Mississippi Water Resources: Mapping the Extent of Critical and Endangered Watersheds to Assist Restoration Efforts and Conservation Planning Using NASA Earth Observations

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Watersheds in Mississippi provide many environmental and recreational benefits to the citizens and visitors of the state. The Nature Conservancy and the Pascagoula River Audubon Center are currently working to protect coastal Mississippi watersheds, in part through an urban coastal preservation initiative. The primary objective of this project was to aid these conservation efforts by delineating watershed extents for nine coastal streams spanning across the three coastal counties of Jackson, Hancock, and Harrison. This was accomplished by using ArcGIS along with the open source Geographic Information Systems (GIS) platform Quantum Geographic Information System (QGIS) with Geographic Resources Analysis Support System (GRASS), to analyze environmental variables corresponding to the study area. An analysis of wetland areas was also performed using a Maximum Entropy (MaxEnt) model. Relevant inputs included elevation, terrain aspect, temperature, and vegetation. Earth Resources Data Analysis Systems (ERDAS) and QGIS were also used to perform a land cover classification. The analyses utilized Landsat 8 Operational Land Imager (OLI) data, National Elevation Data (NED), interpolated lidar data, and stream vectors. Overall, this project illustrated the utility of open data, as well as open-source software. Furthermore, these watershed and wetland maps can aid in protecting endangered streams.

Introduction

Background

Watersheds play an essential role in the health of their local ecologies and the communities which reside there. The identification of watershed boundaries and their delineation play a key role in the understanding and preservation of streams and wetlands. In coastal Mississippi, watersheds fall under the purview of the Mississippi Department of Wildlife, Fisheries & Parks' (DWFP) Mississippi's Comprehensive Wildlife Conservation Strategy 2005-2015, which seeks to preserve the habitats of wildlife species (MMNS 2005). The Pascagoula River is the dominant river in this region, and the largest undammed river system in the continental U.S. (Land Trust for the Mississippi Coastal Plain n.d.). While the state of Mississippi and other environmental organizations work in this area, there is little conservation or restoration detailed for many of the smaller streams on which this project focuses. In addition, much of the areas surrounding these streams are private land, adding additional complexity to their management.

Nine streams were identified as areas of concern by The Nature Conservancy (TNC) and the Pascagoula River Audubon Center (PRAC) in the coastal Mississippi region. Each watershed faces numerous and diverse challenges. Turkey Creek, for example, faces threats from urbanization and has been recognized by the EPA as a critical urban watershed with more than 200 acres recently being place in permanent conservation as a precaution to planned highway projects (NAS 2013). Invasive species pose an issue as well, particularly in Rhodes Bayou. In November 2013, the National Fish and Wildlife Foundation gave $8.2 million to the Mississippi Department of Environmental Quality to fund three conservation projects, with $3.3 million specifically going towards the mitigation of invasive species such as sapium sebifera (Chinese tallow), salvinia molesta (giant salvinia), salvinia minima (common salvinia), and eichhornia crassipes (water hyacinth) (gulflife.com 2013). Due to their coastal proximity, some of the streams are also prone to flooding. This flood risk has resulted in governmental intervention. From 1998 to 2002, 230 at-risk properties were purchased along the Brickyard Bayou under the Brickyard Bayou Acquisition Project to prevent further financial loss. The project cost approximately $19 million and has already paid for itself with losses avoided (FEMA 2006, 1-2).

Objectives

The objective of this project was to delineate the watersheds that TNC and PRAC are working to conserve. Specifically, open source geographic information systems (GIS) were used in order to create replicable methodologies. Furthermore, this project mapped wetland areas and land cover to analyze the health of the watersheds over the study period.

Study Area & Period

The study area spanned the counties of Jackson, Harrison, and Hancock in the southern coastal region of Mississippi (Figure 1). This study focused on watersheds of the following nine urban streams (from west to east): Watts Bayou, Magnolia Bayou, Bear Point Bayou, Turkey Creek, Brickyard Bayou, Coffee Creek, Oyster Bayou, Rhodes Bayou, and Bayou Chico.

The study period was from 2005 to 2014. Elevation data from 2005 to 2011 were utilized for watershed delineation. Landsat data from the year 2014 were analyzed to identify different land types as well as the extent of certain types of wetlands.

National Application Area & Project Partners

This project falls under the Water Resources Application Area, which focuses on monitoring and providing decision support tools concentrated on the availability and quality of water resources for communities, as well as the health of water systems.

The project partnered with The Nature Conservancy (TNC) and the Pascagoula River Audubon Center (PRAC), a branch of the National Audubon Society. Together, they classified nine urban streams as critical freshwater resources and endangered habitats. The TNC and PRAC are currently working together on an urban coastal preservation initiative project. This will include gathering public input and holding public workshops to support these measures, and is scheduled to begin in February 2015. The Nature Conservancy currently conducts field surveys of the watersheds to assess watershed health and identify plant species distribution as part of their Rapid Stream Assessments. Thus, remotely sensed data, such as those utilized in this study, may be used to augment this data collection to allow for more in-depth analyses and on a larger scale.

Methodology

Data Acquisition

Level 1, terrain-corrected Landsat 8 data were retrieved from the USGS Landlook Viewer for the dates of January 19, March 8, and June 21, 2014 for the land cover classification and MaxEnt model. Also for the MaxEnt model, a one-arc second resolution Aster Global Digital Elevation Model (GDEM) version 2, set to the state boundary of Mississippi, was downloaded from the USGS and the Land Processes Distributed Active Archive Center Global Data Explorer platform as a GeoTIFF. 10-meter National Elevation Data (NED) was also downloaded from the USGS National Map Viewer for a subsection of the study area as an IMG for the watershed delineation. In addition, 1-meter lidar data was downloaded from the Mississippi Automated Resources Information System (MARIS), for the immediate areas surrounding each of the nine study streams.

Shapefiles of the study creeks and watersheds were also downloaded from Entergy's Mississippi Site Selection data download site, which hosts data from MARIS. As not all of the creeks were available or labeled, Google Earth was used to identify the course of a few of the creeks, which were then manually drawn in Quantum Geographic Information System (QGIS), based on Google Earth and descriptions provided by project partners at The Nature Conservancy.

Data Processing

Each stream watershed was delineated using the open source software QGIS (with the Geographic Resources Analysis Support System (GRASS) toolbar. These watersheds were then compared to the watershed sub-basins created in ArcMap 10.2.2 using the Hydrology toolbox. Both the 1-meter and 10-meter digital elevation maps (DEM) were run in both software packages.

MARIS provided post-Katrina 1-meter lidar data in LAS format. The LAS files were converted into three LAS datasets in ArcMap corresponding to the location of the streams within the three Mississippi counties. The LAS datasets were then interpolated into an elevation raster using a nearest neighbor approach with a void fill using the "LAS Dataset to Raster" tool in ArcMap. The 10-meter NED was downloaded preprocessed, and thus did not need to be interpolated.

The MaxEnt model required multiple input parameters including tasseled cap (TCAP) transformations for brightness, greenness and wetness; normalized difference vegetation index (NDVI); MNDWI; both thermal Landsat 8 bands (10 & 11); and NED digital elevation models including terrain slope and aspect. The model also required the input of wetland source points which were located from a Landsat 8 RGB band combination (short wave infrared, near infrared, coastal aerosol) and a supervised classification of known wetland areas trained using Google Earth source points. 100 source points each for freshwater forested, freshwater emergent, and estuarine were generated using the random point generator and a Shapefile of the wetland types obtained from the U.S. Fish and Wildlife Service. These source points were saved as a comma separated value (CSV) file for use in the MaxEnt model. The environmental layers were saved as an ASCII type raster in a single folder. All data were re-projected into the NAD 1983 UTM zone 16N coordinate reference system.

The Landsat 8 data were processed from their digital numbers (DN) to top-of-atmosphere reflectance. Dark object subtraction was also applied to account for areas that were within complete shadow (Pax-Lenney et al. s002). The normalized difference vegetation index (NDVI) was calculated using the equation

$$NDVI = \frac{B_{5,NIR} - B_{4,RED}}{B_5 + B_4}$$

The modified normalized difference water index (MNDWI) was also calculated using the equation

$$MNDWI = \frac{B_{3,GREEN} - B_{6,MIR}}{B_3 + B_6}$$

Tasseled cap transformations (TCAP) were performed using the Landsat 8 coefficients (Appendix I) experimentally determined by Baig et al. (2014) to enhance land surface characteristics. QGIS was used to perform these calculations.

Data Analysis
The elevation raster was be used as the primary input layer into the GRASS program's r.watershed tool. For the purpose of this project, no additional parameters such as percent of overland flow, location of depressions, terrain blocking overland flow, etc. were used. The minimum size of exterior watershed basin, however, was an important parameter in defining watersheds. If the value was too high, only a portion of the watershed would be mapped, while if the value was too low the watershed would encompass more than one. For the 10-meter NED, a value of 2000 was used as a minimum basin size. For the 1-meter MARIS data, a value of 20000 was used for Harrison County, a value of 35000 was used for Hancock County, and a value of 10000 was used for Jackson County. For comparable results, the same values were utilized in the sub-basin mapping in ArcMap. The option to allow for multiple flow directions was also chosen. The r.watershed outputs selected for this study were drainage direction and stream segments.

The drainage direction layer produced in r.watershed was then used as the primary input for the r.water. outlet tool. This tool requires the geographic coordinates of a specific cell selected as the outlet point for the watershed. These outlets were selected with QGIS's coordinate capture tool, utilizing the stream segments layer from r.watershed, and a shapefile of the study streams for further reference (Figure 2). These coordinates were used as the easting and northing points for r.water.outlet. The output from this tool was a raster file of the desired watershed (Figure 3).

The Hydrology toolbar in ArcMap was also utilized to delineate watershed sub-basins. To do this, the input elevation data were used to create a flow direction raster, which was then used as the input for the Flow Accumulation tool. The extents of the streams were then calculated using the Raster Calculator, the flow accumulation output, and the various minimum basin sizes described above. Using the stream drainage points created by the Raster Calculator, the Stream Link tool was then run. These outputs were then used in the Watershed tool, with final outputs of the watershed sub-basin rasters. These rasters were then converted into polygons for comparison with the GRASS watershed results.

The MaxEnt model produced graphs and tables of the predicted areas of wetland extent based on the source points' locations in relation to the environmental layers. A number of settings were used for the MaxEnt Model to account for variability within the model (Carter et al. 2011).These included setting the number of runs that the model performed to 10, resulting in average, median, maximum, minimum, and standard deviation outputs calculated from the runs. In addition, the model chooses a random 25 percent of the training data to withhold from each run to be used for result validation. Each MaxEnt run was iterated 5000 times to allow sufficient time for the model to run so that results were not over-or underestimated (Carter et al. 2011, 10).

A supervised Land Use/Land Cover (LULC) classification was performed within ERDAS Imagine. Landsat 8 bands 3, 4, and 5 (green, red, and near infrared, respectively) were used to produce a color infrared raster of the area to be classified. An unsupervised classification was first performed resulting in the raster being split into 50 categories. Using Google Earth and the National Land Cover Database (NLCD) 2011, these categories were grouped into six. Using these six categories as training data, a supervised classification was run using the maximum likelihood algorithm. The accuracy was assessed using 100 randomly generated points, whose classifications were compared manually with Google Earth. 90% of the points were in agreement with the Google Earth images.

Results & Discussion

Analysis of Results

Although outputs such as flow direction and flow accumulation showed results for the entire elevation data, the 10-meter elevation data used in ArcMap did not entirely delineate towards the lower boundaries of the counties. The only streams that were within the boundaries of the ArcMap watershed delineation were Turkey Creek, Coffee Creek, and Rhodes Bayou (Figure 4). This was due to the stream segment length that was set for the amount of streams to be created in the raster calculator. The reason for using the extent value chosen for analysis (greater than 20000) was because the output gave a reasonable amount of sub-basins and sub-basin sizes. In order to capture watershed delineations for the other streams, an extent value of 1000 would need to be used, but with that small of an extent size, the streams are split into so many segments that the watersheds are too subdivided to be a reasonable representation of stream flow (Figure 5).

The GRASS watershed methodology created individual watershed boundaries for each of the nine study streams. These were overlaid with the watershed sub-basin maps created with ArcGIS for comparison. The GRASS results (shown in pink) showed a strong correlation when compared to those delineated in ArcMap (shown in green) (Figure 6). This demonstrated the success of using the open source software.

The MaxEnt model resulted in three prediction maps of wetland extent, one for each of the three types analyzed (emergent, estuarine, and forested). Overall, the maps provided a useful prediction for locating areas where different vegetation types occurred, especially in and around the individual watersheds. The model used different source points over different environmental parameters to give 3 unique maps for the output for each of the 3 wetland types (Figure 7). The similarities between the MaxEnt and LULC results can be seen in the Turkey Creek Watershed (Figure 9), where much of the same forested areas mapped using these two methods align well.

The MaxEnt model also indicated which of the environmental variables used were most influential in the predication maps (Figure 8). For estuarine wetlands, these were the NDVI, green tasseled cap, and slope. For emergent, it was slope, and the green and brightness tasseled caps. While for forested, it was the thermal band, slope, and the brightness tasseled cap. These results suggest that slope is an important predictive variable for wetlands, while for each type of wetland, additional variables play large roles as well. This information can be used to further refine the model in future analyses and should be used in conjunction with the number of source points as well as the location of those omitted when performing the comparison analysis between the predicted and real wetland areas. The jackknife test is also useful in determining the model performance as higher jackknife number corresponds to a precise model while lower numbers correspond to one where points have been chosen randomly and no pattern is apparent. Estuarine area under the curve (AUC) values were very high (~0.90) while those for forested and emergent were much lower (~0.70). When running future models source points should be chosen with perhaps more precision so that the performance of the model will show higher values.

The Land Use/Land Cover classification map gives insight into the spatial relationship between the various land uses and cover types in the study area. The map reveals that wooded wetlands are centered along the Pascagoula River, while the emergent wetland herbaceous is found closer to the coast. Much of the forested area in the region is west of the Pascagoula River, while farm/developed/open land and urban/road/sand areas are intermingled throughout the region (Figure 9).

Comparing the Land Use/Land Cover (LULC) classification to the results given by the MaxEnt model, a high correlation between forested and estuarine/wetland herbaceous was found. The MaxEnt model found that Turkey Creek had a high concentration of forested and emergent wetlands in its central portion but almost none near its southern and northern portion. Similarly, the LULC map for the Turkey Creek watershed designated much of the central portion of the basin as forested (Figure 10). It also showed little to no emergent herbaceous wetland which also is consistent with the MaxEnt prediction of estuarine wetland within the Turkey Creek basin.

Errors & Uncertainty

While the lidar data utilized in this study provided a high resolution analysis of the study area, there were errors in the original data, such as voids and noisy data that could be cleaned for more accurate results in a future analysis. Furthermore, the addition of other parameters (e.g. real depression locations, overland flow, etc.) in r.watershed model may further improve the results. In addition, as several of the study streams themselves have been considerably altered through human interventions such as rerouting of water pathways, especially in urban areas, these effects may need to be further addressed in a watershed delineation model. Moreover, due to the limited availability of stream shapefile data, this project utilized data that were partially created through use of Google Earth and by hands-up digitizing. This may have introduced inaccuracies in the exact paths of the streams.

The LULC analysis had difficulty distinguishing between sand, roads, and urban areas due to their similar spectral properties. Furthermore, classification was challenging due to both the small nature of the study areas and their varying water levels and vegetation content.

Future Work

Because the nine study stream watersheds are part of the larger, regional stream network, the study region could possibly be impacted by streams or other water sources outside the designated study area. An expanded study area for watershed delineations could help in assessing stream interactions.

While the land cover classification illustrated the current conditions in the study areas, using Landsat data from previous years and comparing it to present conditions could identify any decrease in wetland extent. It could also predict future trends of urbanization and which areas are most prone to endangerment. Furthermore, as invasive species are a large concern of the project partners, a LULC could be valuable in determining the current proliferation and potential spread of invasive species within the study area.

Lastly, accuracy of watershed delineation, wetland extent maps, and the LULC were evaluated using Google Earth, and the US Fish and Wildlife Service Wetlands Mapper. Although these are considered reliable, ground truthing would be the next step in determining the quality of the results.

Conclusions

LULC maps can aid in identifying areas at risk from anthropogenic impacts, although further refinement of the maps produced here are needed. By understanding what the land is used for, the project partners can allocate resources to these areas when working to conserve the streams. By combining the land classification maps with prediction maps from the MaxEnt model they can further enhance their decision making. The MaxEnt model is an effective tool for determining wetland areas when the correct environmental data are used and variability is accounted for. Thus, by performing multiple runs, withholding a percentage of source points for comparison, and increasing or decreasing threshold values, the capability of the model can be better refined. In regards to the small size of the study area, both an LULC and prediction map can be used to locate potential watersheds. This project illustrated that open-source software can effectively delineate individual watersheds of small streams. Overall, these results support that watershed extent may be precisely mapped using a combination of open source data processing software and elevation data from NASA Earth Observations.

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References

Carter, Lane, Evangelista, Paul, Young, Nick. 2011. "A MaxEnt Model v3.3.3e Tutorial". Natural Resources ecology laboratory, Colorado State University. September 29, 2014

Federal Emergency Management Agency (FEMA). 2006. "Ch. 9: Mitigation Successes and Best Practices." Mitigation Assessment Team Report Hurricane Katrina in the Gulf Coast. http://www.fema.gov/media-library-data/20130726-1520-20490-9868/549_ch9.pdf (October 9, 2014).

gulflive.com. 2013. "MDEQ Receives $8.2 Million of an Expected $354 Million for Gulf Restoration Projects." November 14. http://blog.gulflive.com/mississippi-press-news/2013/11/mdeq_receives_82_million_of_an.html (October 9, 2014).

Land Trust for the Mississippi Coastal Plain. n.d. "Pascagoula River Watershed." http://www.ltmcp.org/teacher-resources/pascagoula-river-watershed/ (September 29, 2014).

Mississippi Department of Wildlife, Fisheries, & Parks (MDWFP). n.d. "WMA South East Region." http://www.mdwfp.com/wildlife-hunting/wmas/southeast-region.aspx (September 29, 2014).

Mississippi Museum of Natural Science (MMNS). 2005. Mississippi's Comprehensive Wildlife Conservation Strategy. Mississippi Department of Wildlife, Fisheries and Parks, Mississippi Museum of Natural Science, Jackson, Mississippi. http://www.mdwfp.com/media/63792/cwcs.pdf (September 29, 2014).

Muhammad Hasan Ali Baig, Lifu Zhang, Tong Shuai & Qingxi Tong. 2014. Derivation of a tasseled cap transformation based on Landsat 8 at-satellite reflectance, Remote Sensing Letters, 5:5, 423-431, DOI: 10.1080/2150704X.2014.915434

National Audubon Society, Inc. (NAS). 2013. "Audubon and Turkey Creek." Pascagoula River Audubon Center. http://pascagoulariver.audubon.org/audubon-and-turkey-creek (October 9, 2014).

Pax-Lenney, Mary, Curtis E. Woodcock, Scott A. Macomber, Sucharita Gopal, Conghe Song. 2001. "Forest mapping with a generalized classifier and Landsat TM data". Remote Sensing of Environment. 77(3): 241-250. DOI: 10.1016/S0034-4257(01)00208-5.

Table 1: Landsat 8 Tasseled Cap Transformation Coefficients from Baig et al. (2014)

Landsat 8 Band	B2	B3	B4	B5	B6	B7
TCAP Transformation						
Brightness	0.3029	0.2786	0.4733	0.5599	0.508	0.1872
Greenness	-0.2941	-0.243	-0.5424	0.7276	0.0713	-0.1608
Wetness	0.1511	0.1973	0.3283	0.3407	-0.7117	-0.4559

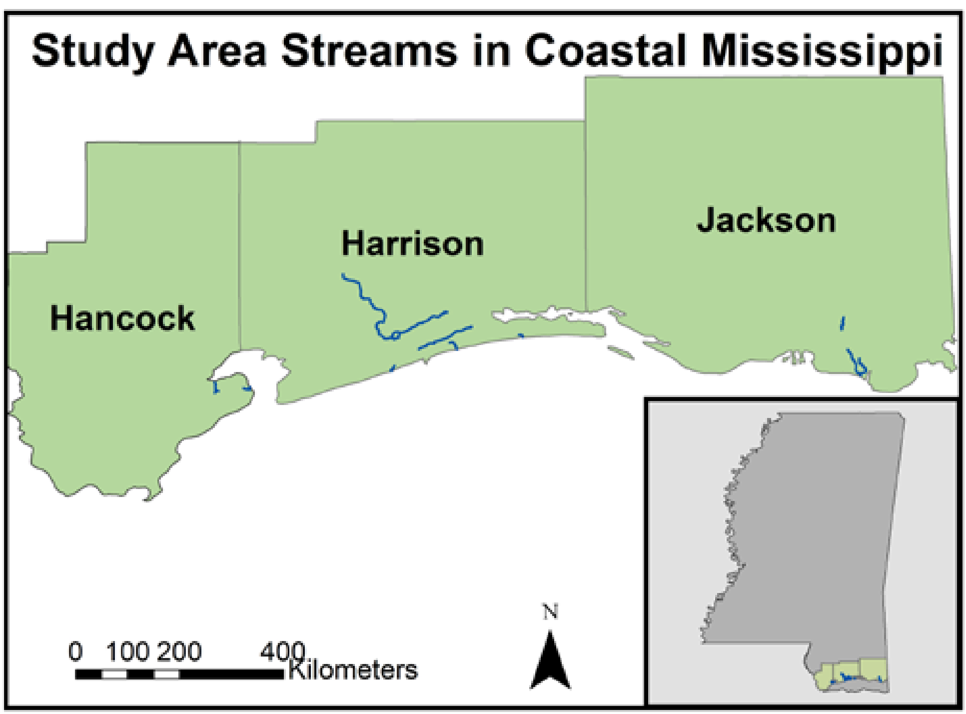

Figure 1. Study Area Coastal Counties and Streams.

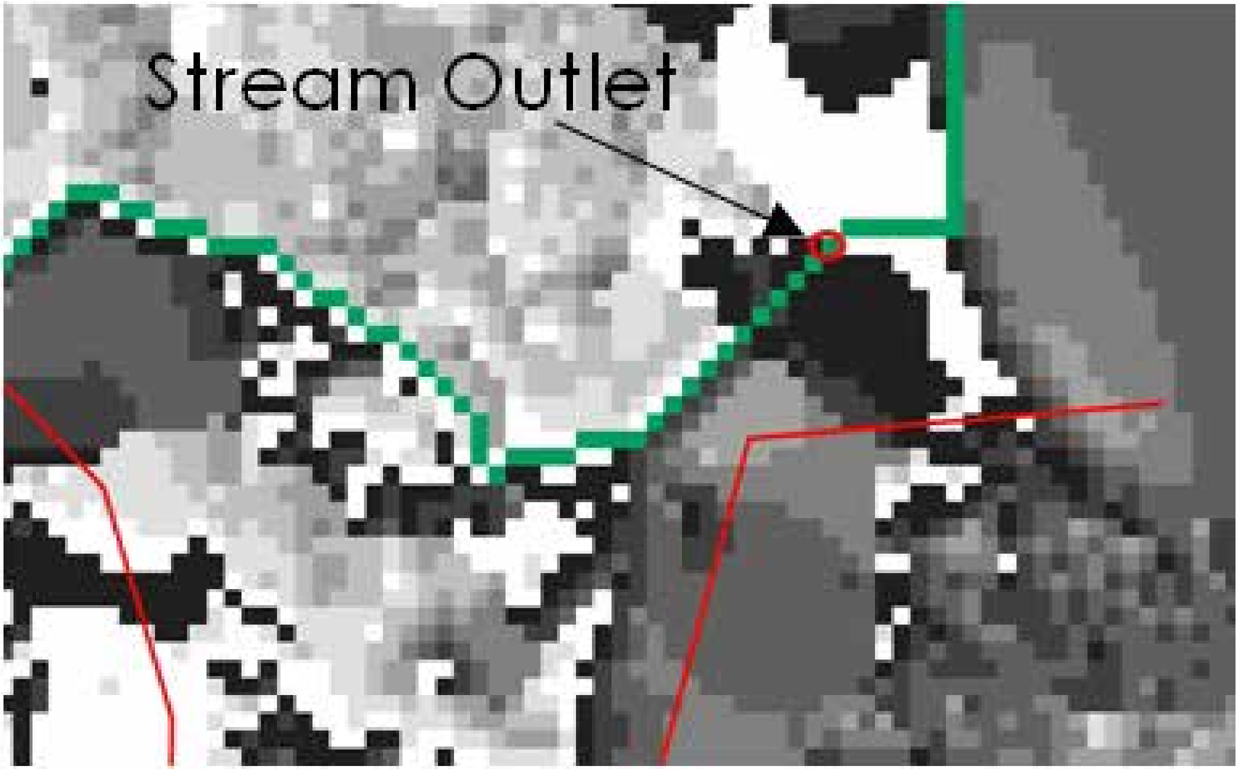

Figure 2. Stream shapefile (red) used as a reference to locate exact coordinates of stream output segment (green) for 1-meter data

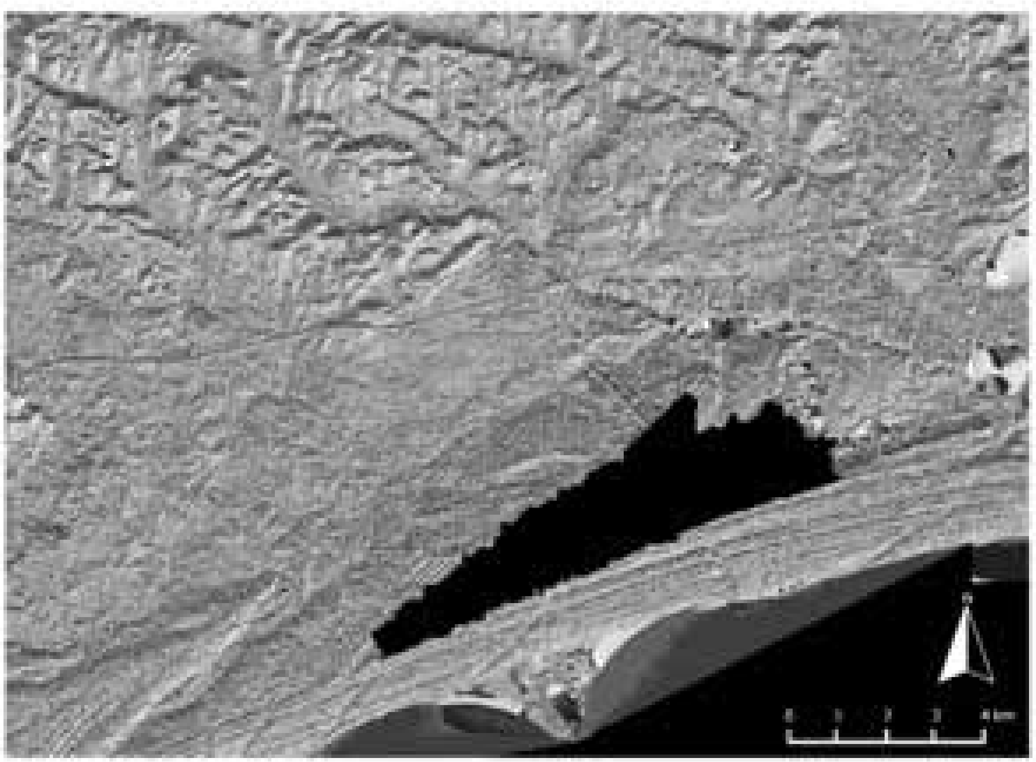

Figure 3. r.water.outlet output basin (black) over drainage direction layer from r.watershed

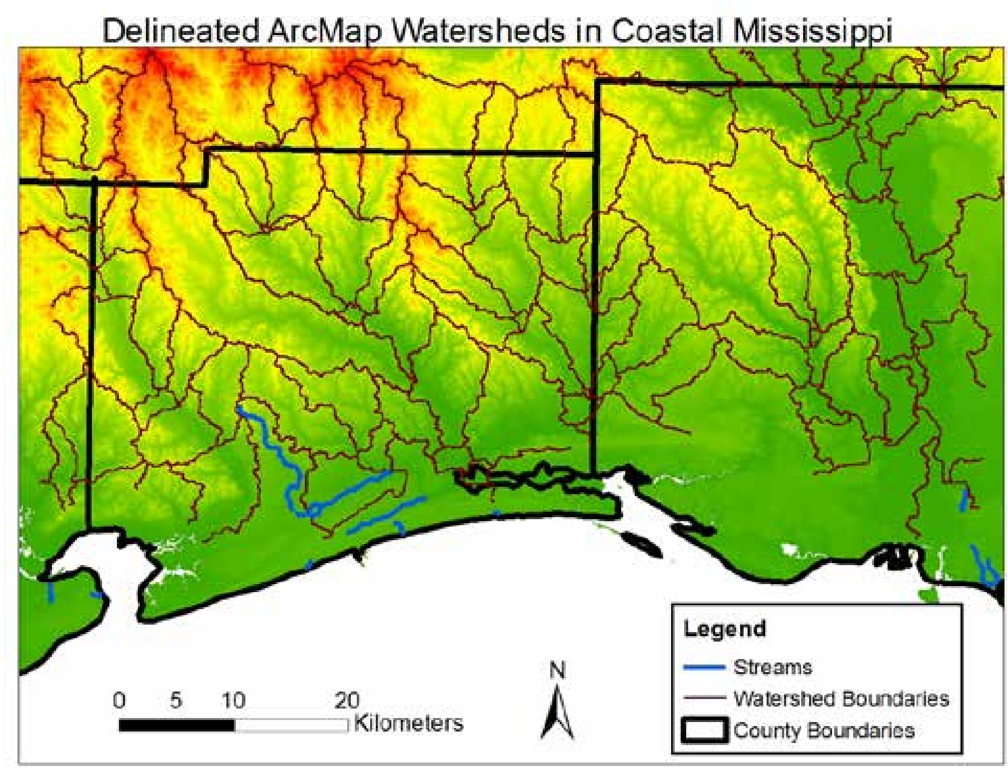

Figure 4. Watershed delineation using ArcMap of entire study area, illustrating the lack of watersheds delineated along the coast.

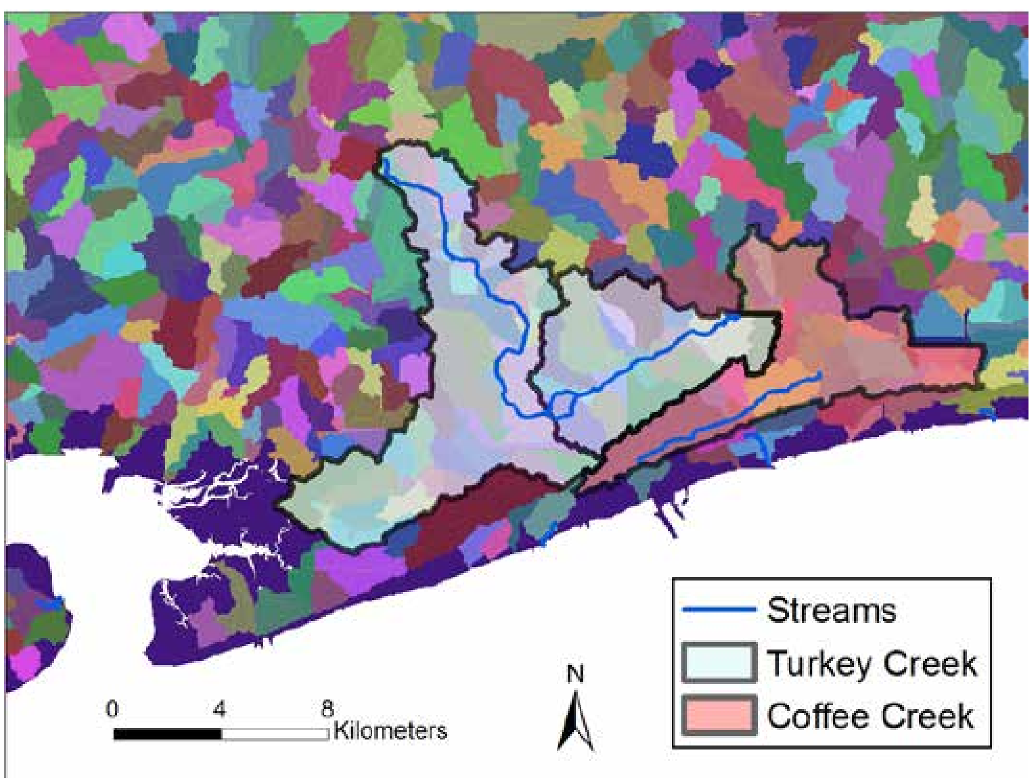

Figure 5. ArcMap watershed delineation of Turkey Creek area when using a stream extent value of greater than 1000.

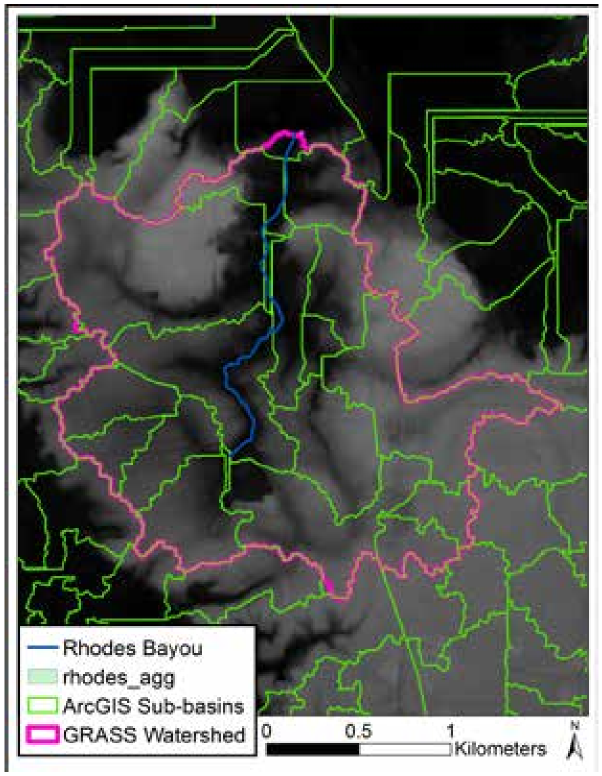

Figure 6. The 1-meter watershed basin for Rhodes Bayou, created in GRASS, is layered on top 0f the sub-basins, created in ArcMap, illustrating their agreement.

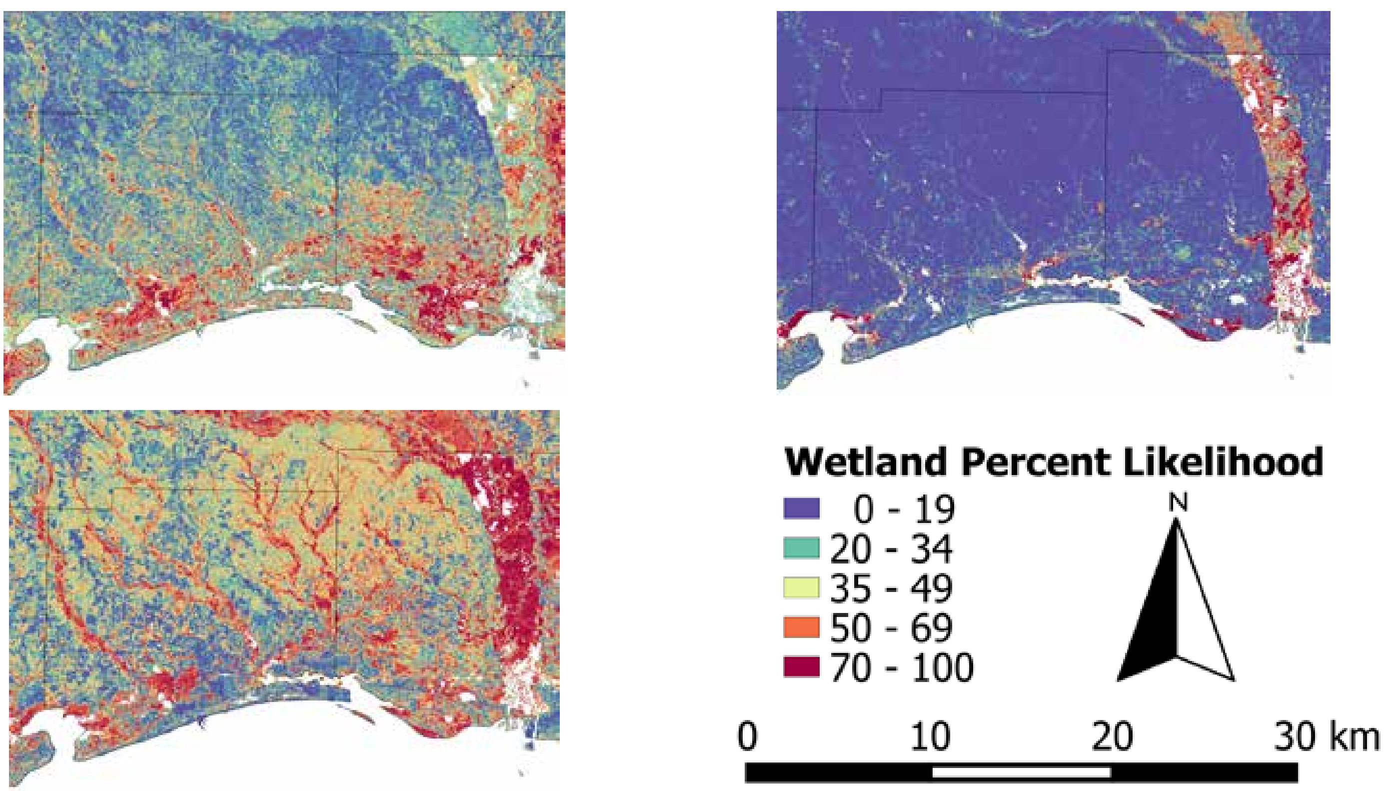

Figure 7. Three wetland prediction maps for Emergent (top left), Estuarine (top right), and Forested (bottom left) wetlands. Red areas indicate a more highly predicted area for the specific type of wetland.

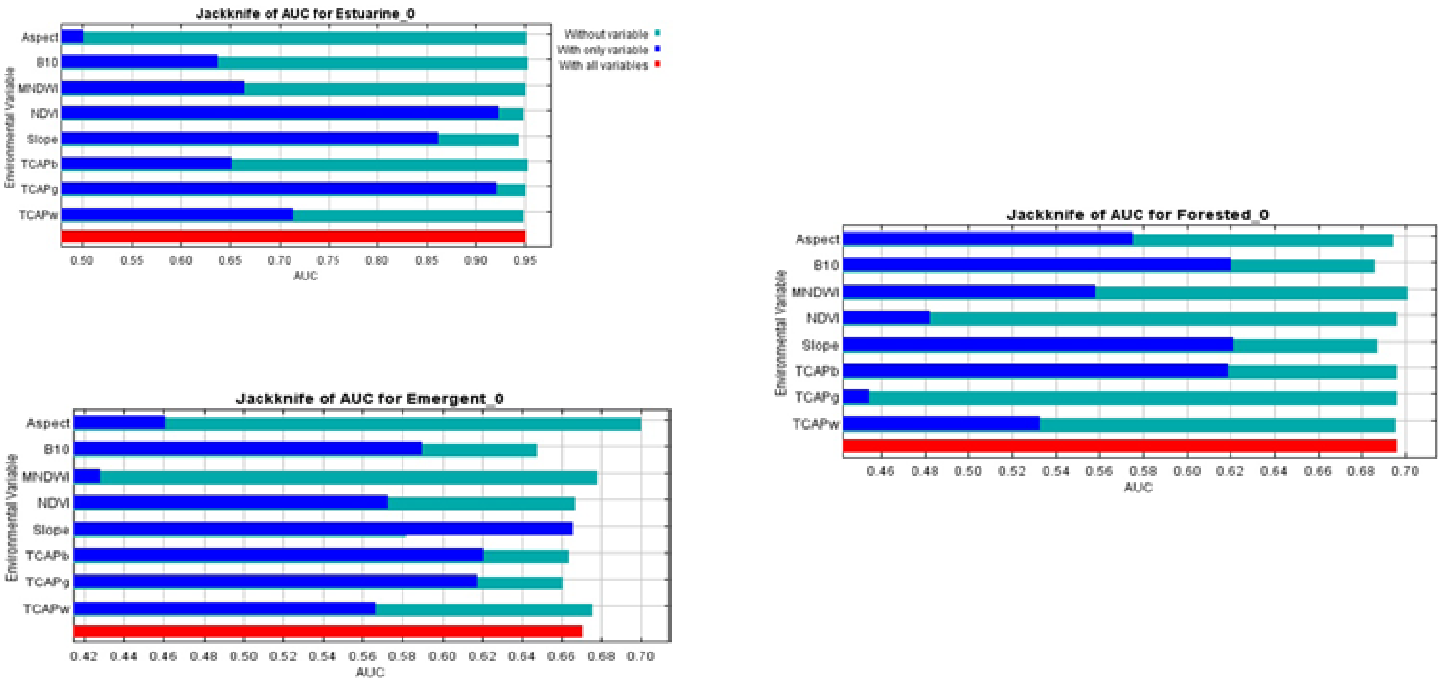

Figure 8. The jackknife tests for the three types of wetlands, indicating which variables were the most influential in each wetland's prediction map.

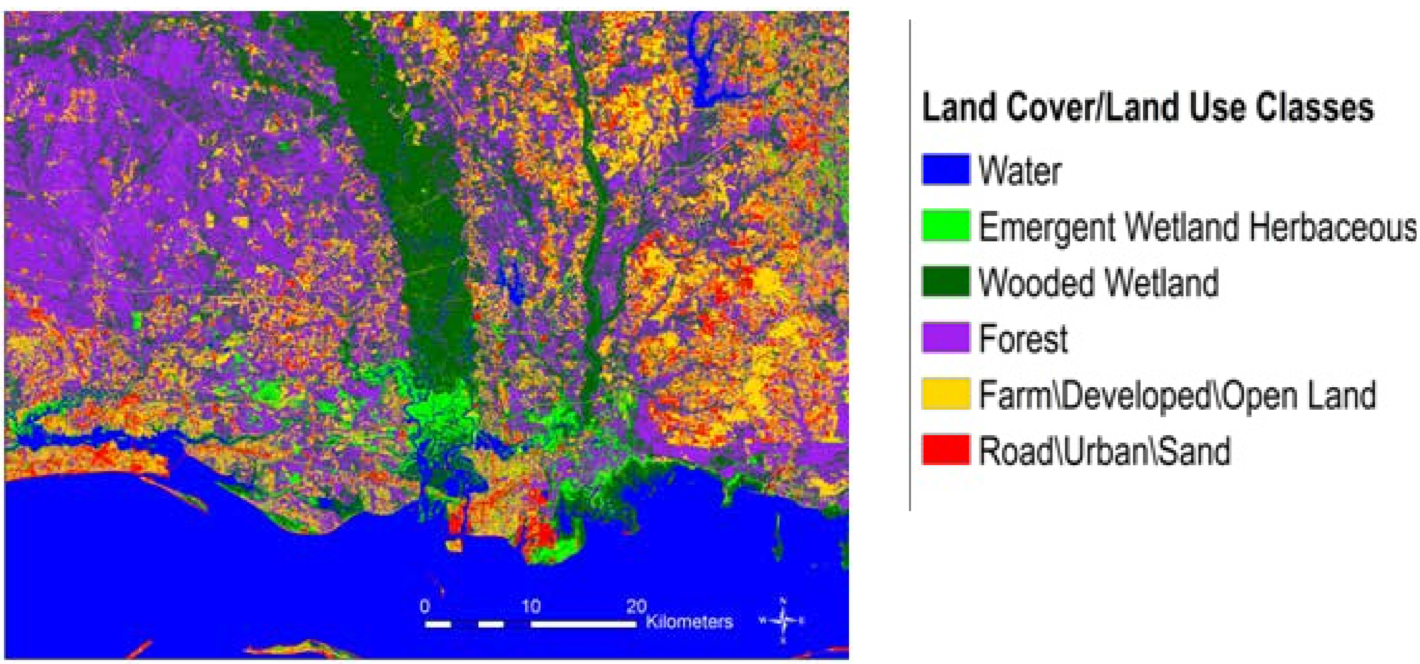

Figure 9. Land Use/ Land Cover map of study area

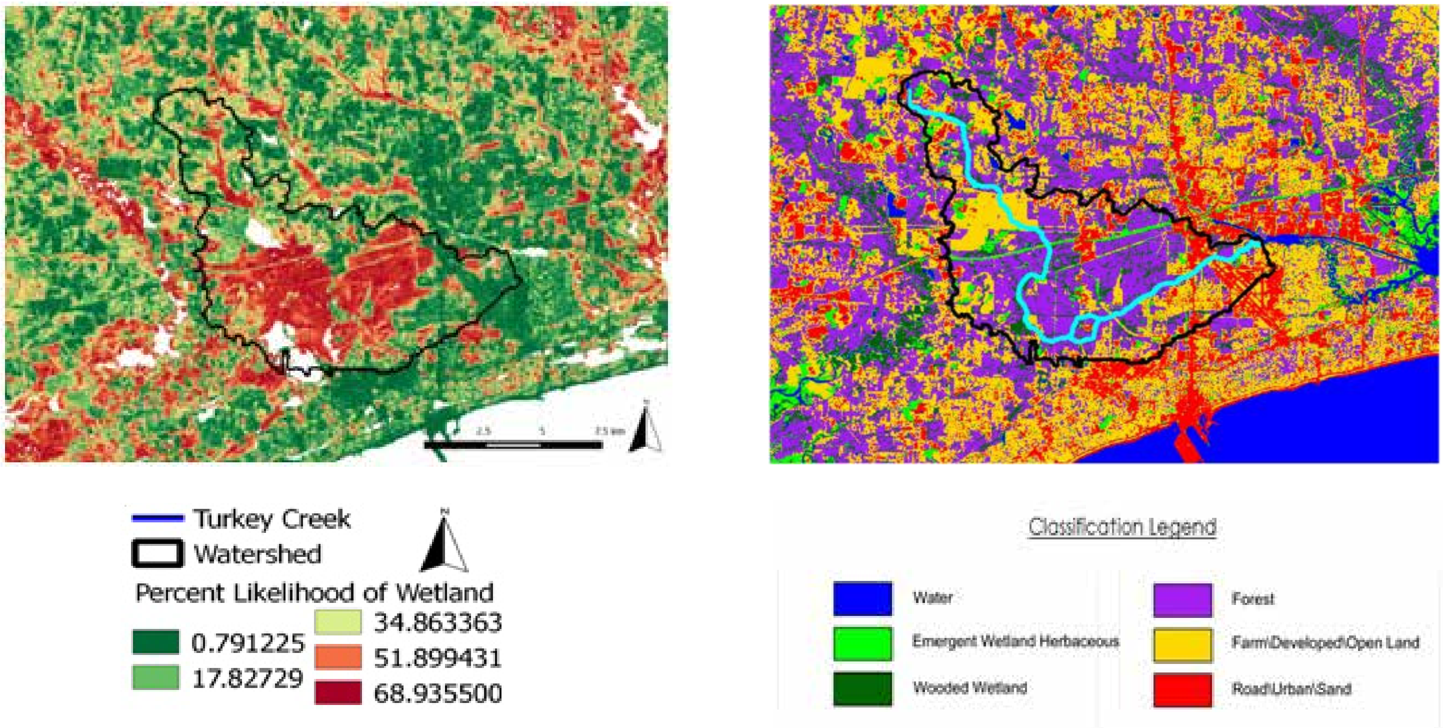

Figure 10. MaxEnt prediction map of forested wetland extent (left) compared to the Land Use/ Land Cover (right) in and around the Turkey Creek Watershed.