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Maryland Ecological Forecasting

Utilizing NASA Earth Observations to Monitor and Strengthen the Survivorship of Maryland’s Sea Turtles)

 **Technical Report**

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# I. Abstract

[Placeholder - do not put anything here until the final draft submission. The abstract in the project summary is where the working draft of the abstract should “live”]

**Keywords**

Loggerhead Sea Turtle, Nesting, Stranding, Climate Change, Surface Temperature, Chlorophyll a

# II. Introduction

Loggerhead sea turtles (*Caretta caretta*) are one of the six marine turtles found in U.S. waters and are listed as threatened on the Endangered Species List and endangered on the global International Union for Conservation of Nature Red list (http://www.redlist.org/). Their heightened conservation status is due to the deaths induced on their populations due to anthropogenic disturbances such as boating collisions, fishing equipment entanglements, and pollution (Gómez de Segura et al. 2006). Their distribution is worldwide but loggerheads typically nest in the subtropics, extending northward along North Carolina with few nesting events further north.

In Maryland, over 450 loggerhead carcasses (referred to as strandings) have been recorded by the Maryland Department of Natural Resources (MD DNR) since 1991 along the Chesapeake Bay and Atlantic Coast (Figure 1: to be created). The loggerheads found in the Chesapeake Bay are usually juveniles that migrated from their natal grounds in South Carolina, Georgia, and a lesser percentage from Florida (Norrgard & Graves 1996). Loggerheads enter the Bay between May to November and leave during the winter since the Bay waters drop to lethal temperatures (Lutcavage & Musick 1985). Similar to the Chesapeake Bay, coastal waters off of Maryland are too cold during the winter months which leads to the southern migration of loggerheads (Mansfield et al. 2009).

There are many causes of these strandings, including recent boat strikes or fishing line entanglements, previous anthropogenic interactions leading to infection, while others have no apparent cause. To better conserve this species, the MD DNR seeks to better understand the reasons for sea turtle strandings that are unrelated to human stresses. One environmental factor affecting loggerhead strandings is low sea surface temperatures. When surface temperatures drop below 9.5°C, sea turtles that have yet to migrate can get cold-stunned causing them to float to the surface and eventually die, although younger loggerheads can withstand slightly cooler temperatures (Schwartz 1978; Burke et al. 1991). Otherwise, loggerheads inhabit waters 15°C and higher (Hawkes et al. 2007; Witt et al. 2010), but there have not been any observations between stranding prevalence and increased surface temperature. Although increased temperatures may not affect the survivorship of loggerheads, it may affect the distribution and availability of their prey (Witt et al. 2010). Another leading cause of unexplained loggerhead strandings is harmful algal blooms (HABs). The red tide inducing *Karenia brevis* has caused many deaths of loggerheads in Florida (Walsh et al. 2010, Fauquier et al. 2013) and the Chesapeake Bay and coastal bays of Maryland are prone to HABs due to nutrient influx (see review: Gilbert et al. 2001). Long term exposure to biotoxins from HABs can cause sublethal effects such as impaired feeding, physiological dysfunction, immunosuppression, and reduction in reproduction and growth (Milton & Lutz 2002). These health and behavioral effects from chronic biotoxin exposure can in turn become an indirect cause of death, leading to  increased susceptibility to events such as boat strikes and bycatches. Our first objective utilizes the stranding data from 1991 to present to investigate correlations between sea surface temperature, algal bloom activity, and loggerhead strandings. If correlations are found, then the MD DNR can react quicker to stranding events and employ more personnel during high volume years and seasons.

Loggerhead conservation is also dependent on reproductive success, particularly during the nesting phase. Few nesting events occur along Maryland’s Atlantic coast since most loggerheads choose beaches in warm temperate and tropical/subtropical waters from North Carolina southward (Plotkin & Spotila 2002, Witt et al. 2010). However, climate change may affect nesting range and breeding timing, with a northward shift and earlier and possibly shorter incubation period (Weishampel et al. 2004). Our second objective is to identify suitable beaches along the Maryland Atlantic coast in the event that climate change pushes loggerhead nesting range northward.

Parameters of currently used loggerhead nesting grounds can be used to identify potential Maryland nesting sites.  These factors are often complex and may not be easily detected with remote sensing technologies. High luminosity and development have been shown to decrease nesting, as these factors may interrupt the female and hatchlings’ navigational ability to and from the ocean (Kaska et al. 2010). Beach specific factors such as natural or anthropogenic barriers and substrate parameters are crucial factors to nesting behaviors and hatchling success (Witherington et al. 2011; Salmon et al. 1995, Rumbold et al. 2001). However, more spatially-explicit factors such as topography and land use also play a role. These factors were thus the focus of the nesting suitability study along Maryland’s coastline.  Loggerheads have been found to next approximately 1 meter above the splash zone of the high tide to avoid inundation and erosion of nests (Katselidis et al. 2014) and are limited the upland portion of the beach, which includes dune toes, cliffs, or natural/manmade barriers (Fish et al. 2004).  Slope is another determining factor of loggerhead nest selection. In general, females tend to prefer a gradual approach to shore. Once on shore, they will crawl over an initial high-slope area (which may be indicative of greater elevation to avoid inundation and erosion) but then prefer lower slopes below 16° (Wood & Bjorndal 2000, Provancha & Ehrhart 1987, Garmestani et al. 2000).

The sex of the loggerhead hatchlings is determined by incubating temperature, with warmer temperatures favoring females. Along the Atlantic Coast, the temperature that produces 50% males and females in a clutch is 29°C (Mrosovsky 1987). Females in the lower portions of their breeding range may lay female-dominant nests which can have severe ramifications on reproduction. Although female loggerheads exhibit high nest site fidelity and usually return to the same nesting grounds as they hatched (Encalada et al. 1998), natural selection may act on individuals to shift their nesting grounds northwards.

Our third objective uses climate models derived from the IPCC4 climate scenarios in 25, 50, and 100 years for two purposes; 1) to forecast future trends in stranding events if strandings are related to SST and 2) to identify potential beaches that would be suitable nesting grounds for future loggerheads. Although warmer temperatures may attract loggerheads to coastal Maryland, sea level rise will impact the amount of available beach and suitable nesting habitat. Our end-user, the MD DNR, will use the suitable habitat that is least affected by sea level rise to monitor in the future and to prevent anthropogenic activities and developments from disturbing the area. This protection prepares for changes in our climate to prevent future population declines in this sensitive species.

# III. Methodology

**Data Acquisition**

To understand loggerhead strandings, chlorophyll-a and sea surface temperature (SST) were obtained as 8-day composites from SeaWIFS, Aqua Moderate Resolution Imaging Spectroradiometer (MODIS), and Advanced Very High Resolution Radiometer (AVHRR) using the NOAA CoastWatch Program’s Environmental Research Division’s Data Access Program (ERDDAP). Oceanic datasets were gathered based on temporal sea turtle migration patterns specifically in the peak months of May to October from 1991 to present. Chlorophyll-a (mg/m3) concentration measurements were acquired from SeaWiFS aboard the Orbview-2 satellite for years 1998 to 2002 and were calculated using the NASA/GSFC SeaWiFS Project OC4v4 algorithm (O’Reilly et al. 2000). From 2003 to present, concentrations were obtained from Aqua MODIS and were processed using the NASA developed OC3M algorithm (O’Reilly et al. 2000), which is analogous to the SeaWiFS data. Daytime sea surface temperature datasets for 1998 to 2002 were obtained from AVHRR onboard the NOAA-17 and NOAA-18 spacecraft and were calculated using the modified version of the non-linear sea surface temperature (NLSST) algorithm (Walton et al, 1998; Kilpatrick et al. 2001). The 2003 to present SST data were taken from the Aqua MODIS and were calculated by Goddard’s Ocean Biology Processing Group (OBPG) using multi-sensor level-1 to level-2 (msl12) software.

Locational information on sea turtle strandings in Maryland waters and coastline were obtained from the Maryland Department of Natural Resources Marine Mammal & Sea Turtle Stranding Program. GPS coordinates of strandings were recorded by trained DNR staff, partners, and trained volunteers upon arrival to the reported site. Additional data including species, morphology of the animal, subsequent rehabilitation/necropsy actions (if any), trauma and condition, and notable observations were also included with these datasets. The datasets were cleaned and collated into one set of Maryland strandings from 1991 to present day.

To investigate the possible nesting suitability of locations along Maryland’s Atlantic coast, a variety of spatial datasets were obtained and created for the roughly 31 miles of coastline. To analyze coastline topography and create additional datasets, a LiDAR-derived digital elevation model (DEM) was obtained from the November 2012 USGS LiDAR survey of the northeast Atlantic Coast following Hurricane Sandy. Civic data including vector files of roads and general/detailed political boundaries were obtained from the United States Census Bureau Topologically Integrated Geographic Encoding and Referencing (TIGER) website and downloaded to ArcGIS Shapefile data format. WorldView-2 imagery was downloaded from EarthExplorer to be used for visual assessments of tides and beach delineation.

**Data Processing**

In order to efficiently process the bulk datasets, data processing was done mainly through scripting custom functions, utilizing a series of modules via Python programming. Once the ESRI ASCII formatted datasets were acquired, they were converted to raster then to point vector format to easily intersect the oceanic data to the region of interest. To analyze the chlorophyll-a and SST conditions at the time of each sea turtle stranding, we averaged the values within a 20 km region which represents the greatest likelihood of point of death (Hart et al. 2009). The chlorophyll-a and SST values were not extracted at time of stranding, but instead using the 8-day composite from at least 14 days prior to the stranding date to account for the time it takes for the corpse to reach shore (Harrison et al. 1967). Finally, the chlorophyll-a and SST values for each pixel of the buffered region were averaged to further correlate these variables to sea turtle mortality per month and per year.

Manual delineation of the shoreline and beach zone was required for modeling nesting suitability along the study area. LiDAR-derived DEMs have no way of distinguishing dry-land topography from wave action (Harris et al. 2005), a hillshade, slope, and aspect layers were derived from the original DEM to aid in the digitization process in a methodology used by other shoreline delineation studies. Visual comparison of the hillshaded DEM and anomalies in high-slope areas and/or aspect direction near the water-land boundary were incorporated into the digitization of the shoreline. A 1m extension was added upon completion to account for any measurement or resolution-generated errors. This shoreline estimate was used to create clipping masks of ocean and land regions for subsequent analysis.

We investigated slope, beach width, and distance from man-made structures as variables that affect loggerhead turtles. A slope layer was generated from the original DEM (after clipping to dry-land) and reclassified to four slope suitability classes (TBD). The beach width was created by TBD. Distance to roads was used as a metric of proximity to anthropogenic influence. All work was completed using ESRI ArcGIS 10.3.

***~methods and applicability to study of beach width analysis in progress/review~***

***~methods for determining weighted habitat suitability across beach zone in progress/review~***

**Data Analysis**

Data manipulation, data visualization, and temporal analysis of environmental variables in regards to sea turtle stranding were done through the various libraries such as pandas, seaborn, numpy, and matplotlib in iPython. After plotting a time series of mortality and oceanic variable data, the correlation coefficient (r) was used to analyze and determine the degree of correlation between the variables. In addition, the coefficient of determination (r2) was used to determine certainty in the correlation. The Chesapeake Bay and Atlantic Ocean strandings were analyzed separately since their geophysical parameters are significantly different.

*This part is in progress.* The Normalized Weighted Risk Index was used to create a map identifying current and predicted regions with the highest likelihood of strandings. The averaged 8-day composite datasets of SST and chlorophyll-a for the peak months of May to June for the year 2015, as well as predicted values, were incorporated into the risk map. A normalized risk value was calculated for each raster layer and combined using the weighted sum tool to characterize risk associated with present and future sea turtle mortality.

# IV. Results & Discussion

There have been approximately 20 loggerhead strandings in Maryland since 1991, with an unexplainable increase to 42 individuals in 2002. Most strandings, both natural and human-caused, occur in June and the surrounding months which coincides with their abundance during summer migration in this region. Approximately 60% of the strandings occurred in the Atlantic Ocean and most individuals had a carapace length less than 85cm, which is indicative of juveniles. During the summer breeding season, most adults are further south on the nesting grounds which explains the prevalence of this age group. Nearly twice as many female turtles stranded than males, but a majority of the loggerheads were of unknown sex due to decomposition or inability to perform a necropsy.

Figure 2 illustrates the average chlorophyll-a concentration and sea surface temperatures taken in 20 km zones of each sea turtle stranding from 1991 to 2014. There is an apparent regional variance in chlorophyll-a levels between the Chesapeake Bay and Assateague coastlines. This is presumably due to the locational variations in nutrient availability, wind patterns, ocean currents, among other anthropogenic and natural components that determine algal bloom frequencies.

**Figure 2:** Regional chlorophyll-a (top) and sea surface temperature (bottom)  20 km concentration zone of

stranded sea turtles (1998-2014).

Overall, the figure reveal stranded sea turtles are exposed to a higher range of chlorophyll-a concentration in the Chesapeake Bay. There have been increasing concerns regarding eutrophication and HABs in the bay, caused mainly by excess nutrient runoff from nonpoint sources such as sewage and agricultural chemicals (Milton & Lutz 2002).  Many stranded turtles experience values from roughly 0.5 mg/m3 to 20 mg/m3. Furthermore, the amount of chlorophyll-a levels associated with sea turtle exposure to algal blooms are increasing especially in the bay, where record highs were seen from 2004 to present. On the other hand, sea surface temperatures do not indicate significant difference between the bay and coastline areas, which range from about 10 to 30°C. With the lack of *in situ* measurements corresponding to the strand date, there are uncertainties in regards to chlorophyll-a and sea surface temperature values and are highly dependent upon the sensor’s resolution and algorithm used for detection.

Analyses here between number of strandings per year as related to SST and CHLa

Analyses and images here about optimal nesting locations, timelines of when temperatures would be warm enough for nesting, and effects of sea level rise on nesting.

Future work dependent on current findings: TBD

# V. Conclusions

Really cool results on how we can save the turtles! Or at least protect future nesting habitats and not let them die so much.

# VI. Acknowledgments

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# VIII. Content Innovation

TBD.

# IV. Appendices



**Figure 1.** Illustrates monthly sea turtle stranding occurrences from 1991-2014. The greatest sea turtle strandings have been occurring in the month of June. While, the peak months are primarily during summer months from May to September. In addition, the highest number of strandings took place in 2002 with a total of 42 strandings. It is important to note that strandings are the minimum numbers of sea turtle death due to the low probability of a carcass reaching ashore are determined by physical (e.g. ocean currents) and biological (e.g. decomposition) factors (Hart et al. 2009).