. Movement could decrease if the is not in the turtle's comfort level. A wide variation in temperature for a particular turtle across different capture/tagging events may indicate that the turtle utilizes multiple habitats with different thermal conditions or that the turtle was captured at varying times of the day, such as during a warm afternoon or cooler evening.

Reference

[Commodore Productions], *"Bay County Box Turtle Project- Citizen Science Lecture Series Presentation"*, [52:38], published [2022], [https://www.youtube.com/watch?v=9vIOLkW-7vU].

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