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GEOG 586 Term Project:
Two Habitat Suitability Analyses on Potential Range Expansion for American Alligators

Abstract

American alligators (*Alligator mississippiensis*) have specific habitat requirements to survive and reproduce. The current range of the American alligator keep the populations concentrated in the southeastern corner of the United States, as far west as mid-Texas and as far north as southern North Carolina. But the planet is warming with climate change, and the range of the American alligator could soon shift with the rising temperature and changing precipitation. In this study, I analyzed whether the climate has already changed enough for alligators to survive outside their current range. I used two methods to answer this research query with habitat variables of wetland cover, air temperature, precipitation, and salinity. My first method included finding suitable ranges for temperature and precipitation by measuring them against current alligator range then combining the raster layers together with the wetland cover to see where fresh wetlands exist within the suitable ranges for temperature and precipitation. The first result showed that alligators could potentially survive in areas as far north as Maryland and in western areas of southern California and Arizona, as well. For my second habitat suitability analysis, I ran the Maximum Entropy tool to create a Spatial Statistics Model (SSM) of probability presence of alligators based on temperature and precipitation. I then rasterized that model and combined with the wetland cover to get a similar result that showed the possibility of alligators surviving in areas northward and westward of their current range.

Background

For this term project, I looked at how the American alligator (*Alligator mississippiensis*) might spread northward in the United States as a result of the warming climate and the changing landscape that has accompanied it. An increase in humidity and heat is an inevitability with global warming, with average global temperatures expected to increase between 0.5°F to 8.6°F by 2100 and temperatures having already increased by 2°F since 1880 (Lindsey et al., 2023). I wondered if this change has made wet areas in farther north areas of the country more suitable for alligators despite their current native range keeping them south of Virginia (Figure 1).

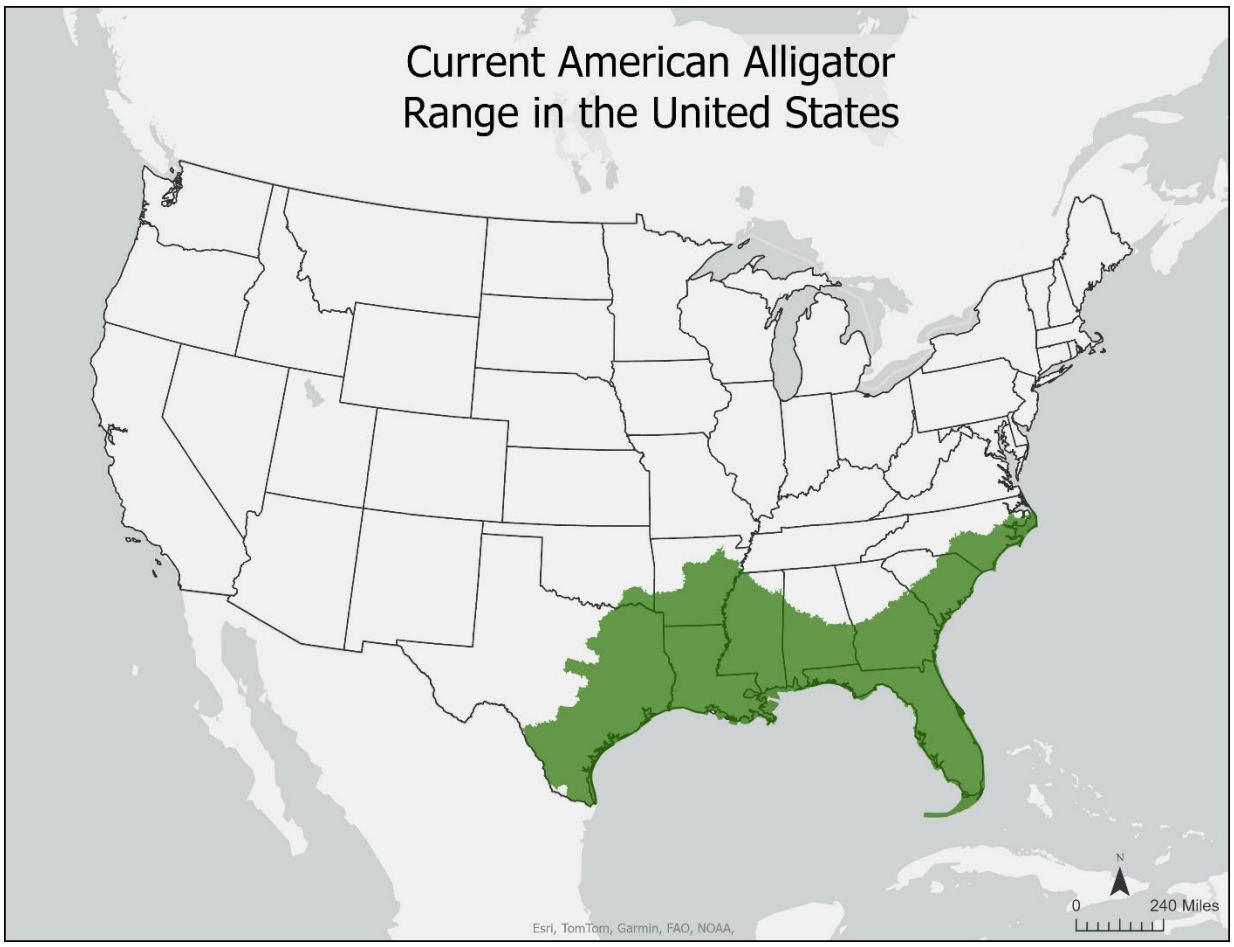

Figure 1. Current native range of the American alligator in green (per USGS).

Osland et al. (2021) discussed the process of tropicalization, defined as the transformation of temperate ecosystems by north-moving tropical organisms in response to warming temperatures. In their paper, they examined how a variety of flora and fauna, including terrestrial plants, coastal wetland plants, coastal fishes, sea turtles, terrestrial reptiles, amphibians, manatees, and insects, have their range limits extended northward by a warming climate (Osland et al., 2021). With their findings as an example, alligators should also see a similar northward expansion in their range.

A study by Dunham et al. (2014) modeled American alligator populations in northern ranges (North and South Carolina) versus southern ranges (Florida and Louisiana). They found that southern populations were stable and increasing while northern populations were decreasing. They also factored in potential climate change impacts and determined that the increase in temperate would benefit northern populations, but the decrease in precipitation would likely hurt populations.

Another aspect of the topic I considered comes from a study by Bock et al. (2020), in which they research the effects of temperature on sex determination of alligator eggs. Warmer temperatures result in eggs becoming mostly males, and colder temperatures result in mostly females. As planet warms, even just by a few degrees, alligators might be in trouble of major population declines if there are not enough eggs becoming both females and males (Bock et al., 2020). This dismal future could be avoided if enough alligators move northward to stay within temperatures ideal for producing a balanced population of males and females.

Objectives

I wanted to determine if there is already a potential new range for American alligators in the United States due to the change our climate has already experienced. Alligators prefer fresh wetlands in warm weather; could habitats farther north of their current range already be suitable to house alligator populations. How far north along the east coast could these reptiles be living as of today?

Methodology

I conducted a habitat suitability analysis to see where alligators could extend beyond their current range. To better understand suitable alligator habitat, I referred to a few previous studies. Fujisaki et al. (2014) studied alligator use of estuary habitats and looked at how their movement rates were highly influenced by salinity, temperature, and season. Waddle (2017) prepared a report highlighting a habitat suitability index model for American alligator to quantify habitat condition in response to restoration efforts. The five Habitat Suitability Index (HSI) variables Waddle considered in their study were percent open water, relative water depth, habitat type, edge, and salinity. This HSI is meant to be specifically for coastal Louisiana, though, and may not be applicable to the larger context of the southeast and Mid-Atlantic regions I wanted to examine for this project.

I looked at datasets for wetland cover, temperature, water salinity, and precipitation. For the current range of alligators in the US, I downloaded a data file from USGS (2018). I used a land cover projection from Sohl et al. (2018) that includes herbaceous wetland and woody wetland land cover data for every year between 1992 and 2100. I used the 2023 layer. For current precipitation and temperature data, I downloaded NetCDF4 files showing mean US precipitation data and minimum temperature data from Vose et al. 2014 at NOAA. I used NetCDF4 to Raster to import the rasters into ArcGIS Pro. For salinity, I considered the coastline as a mask for my suitable range, following the current alligator range layer downloaded from USGS, which cuts off along the coast.

I ran two different types of habitat suitability analyses for present day to see if there are any areas of the US where alligators potentially already be living outside their current range. I wanted to be able to compare the results between the two different methods: one method where I used the current range of alligators as a guide to determine ideal temperature and precipitation ranges and various raster tools to find wetland areas within those ranges and away from the coast that could potentially be home to alligators; the second method I used is the Maximum Entropy tool with alligator presence point data and the variable rasters to determine a gradient of possible presence of alligators.

Considering the studies by Waddle and Dunham et al., I analyzed wetland cover, salinity, precipitation, and temperature for my habitat suitability analysis (Table 1). For wetland cover, I considered herbaceous wetland and woody wetland as potential habitat for alligators. Alligators are a freshwater organism but can tolerate a certain level of salinity in estuarine areas (Waddle, 2017). In Waddle's (2017) study in coastal Louisiana, water with salinity over 10 ppt was considered too salty for alligator reproduction so I excluded all water areas with salinity greater than 10 ppt. However, due to a lack of water salinity raster data, I followed the current habitat range of alligators from USGS and just considered the coastline as the cut off for salinity. For temperature, alligators are most active between 82 and 92 F and go dormant below 55 F (*Alligator facts*, n.d.).

Using the current range as my feature zone and the temperature raster data as the input raster, I calculated the minimum and maximum temperatures that alligators currently tolerate. I repeated this process with the precipitation raster. I used Raster Calculator to convert the temperature raster from C to F by multiplying the values by 9/5 and adding 32. Then After running the Zonal Stats tool in ArcGIS Pro, I determined that for the purposes of my analysis, American alligators can find suitable habitat in wetland areas where air temperatures go no longer than 48 °F-74 °F and precipitation is no lower than 114 mm and 2790 mm.

Table 1. Variables considered in the habitat suitability analysis.

Habitat Suitability Variables	**Description**
Wetland Cover	"Water," "Herbaceous Wetland," and "Woody Wetland" are values that count toward suitable alligator habitat
Water Salinity	Coastline acts as edge of acceptable salinity range
Air Temperature	Minimum suitable range between 48 °F and 74 °F
Precipitation	Minimum suitable range between 114 mm and 2790 mm

For my first habitat suitability analysis, I identified inland, wetland areas in the United States where the temperature falls between 48 °F and 74 °F and the precipitation falls between 114 mm and 2790 mm. I used Raster Calculator to isolate the ranges for the temperature raster and the precipitation raster. To keep the three raster layers consistent for my analysis, I ran Project Raster to make them all Albers projection with cell size 250. I then used Reclassify to change the "0" values to "NoData" so value of "1" are suitable ranges. Returning to Raster Calculator, I added the three new raster layers (Suitable_Temp, Suitable_Precipitation, and Wetland_Cover) together. The resulting raster pixel with values of "3" were areas on the map where wetlands fell within the suitable ranges of temperature and precipitation for alligator survival.

For my second habitat suitability analysis, I wanted to use the Maximum Entropy (MaxEnt) tool in ArcGIS Pro to produce a presence probability model for alligators based on precipitation, temperature, and wetland data. I downloaded point data from iNaturalist to have alligator range represented as points. I removed the points outside the USGS alligator range polygon as those were outliers likely as a result of an escaped pet or something. I then ran the MaxEnt tool using the point data as my input feature and the temperature and precipitation raster layers as my training rasters, omitting the wetland cover raster as it was categorical data and I did not know if that would cause issues with the tool. MaxEnt generated the Spatial Statistics Model (SSM) file and I then used Predict Using Spatial Statistics Model File tool to create a raster based on the model. I ran Raster Calculator next and multiplied the newly created alligator predicted presence raster with the wetland cover raster so non wetland areas were excluded. The resulting

raster showed the likelihood of alligator presence in US wetlands based on average minimum temperature and precipitation values.

I then created two maps showing where alligators could potentially exist outside their current range and where they might be able to migrate to in a changing climate based on my two habitat suitability analysis methods (Figures 2, 3, and 4).

Results

With this analysis, I sought to answer the question of whether alligators could survive in areas of the United States outside their current range. Climate change has created hotter temperatures in recent decades, and I hypothesized that this increase in temperature, along with precipitation and wetland coverage, might enable the possibility for alligators to exist farther north than they currently do. I ran two different analyses to try to answer this question.

The first analysis, where I determined ideal temperature and precipitation ranges using current alligator range then identified wetland areas within these ranges, resulted in many areas outside the current where alligators should be able to currently survive (Figure 2). These wetlands are mostly north of the current range, per my hypothesis, extending into Oklahoma, Tennessee, Virginia, even into southern parts of Maryland around the Chesapeake Bay watershed. Additionally, wetlands areas in central California and in Arizona, especially around the Colorado River, also appear to be suitable for alligator life.

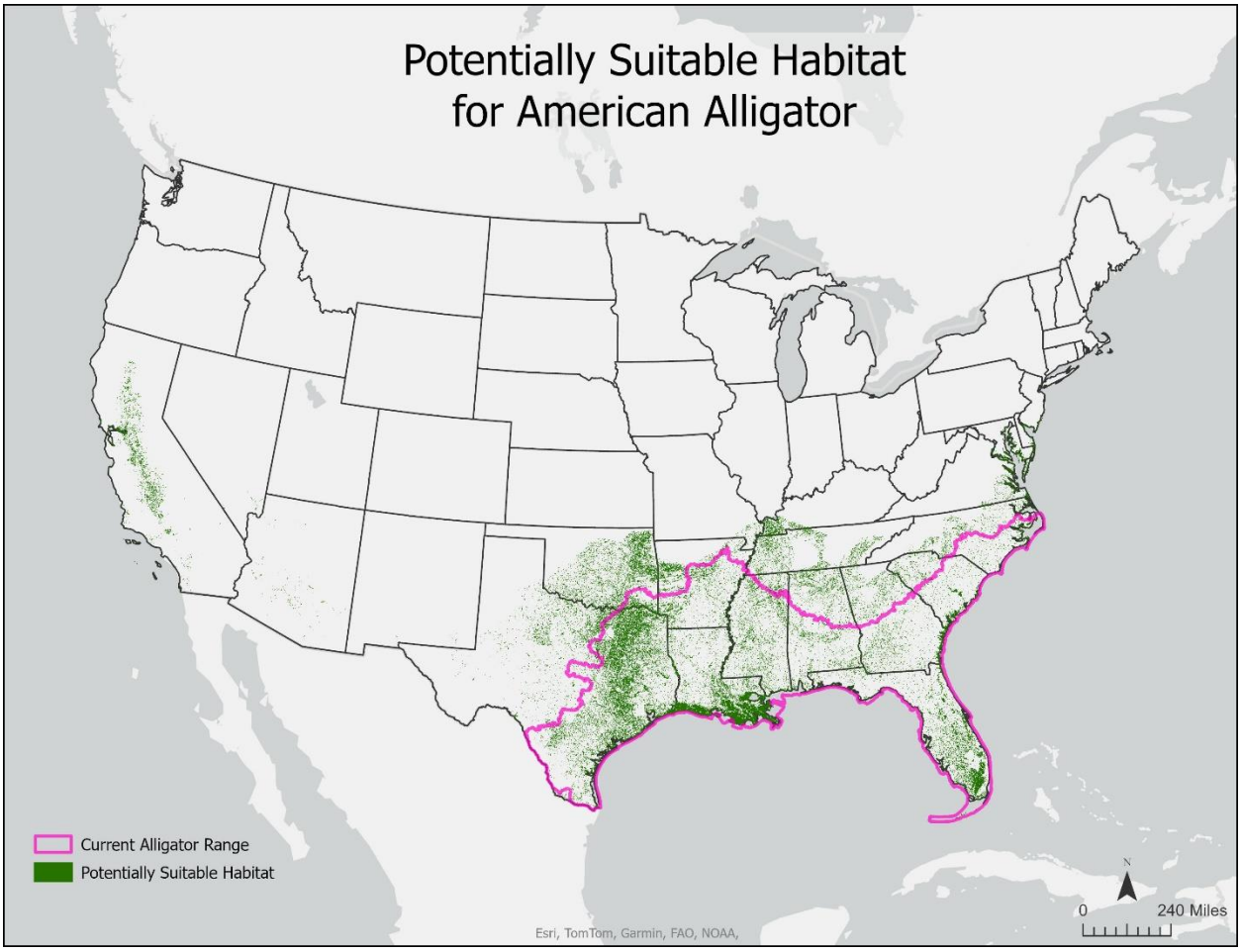

Figure 2. Wetlands within the suitable ranges of temperature (48 °F and 74 °F) and precipitation (114 mm and 2790 mm) for alligator habitat. Based on this analysis, there are many wetland areas outside the alligator current range (pink border) that could be suitable.

My second analysis used the MaxEnt tool to create a presence probability of alligators based on known presence points along wetland cover, precipitation, and temperature. I omitted the wetland cover raster from the Spatial Statistics Model (SSM), using only precipitation and temperature to create my initial modeled raster. The probability of alligator presence is represented by the green heat map (Figure 3). This map shows there is the possibility that alligators could be present in ranges north and west of their current range, though not extremely likely. The most likely areas outside the range where gators could exist according to this limited model are in the southern tip of California and western Arizona. But again, this map is just based on temperature and precipitation; it does not factor in wetland cover.

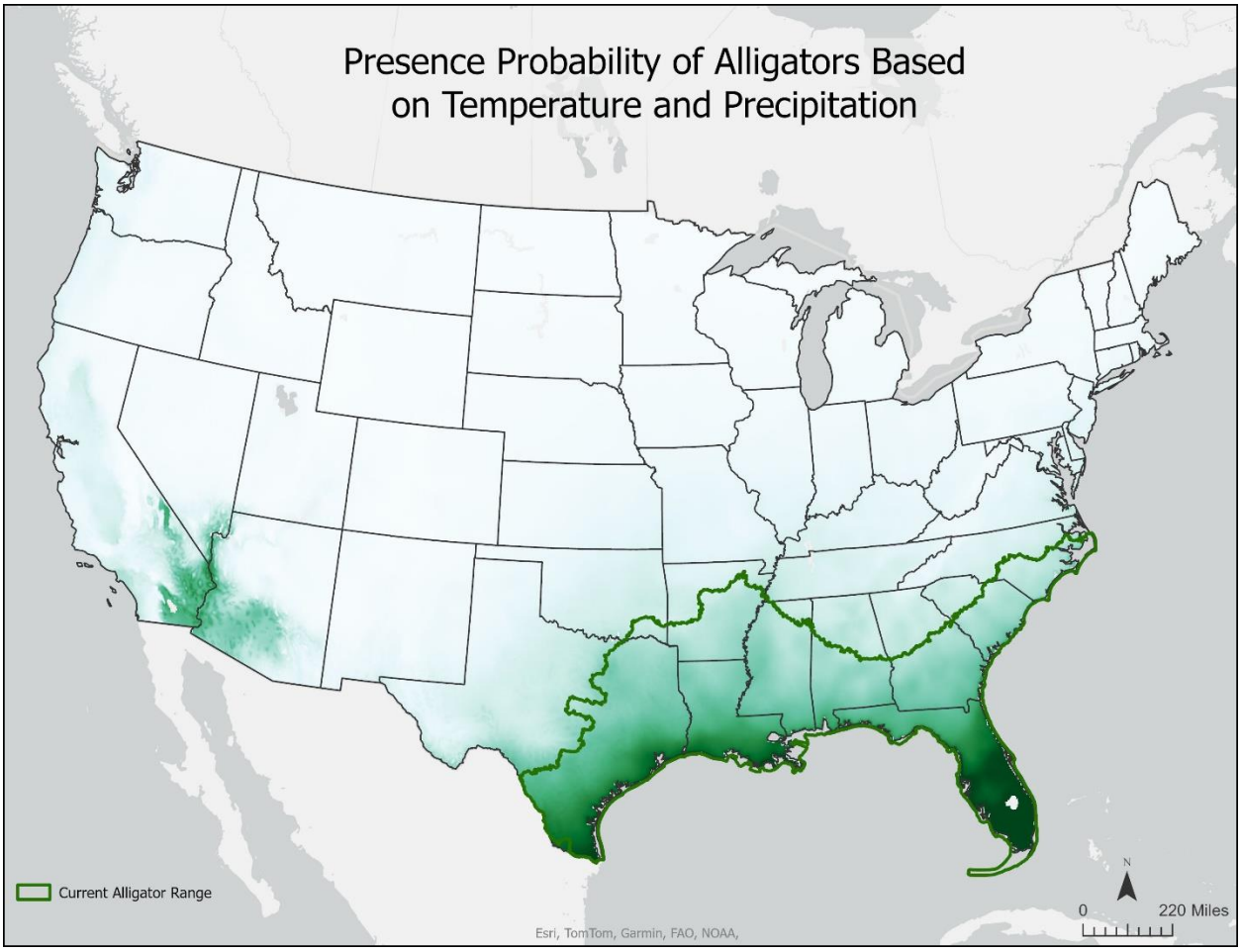

Figure 3. The raster layer created using the Spatial Statistics Model before I added wetland cover to the analysis. This map is effectively a heat map of alligator presence probability based solely on current range trained on temperature and precipitation data.

Figure 4 displays the SSM-generated raster from Figure 3, but only within wetlands. This map also shows the possibility for alligator presence in ranges north and west of their current range. The models are not perfect in this analysis, but both methods of analysis resulted in maps that visualize the possibility that the American alligator could survive in US areas outside its current range. The changing climate is likely the reason the species could move northward with warming temperatures and increased precipitation.

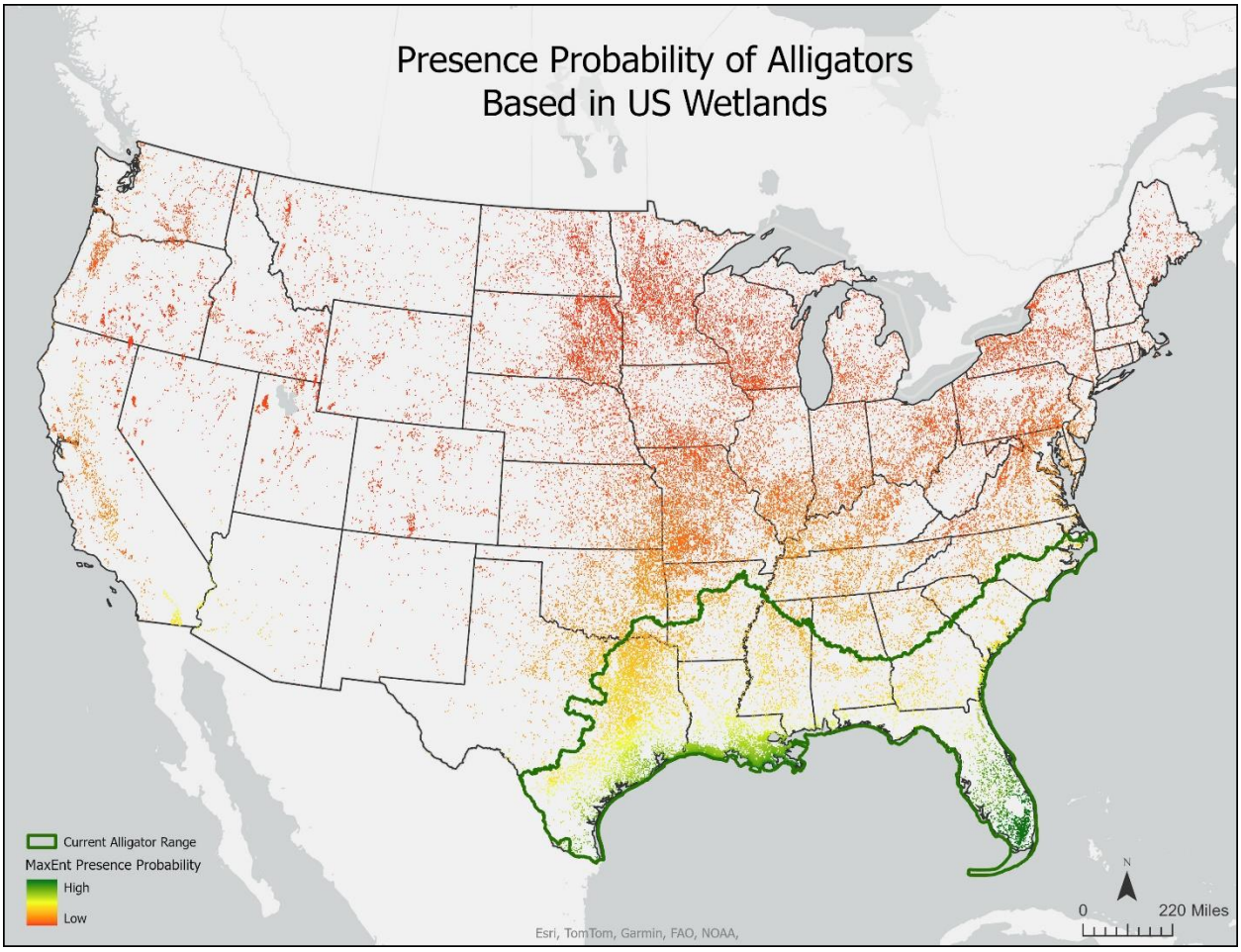

Figure 4. The final raster layer created using the MaxEnt SSM. This map shows the presence probability of alligators within US wetlands.

Reflection

I think these analyses went well once I minimized the scope of the project to only look at present-day and not try to factor in future modeled precipitation, temperature, and wetland cover to see where alligators could be in a century. Trying to answer that question as well was a bit more complicated in practice than in theory than I realized while I was writing my proposal. I am happy, however, that the analyses produced results consistent with my hypothesis that alligators could already live in areas outside their current range in the United States.

I do think I maybe should have considered other variables for habitat suitability. Humidity could be one, or soil temperature or soil salinity. Abundance of prey would be another good variable to check. There could be a reason my analysis shows the potential for alligators to live on the west coast in California and

Arizona, considering none live there now. But maybe alligators could exist in those areas and just have not been able to migrate there ever.

Time permitting, the project could be expanded to examine where alligators might be in the future using modeled datasets for climate change. I wonder if suitable habitat for alligators in the US would slowly move north as the world warmed and if eventually alligators would be best suited to Mid-Atlantic or even New England states one day. The harsh reality of climate change is bleak and is resulting in dire social, economic, and environmental consequences. That said, I do find it interesting to imagine alligators one day roaming the tributaries of the Chesapeake Bay.

References

Alligator facts. Florida Fish And Wildlife Conservation Commission. (n.d.). https://myfwc.com/wildlifehabitats/wildlife/alligator/facts/#:~:text=Alligators%20are%20most%20active%20when,much%20of%20the%20winter%20season.

Bock, S. L., Lowers, R. H., Rainwater, T. R., Stolen, E., Drake, J. M., Wilkinson, P. M., Weiss, S., Back, B., Guillette, L., & Parrott, B. B. (2020). Spatial and temporal variation in nest temperatures forecasts sex ratio skews in a crocodilian with environmental sex determination. *Proceedings of the Royal Society B: Biological Sciences*, *287*(1926). https://doi.org/10.1098/rspb.2020.0210

Dunham, K., Dinkelacker, S., & Miller, J. (2014). A stage-based population model for American alligators in northern latitudes. *The Journal of Wildlife Management*, *78*(3), 440–447. https://doi.org/10.1002/jwmg.688

Fan, Y., and H. van den Dool (2008), A global monthly land surface air temperature analysis for 1948-present, J. Geophys. Res., 113, D01103, doi:10.1029/2007JD008470. https://psl.noaa.gov/data/gridded/data.ghcncams.html

Fujisaki, I., Hart, K.M., Mazzotti, F.J. *et al.* (2014). Home range and movements of American alligators (*Alligator mississippiensis*) in an estuary habitat. *Anim Biotelemetry* **2**, 8. https://doi.org/10.1186/2050-3385-2-8

Lindsey, R., & Dahlman, L. (2023). *Climate change: Global temperature*. NOAA Climate.gov. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature#:~:text=According%20to%20NOAA's%202021%20Annual,more%20than%20twice%20that%20rate.

NOAA. (n.d.). *Station selection - NOAA tides & currents*. Tides & Currents. https://tidesandcurrents.noaa.gov/stations.html?type=Datums

Osland, M. J., Stevens, P. W., Lamont, M. M., Brusca, R. C., Hart, K. M., Waddle, J. H., Langtimm, C. A., Williams, C. M., Keim, B. D., Terando, A. J., Reyier, E. A., Marshall, K. E., Loik, M. E., Boucek, R. E., Lewis, A. B., & Seminoff, J. A. (2021). Tropicalization of temperate ecosystems in North America: The northward range expansion of tropical organisms in response to warming winter temperatures. *Global Change Biology*, *27*(13), 3009–3034. https://doi.org/10.1111/gcb.15563

Parkes, S., Luce, C. H., & Lute, A. (2017). National Forest Climate Change Maps: Your Guide to the future. Rocky Mountain Research Station. https://www.fs.usda.gov/rm/boise/AWAE/projects/NFS-regional-climate-change-maps/categories/us-raster-layers.html

Sohl, T.L., Sayler, K.L., Bouchard, M.A., Reker, R.R., Freisz, A.M., Bennett, S.L., Sleeter, B.M., Sleeter, R.R., Wilson, T., Soulard, C., Knuppe, M., and Van Hofwegen, T. (2018). Conterminous United States Land Cover Projections - 1992 to 2100: U.S. Geological Survey data release, https://doi.org/10.5066/P95AK9HP.

U.S. Geological Survey (USGS) - Gap Analysis Project (GAP), 2018, American Alligator (Alligator mississippiensis) rAMALx_CONUS_2001v1 Range Map: U.S. Geological Survey data release, https://doi.org/10.5066/F7N58KGK.

Vose, R. S., S. Applequist, M. Squire, I. Durre, M. Menne, C. N. Willams Jr., C. Fenimore, K. Gleason, and D. Arndt, 2014: Improved Historical Temperature and Precipitation Time Series for U.S. Climate Divisions. J. Appl. Meteor. Climatol., 53, 1232-1251. https://doi.org/10.1175/JAMC-D-13-0248.1

Waddle, H. (2017). Alligator mississippiensis, - coastal protection and Restoration Authority. http://coastal.la.gov/wp-content/uploads/2017/04/Attachment-C3-10_FINAL03.09.2017.pdf

Xie, P., and P.A. Arkin, 1997: Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs. Bull. Amer. Meteor. Soc., 78, 2539 - 2558. https://psl.noaa.gov/data/gridded/data.cmap.html