PREDICTING THE EFFECTS OF CLIMATE CHANGE ON SEA TURTLE NESTING HABITAT IN FLORIDA

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Introduction

Rising global temperatures threaten the survival of many plant and animal species. Having already risen at an unprecedented rate in the past century, temperatures are predicted to rise between 0.3 and 7.5°C in North America over the next 100 years (Hawkes et al. 2007). Studies have documented the effects of climate warming on phenology (timing of seasonal activities), with observations of early arrival at breeding grounds, earlier ends to the reproductive season, and delayed autumnal migrations (Pike et al. 2006). In addition, for species not suited to the physiological demands of cold winter temperatures, increasing temperatures could shift tolerable habitats to higher latitudes (Hawkes et al. 2007). More directly, climate warming will impact thermally sensitive species like sea turtles, who exhibit temperature-dependent sexual determination. Temperatures in the middle third of the incubation period determine the sex of sea turtle offspring, with higher temperatures resulting in a greater abundance of female offspring. Consequently, increasing temperatures from climate warming would drastically change the offspring sex ratio (Hawkes et al. 2007). Of the seven extant species of sea turtles, three (leatherback, Kemp's ridley, and hawksbill) are critically endangered, two (olive ridley and green) are endangered, and one (loggerhead) is threatened. Considering the predicted scenarios of climate warming and the already tenuous status of sea turtle populations, it is essential that efforts are made to understand how increasing temperatures may affect sea turtle populations and how these species might adapt in the face of such changes.

In this analysis, I seek to identify the impact of changing climate conditions over the next 50 years on the availability of sea turtle nesting habitat in Florida given predicted changes in temperature and precipitation. I predict that future conditions in Florida will be less suitable for sea turtle nesting during the historic nesting season. This may imply that sea turtles will nest at a different time of year, in more northern latitudes, to a lesser extent, or possibly not at all. It seems likely that changes in temperature and precipitation patterns will alter the distribution of sea turtle nesting locations worldwide, provided that beaches where the conditions are suitable for nesting still exist.

Hijmans and Graham (2006) evaluate a range of climate envelope models in terms of their ability to predict species distributions under climate change scenarios. Their results suggested that the choice of species distribution model is dependent on the specifics of each individual study. Fuller et al. (2008) used a maximum entropy approach to model the potential distribution of 11 species in the Arctic Coastal Plain of Alaska under a series of projected climate scenarios. Recently, Pike (in press) developed Maxent models to investigate the impacts of climate change on green sea turtle nest distribution and timing. In each of these studies, a set of environmental predictor variables (including climate variables), for which 'current' conditions are available and 'future' conditions have been projected, is used in conjunction with species occurrence data to map potential species distribution under the projected conditions. In this study, I will take a similar approach in mapping the potential sea turtle nesting habitat in Florida by developing a Maxent model based on environmental and climate data and projecting the model for future climate data.

Methods

The state of Florida (latitude: 24°30'N to 31°N, longitude: 79°48'W to 87°38'W) consists primarily of a large peninsular land mass, bordered by the Gulf of Mexico on the west and south and by the Atlantic Ocean on the east. Florida's extensive coastline includes approximately 1100 miles of beaches, many of which provide nesting habitat for three species of sea turtles: the endangered green (*Chelonia mydas*) and leatherback (*Dermochelys coriacea*) and the threatened loggerhead (*Caretta caretta*). In fact, most of the sea turtle nesting in the continental United States occurs in Florida. The leatherback and green sea turtles rarely nest north of Florida, and approximately 90% of loggerhead nests in the United States are in Florida.

Turtle nesting data was collected by the Florida Fish and Wildlife Research Institute for the three species during the 2006 nesting season. Separate feature classes representing the three sea turtle species were selected from the overall set of turtle nesting points. From a total of 295 turtle nesting points, 74 green turtle nesting points, 43 leatherback nesting points, and 178 loggerhead nesting points were obtained. Elevation data (30 m resolution) for Florida was obtained from the USGS National Map Seamless Server, projected into Albers Equal Area Conic, and mosaicked into one elevation raster for the entire state. For the preliminary analysis, the elevation raster was resampled to 1 km spatial resolution to match the resolution of the climate data. The explanatory variables slope, aspect, and solar exposure were derived from the elevation raster. Using the elevation raster and the TarDEM executables (Tarboton 2000), the topographic convergence index (a soil moisture estimate) was derived. The terrain shape was also computed from the elevation raster. A raster of landcover was obtained from the Florida Fish and Wildlife Research Initiative and resampled to 1 km spatial resolution. This dataset was used as a mask for all data processing and geospatial analysis performed in ArcGIS. Also, cells representing development were extracted from the landcover raster and used to compute a Euclidean distance to development raster. Monthly precipitation and minimum and maximum temperature data for the month of June (during peak turtle nesting) were obtained for 'current' conditions and 'future' conditions from the WorldClim database (Hijmans et al. 2005). The resolution of these datasets is approximately 1 km. Projected future climate data was from the Hadley Centre Coupled global climate model for emission scenario A2. All data processing and geospatial analyses were performed in ArcGIS version 9.3 (ESRI, Redlands, CA, USA).

The maximum entropy (Maxent) method provides an estimate of the spatial distribution of a species by determining the probability distribution of maximum entropy (most uniform) under a given set of constraints (the locations of known occurrences)(Phillips et al. 2006). It can be used to model species distributions using the environmental conditions of sites where the species is known to be present without requiring information regarding where the species is absent (Phillips et al. 2006). Predictive habitat distribution models like the Maxent method are based on Hutchinson's definition of the niche concept, where the fundamental niche includes all conditions necessary for the long-term survival of the species and the realized niche consists only of the portion of the fundamental niche that the species actually occupies (Pulliam 2000, Phillips et al. 2006). Such a model can predict environmental suitability for a species as a function of a set of environmental variables. Since the environmental variables are in GIS format and relate to the same geographic study area, the predicted ecological suitability can be projected back into geographic space to provide an area representing the potential distribution of the species (Phillips et al. 2006).

The Maxent model uses species occurrence (point) data in conjunction with environmental variables to predict species distribution. Once the environmental variables were masked to the same spatial extent, they were input along with species location data into the Maxent software program (Phillips et al. 2006). The Maxent program generated a probability distribution for each species from the input data, and the output files of the probability distributions were imported into ArcGIS. In addition to the output probability distributions, the Maxent program also output the receiver operating characteristics (ROC) curves and area under the ROC curve (AUC) statistics for the spatial models it produced. The ROC curves indicate the proportions of correctly and incorrectly classified predictions over a range of threshold values relative to a random sampling. These can be used to evaluate the appropriateness of the model (higher AUC indicates a more discriminating model) as well as the appropriate threshold probability value to use in distinguishing between suitable and unsuitable habitat (Phillips et al. 2006).

Maxent was an appropriate model selection for this study because it has performed well in modeling species distributions from presence-only data (Fuller et al. 2008). At the same time, because there are implicit assumptions about the environmental variables used, these indicators must be selected carefully (Phillips et al. 2006). For instance, species occurrence data and the environmental variables must correspond to the same time period, and the relevant scale of the analysis must be considered when selecting the environmental variables that should affect species distribution. Also, using Maxent models to project species distributions under future climates assumes that the species is capable of dispersing to suitable habitat. This is only a somewhat reasonable assumption for sea turtle nesting locations because, although sea turtles are migratory species and capable of traveling great distances, nesting sea turtles have demonstrated fidelity to the site of their own birth. Furthermore, the analysis assumes that climate is a key determinant of species distribution, rather than other factors such as prey availability or vegetation (Fuller et al. 2008).

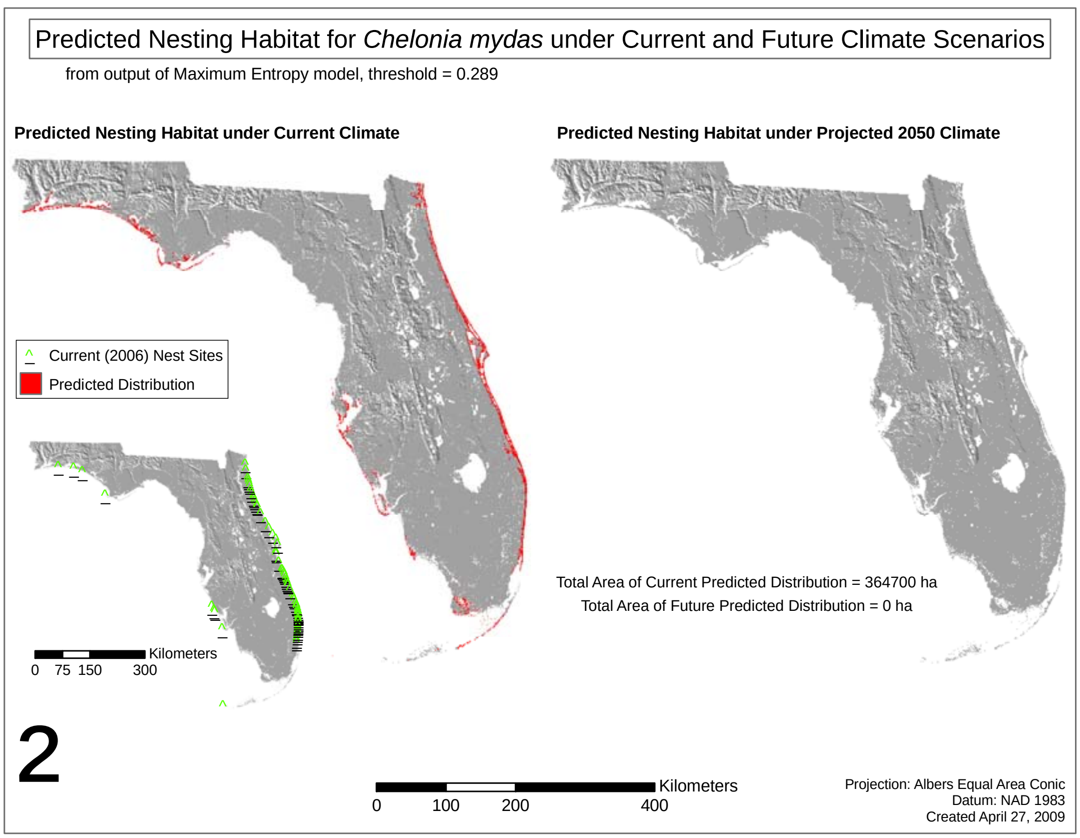
Results

Under the A2 climate scenario for 2050, the area of potential nesting habitat decreased for *Chelonia mydas* , *Dermochelys coriacea*, and *Caretta caretta* (Figure 1). Although Caretta caretta experienced the greatest reduction in potential nesting habitat, 518,100 hectares, the preliminary findings suggest it is the only one of the three species predicted to have any nesting habitat remaining in Florida by 2050 according to the A2 scenario (Table 1). These preliminary findings suggest the need for further exploration of the model at higher spatial resolution and examination of which environmental and climate variables are driving the model predictions.

Discussion

The potential reduction in nesting habitat availability for a group of species already at risk of extinction from so many other factors is a major concern. The predicted nesting site distributions from the current environmental data match closely with the observed turtle nesting sites, which suggests that the models have provided a reasonable approximation of current sea turtle nesting site distribution. At the same time, there are clearly limitations of the analysis that must be considered. First, the analysis assumes that climate is the only factor changing over time, when in reality there will be changes in landcover (e.g. development will expand), elevation if sea level rise occurs, and the overall make-up of the beach ecosystems. Also, the analysis only considers one seasonal behavior of sea turtles, which could also be affected by climate change as they are foraging or migrating as well. Future climate data is still rather limited (only three variables), and predictions about future species distributions would certainly benefit from additional variables that may affect sea turtle nesting. In addition, because higher resolution data was not available for all of the environmental variables, the analysis was unable to consider highly localized, fine-scale differences in habitat selection. To improve the strength of modeling species distributions, a more complete selection of high-resolution environmental predictor variables must be developed.

In conclusion, under the scenario of climate warming, sea turtle nesting habitat in Florida may be greatly diminished and species may even be extirpated from the state because of lack of available nesting habitat. This could devastate already struggling sea turtle populations and suggests that scientists need to closely monitor nesting populations. To increase the accuracy of the models and allow more localized analysis of habitat suitability, further research is needed to incorporate potential sea level rise into the models and to increase the availability of higher-resolution environmental and climate variables, particularly for projected future scenarios.



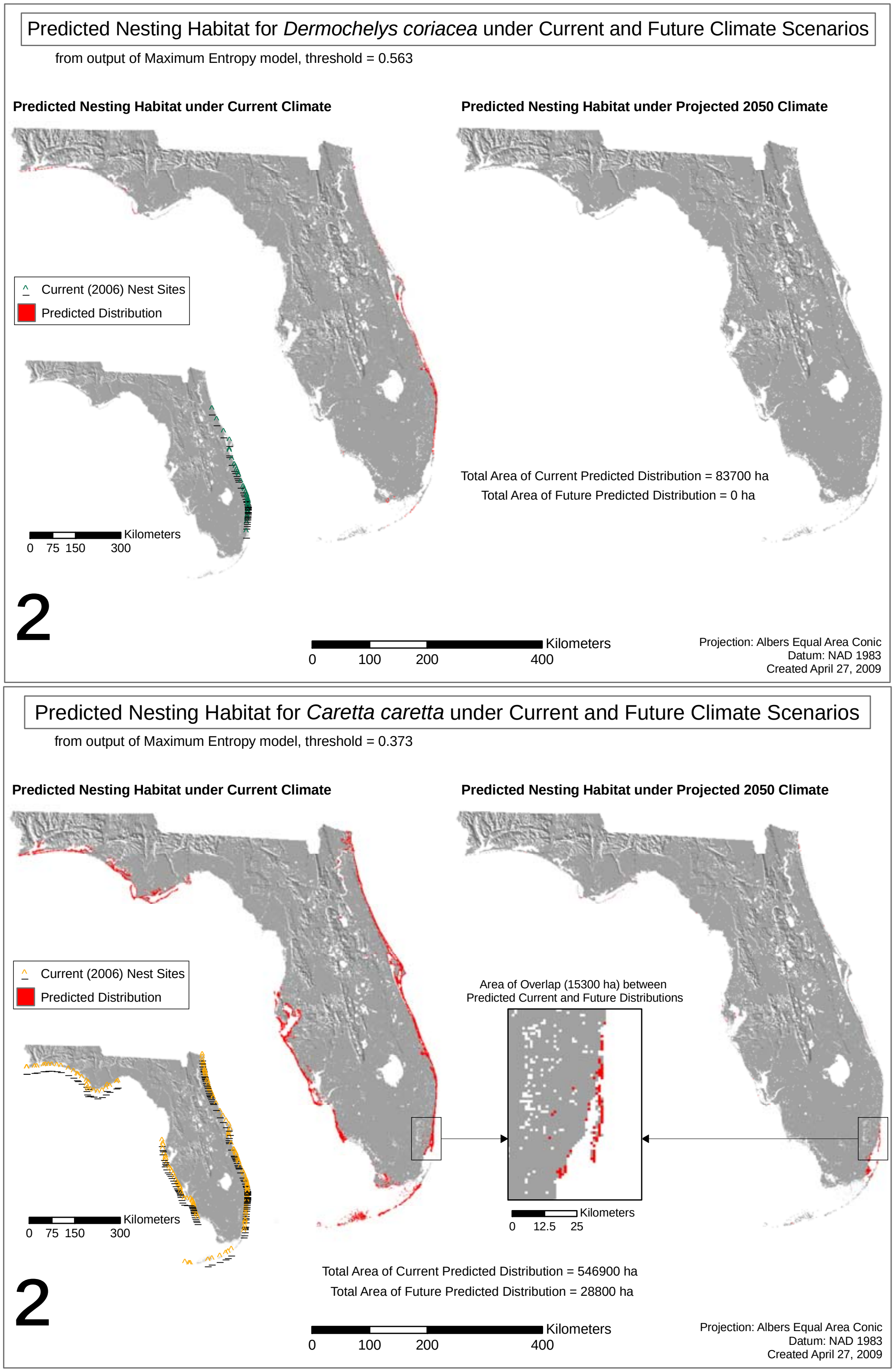


Figure 1. Predicted nesting habitat under current and future climate

Table 1 – Area (ha) of predicted nesting habitat for current and future climate

	C. mydas	*D. coriacea*	*C. caretta*
Current Climate	364700	83700	546900
Future Climate	0	0	28800
Change in Area	364700	83700	518100

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