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North Alabama Ecological Forecasting: Spatial Modeling of the Fragmentation of Local Species Habitat from Increasing Urbanization in North Alabama

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Abstract **–** Alabama is one of the most biodiverse states in the United States, including the greatest diversity of aquatic species. As urbanization continues to increase in Alabama, this biodiversity is at risk. NASA DEVELOP partnered with the Land Trust of North Alabama to identify sensitive habitats that are at risk from urbanization within Madison and Limestone counties. The Land Trust of North Alabama works to preserve land, primarily in Madison and Limestone counties, and encourages stewardship through environmental education. The team conducted a supervised classification of land class type, utilizing data from Landsat 5 Thematic Mapper (TM), Landsat 8 Operational Land Imager (OLI), and Shuttle Radar Topography Mission Version 4 (SRTM) to identify land cover changes and areas most vulnerable to future urbanization. By incorporating land classification analysis and additional parameters indicative of urbanization, the team produced an urbanization prediction tool and a landscape fragmentation map. The urban prediction tool identified land highly suitable for development and found that 25% of highly suitable land will be urbanized by 2045 using the measured 0.87% growth rate. Ecological impact was established using observation data for species of interest to the project partners. These tools will enable the Land Trust to target high risk areas of land for preservation.

I. Introduction

With just over 3,600 square kilometers of biodiverse land, Madison and Limestone counties in northern Alabama (**Figure 1**) have undergone significant development in recent years and urbanization is expected to continue to increase (U.S. Census Bureau, 2012). In order to provide for the growing population, land is often converted for agricultural and residential use (Bostick, 2017). More large-scale agricultural fields lead to increased runoff pollution, which negatively impacts native species' habitats (Ongley, 1996). In addition to agricultural development, urban growth is also a concern for local species' habitats due to fragmentation and subsequent competition and reduced carrying capacity. From 1980 to 2010 the Madison County population increased by over 137,000 people and the city of Huntsville, located in Madison, is one of America's fastest growing cities. Limestone County grew by over 36,000 people from 1980 to 2010 (U.S. Census Bureau, 2012). The Land Trust of North Alabama is specifically concerned that rapid growth and development in Madison and Limestone counties will negatively impact the natural landscapes of the region, and more importantly, the habitats of threatened and endangered species. This boom in urbanization highlights the need to expand conservation efforts. Without sufficient conservation efforts, many species in the area could be at risk of habitat loss, including 30 endangered and threatened species (U.S. Fish & Wildlife Service, n.d.).

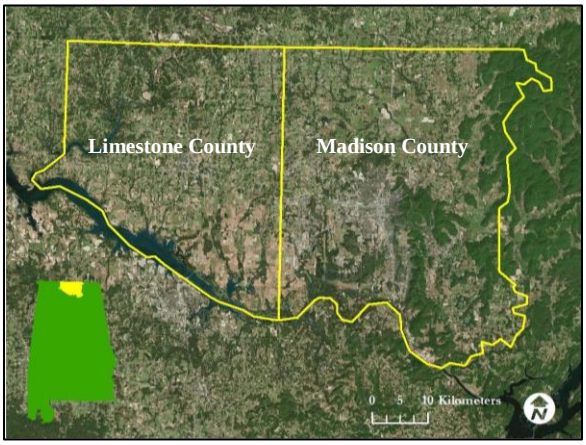

Figure 1: *Madison and Limestone counties in northern Alabama*

The Land Trust works with local government officials to acquire land for conservation and to educate the public, including private landowners, about the natural habitats and ecosystems that are present in the local area (Land Trust, 2017). There are some restrictions at the federal level that encourage conservation, such as building restrictions in flood plains mandated by the Federal Emergency Management Agency. However, the Land Trust works to preserve land that is not protected at the federal level and thus would otherwise be available for

development. Currently, the Land Trust primarily obtains land in Madison County. Due to increasing populations and urbanization, they seek to preserve land in Limestone County as well. The Land Trust's decision-making heavily relies on field studies and outsourced or volunteered research. To assist the Land Trust with decision-making regarding conservation, urbanization patterns from 1986 to 2017 were analyzed. Then, Fuzzy Logic in ArcMap 10.4.1 was used to create the Favorability for Development Map that forecasted urbanization to 2045. A Species Impact Tool was created to assist the Land Trust in effectively choosing land for conservation by assessing the potential impact on habitats from land change. Once the land is obtained, the Land Trust can allocate the necessary resources to preserve and protect areas of interest that are home to threatened or endangered species. Aside from informing acquisition of land, the Land Trust will be able to use the tools developed from this project to educate the public and land owners in the area about the potential impact of development on local species habitats and promote conservation efforts.

II. Data Acquisition

The team acquired Landsat 5 Thematic Mapper (TM) Top of Atmosphere Reflectance (TOA) orthorectified with Fmask and Landsat 8 Operational Land Imager (OLI) TOA Reflectance image collections through Google Earth Engine (GEE) with a code developed by the team. The code retrieved the least cloudy images that covered the study area for each year of the study period. Image pairs were mosaicked and clipped to the study area. Shuttle Radar Topography Mission (SRTM) v4 data were downloaded from cgair-csi.org to provide the topography of the region (Jarvis, Reuter, Nelson, Guevara 2008). Landsat 8 OLI and Landsat 5 TM both have 30 m resolution, with a repeat cycle of 16 days.

The Land Trust identified several species of particular interest due to their native status and rare nature, including the green salamander (*Aneides aeneus*) and Morefield's leather flower (*Clemamtis morefieldii*). The team also acquired data on the American black duck (*Anas rubipes*), the cave salamander (*Eurycea lucifuga*), and the northern slimy salamander (*Plethodon glutinosus*). Green salamander observations within the study area were acquired from Andrew Cantrell, a student researcher at Alabama Agricultural and Mechanical University (Cantrell, 2011), and Rebecca John from Auburn University (John, 2017). Data for American black duck observations were retrieved from the eBird website as a text file and converted to a comma-separated values (CSV) file for use in Esri ArcGIS. Cave salamander and northern slimy salamander data were acquired from Christine Easterwood at the U.S. Army Garrison, Redstone Arsenal, and Rebecca John at Auburn University (John, 2017). Morefield's leather flower data were acquired from Michael Barbour at the Alabama Natural Heritage Program, Auburn University (Alabama Natural Heritage Program, 2016).

Location data for colleges, fire stations, hospitals, and public schools were acquired from the Homeland Infrastructure Foundation-Level Data (HIFLD) Subcommittee open data webpage. HIFLD data incorporated locations of interest beyond the Madison and Limestone county borders, such as large cities just outside of the study area, to more accurately represent the distribution of infrastructure affecting potential urban growth. The two most recent 30-meter land cover layers available from the Multi-Resolution Land Characteristics Consortium (MRLC) website were acquired in order to determine the average urban growth rate for the study area.

III. Data Processing

The Landsat 8 and Landsat 5 imagery acquired by GEE had undergone a Top of Atmosphere (TOA) correction to convert the remotely sensed digital numbers to reflectance values. The SRTM data covering Limestone and Madison counties were acquired as two separate rasters and mosaicked in ArcMap 10.4. The Landsat series and SRTM rasters were clipped to the study area. An additional shapefile was created to encompass the study area and surrounding cities. HIFLD infrastructure data were clipped to the shapefile, and distance rasters for each dataset were made using the Euclidean Distance tool in ArcMap 10.4.1.

Maximum Likelihood Classification was conducted for the least cloudy Landsat imagery collected from 1984 to 2016. First, a total of seven land cover classes were distinguished, including forest, agriculture, barren, water and three levels of urbanization. 100 polygons were created for each class by using 2016 Worldview data as the guide to land cover type. Three band math ratios were tested using the Maximum Likelihood Classification: Normalized Difference Vegetation Index (NDVI), Normalized Difference Built Index (NDBI), and Enhanced Built-Up and Bareness Index (EBBI). When a visual comparison with the National Land Classification Database (NLCD) demonstrated that this approach

resulted in a large numbers of ponds where no ponds exist, the number of classes was reduced to three: Developed, Undeveloped, and Water. Gross inaccuracies remained, and the Maximum Likelihood Classification approach was discarded in favor of the NLCD. This may have been a result of focusing on using the least cloudy image from each year, rather than utilizing a seasonality approach and incorporating the least cloudy image from the same season. Within the scene for one year, the least cloudy images could be up to 6 weeks apart and the scenes varied from a collection month of January to November. Since forested areas may look bare in a winter scene and vegetated in a summer scene, these differences in collection time may have impacted the usability of the land classification.

To forecast urbanization, Fuzzy Logic Modeling was used in ArcMap 10.4. First, the Fuzzy Membership tool was used to assign Fuzzy Membership values to each of the datasets being used. The team determined that the most appropriate membership for distances to colleges, fire stations, public schools, and hospitals was a linear membership because people prefer to live near these types of infrastructure. An MSLarge membership was used for the reclassified NLCD, meaning that the input values with larger values have a higher membership which declines sharply after the mean. After assigning the Fuzzy Memberships, the data were clipped to the study area shapefile and all of the Fuzzy Memberships were input into the Fuzzy Overlay tool. The "AND" operator was used to create the final suitability layer based on a high fuzzy membership in all the component layers.

IV. Data Analysis

The average total change of developed land per year was calculated using the 2006 and 2011 NLCD. All pixels classified as developed (i.e. High, Medium, Low, and Open) were counted, the 2006 total was subtracted from the 2011 total, and then divided by the intervening years. This process generated an urban growth rate of 1% per year for northern Alabama, which can be useful for identifying overall growth, but will not identify any volatile years within the period that had higher or lower growth. This calculation was repeated with a Maximum Likelihood land classification for the Landsat 8 and Landsat 5 imagery for years 2006 through 2011 to provide higher temporal resolution data than the NLCD. However, the Maximum Likelihood land classification misidentified large areas when compared with the NLCD. In addition, the Maximum Likelihood land classification average urban growth rate was approximately 2%. The accuracy of the NLCD classification is 85% (Wickham et al., 2013) and incorporates a ground truth verification process. Due to the obvious errors of the Maximum Likelihood classification and the verified accuracy of the NLCD, further analysis used the temporally limited growth rate derived from the NLCD rather than the visual classification created.

Using the NLCD classification growth rate, development was projected through 2100. To understand the significance of this urban growth rate, the number of years it would take this 1% urban growth per year to develop all of the highly favorable lands was calculated. Highly favorable lands are open lands that have the lowest average distance from fire stations, colleges, hospitals, and public schools. Zoning codes were unavailable for the entire study area, and so were not included. The estimated growth was subtracted from the total area (km^2) of the highly favorable classification from the Favorability for Development Map. This process shows the estimated number of years it would take at 1% urban growth per year to develop all of the highly favorable lands.

After urban growth was projected, an impact analysis was conducted on local species habitats to assess where potential land development could impact local species. The point location observations of each species served as a basis for the species impact map. The impact of urbanization does not need to be directly on top of the existing species habitat to impact the species; therefore, a buffer was created around each point of the species data in efforts to better represent the impact of encroaching urbanization. Songbirds typically need a buffer of at least 45 to 100 meters, and sometimes can extend to 200 meters (Hannon, 2012). Mammals can require a buffer ranging from about 90 to 300 meters around their habitat (Bilecki, 2003). Fish and aquatic species need a relatively small 10 to 100 meter buffer (Jones, Helfman, Harper, Bolstad, 1999). Ultimately, a 250 meter buffer was selected to represent the maximum necessary buffer size for most species. After the buffers were created, each species' habitat was intersected with the data from the Favorability for Urban Development Map.

V. Analysis of Results

Areas within Madison and Limestone counties that are favorable for urban development were identified (**Figure 2**). Low favorable land was located along the county line and covered 35% (1,293 km^2) of the study area. Medium favorable land covered 28% (1,059,542 km^2) of the study area. High

favorable land accounted for approximately 1,057 km^2, or almost 20% of the total study area. The location of the low favorable land could be due to the geography of the region, as the Tennessee River flows along the southern edge of Limestone and Madison counties. Additionally, the region along the eastern Madison county line is more mountainous than the rest of the study area. These areas may be more difficult to access, and in the case of the areas along the Tennessee River, may face more restrictions in terms of building residential areas.

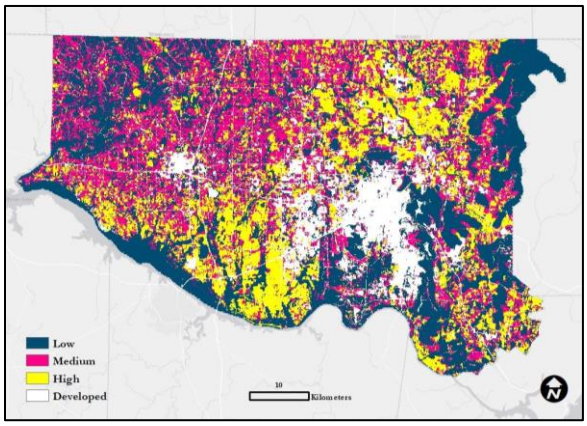

Figure 2: *The Favorability for Urban Development Map shows the probability that an area within Limestone and Madison counties will become urbanized.*

Based on the current urban growth rate in these counties, it is projected that by 2045 approximately 25% of all highly favorable land will be developed (**Figure 3**). The 25% increase in developed areas across north Alabama would result in 20% of the total land area in Madison and Limestone counties being considered developed land. Furthermore, if the approximately 1% growth rate remains constant into the future, all highly favorable lands are projected to be developed by the year 2100. As Limestone and Madison counties continue to grow, it is possible that the 1% growth rate will increase over time.

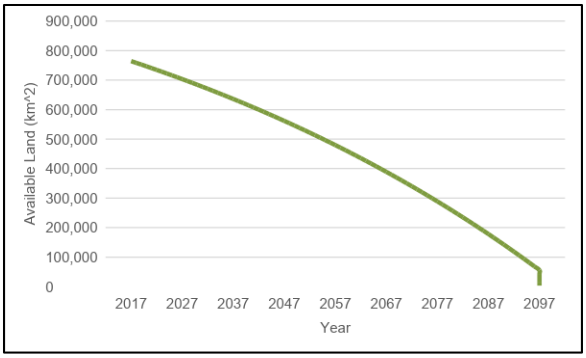

Figure 3: *Total projected amount of highly favorable land available (in square kilometers) in north Alabama from the 2017 through 2101*

The area of each species habitat is relatively small compared to the study area due to the limitations of the observation datasets utilized. The American black duck had the largest amount of habitat in areas highly favorable for future land development, and accounted for the highest overall threat with 2.7 km^2 of their habitat falling into a high or medium category of development (**Table 1**; **Figure 4**). With such a large amount of the American black duck habitat falling into high and medium levels of potential development, the species will likely be negatively impacted by future development.

The green salamander, cave salamander, and northern slimy salamander all had similar amounts of habitat that fell into each development favorability level. This is most likely due to their similar habitat requirements. The salamanders' habitats primarily fell into the low favorability classification, which means that the potential impact from future urban growth is minimal in the near future. This is likely due to their cave habitat lying in areas where development is likely not to occur. The Morefield's leather flower had the lowest amounts of area in any of the development favorability categories. The threat of impact on the American black duck habitat is the greatest of all species studied for this project with 0.19% of habitat at high suitability for development.

Species	Habitat in High (m^2)	Habitat in Medium (m^2)	Habitat in Low (m^2)	Total Habitat (m^2)
American Black Duck *Anas rubripes*	$1.7x10^6$ (0.19)	$1.0x10^6$ (0.11)	$6.0x10^6$ (0.69)	8.7×10^6
Green Salamander *Aneides geneus*	$6.2x10^4$ (0.01)	$3.0x10^5$ (0.04)	$7.4x10^6$ (0.95)	7.8×10^6
Morefield's Leather Flower *Clematis morefieldii*	$1.1x10^4$ (<0.01)	$4.9x10^4$ (0.03)	$1.7x10^6$ (0.97)	1.76×10^6
Northern Slimy Salamander *Plethodon alutinosus*	$6.2x10^4$ (0.01)	$3.0x10^5$ (0.04)	$7.4x10^6$ (0.95)	7.8×10^6
Cave Salamander *Eurycea Lucifuga*	$6.2x10^4$ (0.01)	$3.0x10^5$ (0.04)	$7.4x10^6$ (0.95)	7.8×10^6

Table 1: *An analysis of threat to species habitat due to increasing development*

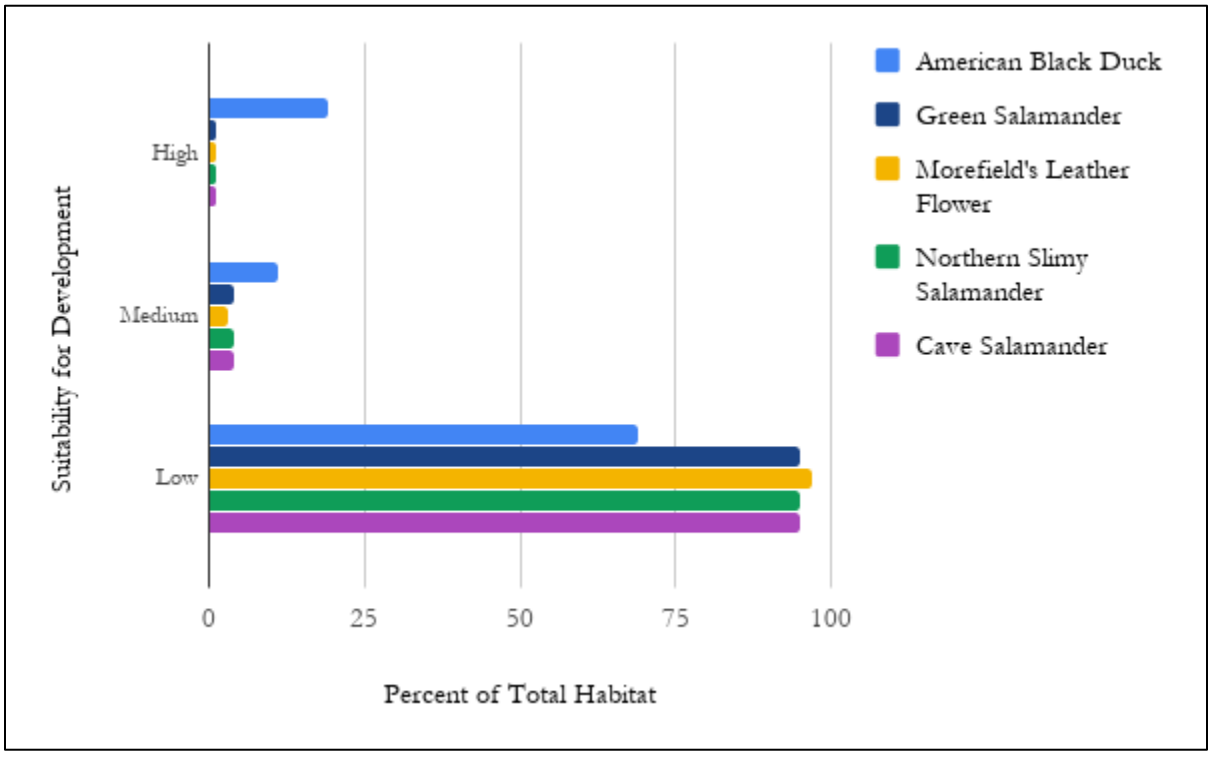

Figure 4: *Threat to species habitat due to suitability for urban development*

VI. Future Work

Incorporating a larger variety of species into the analysis would improve our understanding of the impacts of development. This project only assessed the impact of urbanization on selected species, but all species living in the areas facing development will be affected directly and indirectly. The species studied were chosen based on project partner interest and available data, but measuring the potential impact of urbanization on these few species may be misleading. If the impact is underestimated, further development could be extremely detrimental to species not included in this project. On the other hand, if the impact is overestimated, development may be impeded, resulting in lost profits for the county.

This study investigated urban development, but the transition of forest to agriculture is an important issue in North Alabama. Most of the endangered species in the study area are aquatic, such as clams, snails, and fish. Creating a hydrological model would more accurately portray the impact of urbanization on aquatic species. This model would provide a meaningful way to measure the estimated effects of potential runoff from new urban and agricultural development on aquatic species.

This project was designed around the Landsat series of satellites to gather a better understanding of the historical context of urbanization of north Alabama. Looking forward, this project could be conducted using Sentinel-2 data, with its higher spatial of 10 m to 60 m and 10 day return period.

VII. Conclusions

Habitat in Limestone and Madison counties is being replaced with urban and agricultural areas. Areas that are highly suitable for urban development are forecasted to be urbanized by 2045, with most of urbanization taking place in the areas located between Huntsville, Athens, and Decatur. Further agricultural development is expected to support these new urban areas. The American black duck, green salamander, Morefield's leather flower, northern slimy salamander, and cave salamander are all expected to be negatively impacted from increased urbanization. The species selected for this study were chosen based on partner interest and data availability. They include a large variety of species, somewhat representative of species native to north Alabama. Habitats for the American black duck that are negatively impacted by urbanization will also likely harm the habitats of other waterfowl species, such as the Whooping crane (*Grus americana*). Similar conclusions can be made for other salamander or plant species. The Land Trust of North Alabama works to conserve land and will be able to utilize the tool created during this project to help study the impact of urbanization on any potential species using location point data. The maps generated from this project, and future maps generated from the tool, will allow the Land Trust to educate local government officials and land owners on the potential negative impacts of urbanization on local species' habitats within Madison and Limestone counties. Ultimately, they will be able to identify areas where conservation efforts are needed.

VIII. Acknowledgments

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