Identification and Classification of Geographically Isolated Wetlands in North Alabama using Geographic Object Based Image Analysis (GeOBIA)

by

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Abstract

Due to recent Supreme Court rulings there has been an increased interest in the isolated wetlands of the United States. These types of wetlands while generally smaller in extent than traditional wetlands serve vital ecological roles such as water quality regulation and as a habitat of biological diversity. This thesis focuses specifically on mapping of geographically isolated wetlands, or those that are separated from traditional wetlands by a given spatial extent, using Geographic Object Based Image Analysis (GeOBIA). GeOBIA is a type of remote sensing analysis that identifies objects and features present within both raster and vector datasets via automated methodologies. This type of analysis offers the opportunity to greatly increase the efficiency of what has traditionally been a very labor intensive process of manual photo-interpretation. This analysis resulted in the delineation of 26,424 areas within the study area as geographically isolated wetlands. These results were assessed for accuracy through both manual inspection of aerial imagery and field verification which yielded accuracies of 83.7% and 87.7% respectively.

Acknowledgments

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CHAPTER 1

INTRODUCTION

1.1 Study background

The term wetland has different meanings given different contexts. Generally, a wetland is thought of as an area of land with soil that is saturated with water either permanently or seasonally (CFR Title 40, 2011). More specific characterizations are also applied to wetlands such as water salinity, vegetation types, soil composition, and proximity to large bodies of water. Until the 1970's the extent of the nation's wetlands was not known given that many scientists could not agree on a formal definition of the term (Peters, 1994). The National Wetlands Inventory (NWI) program was instituted by the United States Fish and Wildlife Service (FWS) in the mid 1970's to attempt to map wetlands for the first time (USFWS, 2013). In Alabama, a brief inspection of existing NWI data reveals that several portions of the state's analog maps have yet to be digitized, and also the majority of wetland mapping effort seems to have been placed on mapping coastal regions and large flowing bodies of water with less emphasis on isolated and ephemeral waters. Figure 1.1 is an example of NWI for a portion of Alabama showing substantial gaps in the dataset.

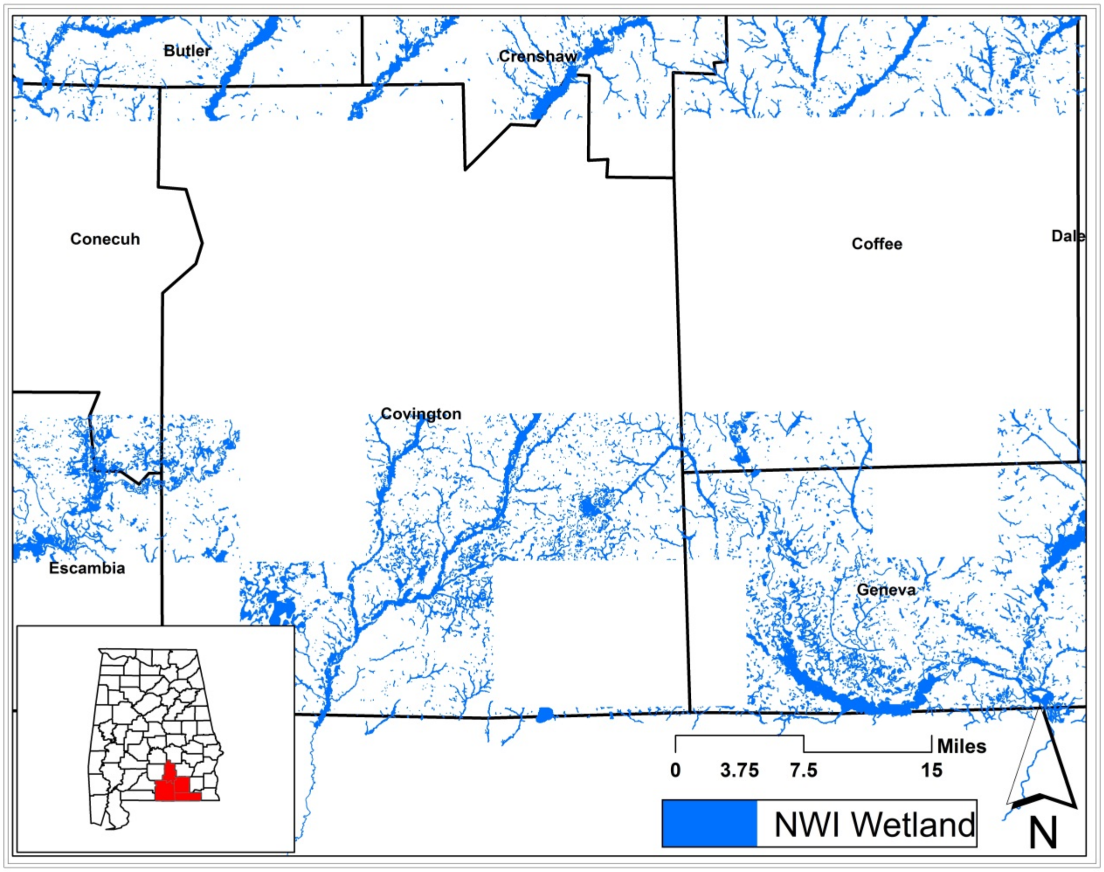

Figure 1.1 Example showing gaps in the current NWI digital database.

Although studies have been conducted for mapping wetlands using Geographic Information Systems (GIS), the current extent of the nation's isolated wetlands versus other wetlands remain largely unknown (Tiner, 2003a). Many problems exist when using a GIS model to map wetlands. The maps produced with GIS are dependent on secondary data sources that often do not line up. Also, these data sources tend to be static in time and may not be collected very often. For instance, the most current and comprehensive imagery dataset with the level of detail needed to map isolated wetlands is produced by the USDA for the National Agricultural Imagery Program (NAIP). NAIP can have a problem with canopy closure during the growing season which makes identification of wetlands difficult in those areas. In addition, some isolated wetlands are very small with shorelines that are ever changing from season to season. Since rainfall and other hydrologic factors change from year to year, the shape and size of these wetlands may vary throughout time.

Datasets collected with remote sensing methods have evolved greatly over the past several decades ranging from the launch of the Earth Resources Technology Satellite (later renamed Landsat) which had a spatial resolution of 80 meters to the widespread use of high resolution aerial photography which can have a spatial resolution of only a few inches. When performing analysis of digital imagery the smallest addressable image element is the pixel. This represents a single area in an image and high resolution imagery can contain many hundreds of thousands of pixels for a relatively small area. Pixel based analysis utilizes only a small portion of the information that we as humans use naturally in our visual cortex. There are new methods being developed in the Remote Sensing community that focus on grouping pixels together into image objects. Once this has been accomplished, the objects can then be analyzed in a way that more closely resembles the human visual experience, as well as increases efficiency (Lang, 2008). These methods are called Geographic Object Based Image Analysis (GeOBIA) and this thesis explores ways of utilizing GeOBIA to efficiently map wetlands.

1.2 Statement of the problem:

Isolated wetlands have started to garner increased interest in the past few years due to recent legislation (531 U.S. 159 (2001). This increased interest has recently led to studies enabling society to begin to understand their importance to local and regional ecological stability. In addition, the historic lack of uniformity in defining the term "isolated" has further compounded the issue (Tiner, 2003b).

In Alabama, a wetland study in an area of over 25,000 acres found that between 62-67 percent of the area's wetlands were geographically isolated (Tiner, 2003a). These findings indicate that a significant portion of the state's wetlands have the potential of being geographically isolated yet there has been no attempt at mapping the entire state. Establishing a baseline for the number of isolated wetlands would be helpful in creating a comprehensive wetland program plan that would in turn allow for mitigation of wetland loss. Historically, wetland mapping projects have been conducted using manual photointerpretation of aerial imagery by wetland experts (Peters, 1994). This process is both labor intensive and expensive which required national wetland mapping efforts like the NWI to require very large budgets to complete. Geographic Object Based Image Analysis (GeOBIA) automated methods are tested in this study as a potential alternative application for improving on the traditional methods of wetlands mapping with a focus on those that are considered geographically isolated. These methods coupled with the baseline information regarding isolated wetlands could then be repeated as more data became available allowing for the establishment of a comprehensive monitoring program.

1.3 Thesis Outline

Chapter1:

Introduction:

Study background

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Research Question Conclusions

Importance of Study and Future Work

1.4 Study area:

The study area consists of all lands of the state of Alabama that fall on or north of 34 degrees of latitude. This area either partially or completely covers 17 different counties and approximately one-quarter of the area of the state. This area of Alabama contains the lower Appalachian Plateau to the east that is characterized as hills, mountains, valleys, and plateaus with the west consisting mostly of limestone valleys and uplands. This area was selected primarily due to the researcher's familiarity with the area along with the expectation that open water areas of these wetlands would appear in sharp contrast to their surroundings. Also, time constraints for necessary fieldwork, completion of the M.S. degree, and defense of thesis required limiting the study area to only those lands north of the 34^{th} parallel while the larger project does seek to map the isolated wetlands of the entire state of Alabama.

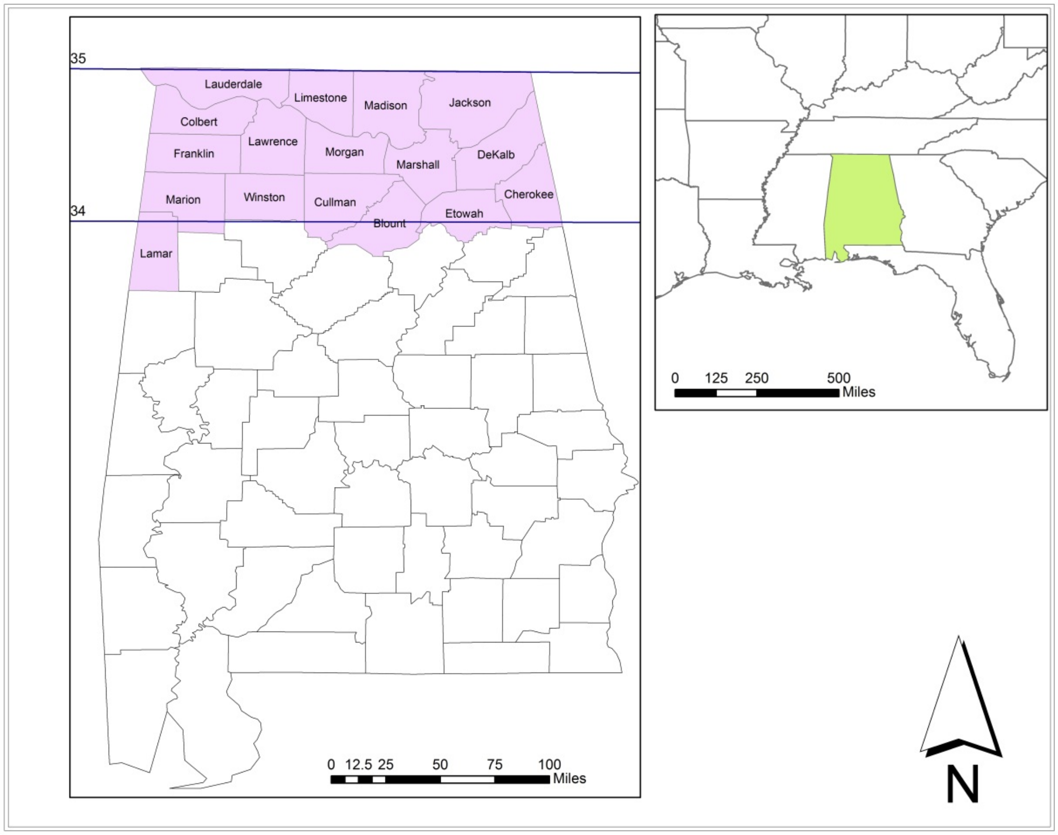


Figure 1.2 Map of the counties with area falling north of 34°

1.5 Significance of the study:

The Alabama Wetland Protection Plan identified a need to compile existing wetland inventory maps and location information. One of the most common sources of existing wetland maps is the U.S. Fish and Wildlife Service's National Wetlands Inventory (NWI) data (USFWS, 2013). Unfortunately, the dataset for Alabama is both incomplete and obsolete since it was produced with outdated imagery; some being over 30 years old. Due to rapid development in several areas of Alabama this dataset provides a poor overall account of the status and extent of the state's current wetlands. Since the major datasets used in this study are publicly available there exists the opportunity to create methodologies that can accurately map large areas using minimal manpower and costing less than traditional mapping projects. Furthermore, research has shown that isolated wetlands have the potential for representing a significant portion of the state's wetlands (Tiner, 2003a).

Given the recent rulings by the United States Supreme Court there lies the possibility that many of the wetlands identified as isolated in an ecological sense, such as is the focus of this study, may also be identified as isolated in a regulatory sense. The study provides resource managers with information on the extent and condition of these wetlands that will assist in decision-making processes. The study also provides further evidence of the benefits to using GeOBIA techniques for creating vector datasets using remotely sensed data.

1.6 Aim and objectives:

The aim of this study is to gather historical data and develop methods to identify, classify, and assess isolated wetlands which can be applied to the state of Alabama as well as other states with similar physiography. The study posits that Geographic Object Based Image Analysis coupled with GIS mapping techniques can be used to evaluate the extent of these isolated wetlands more efficiently than traditional wetland mapping methods. These specific tasks included:

- Compilation of existing wetland inventory maps and location information from available resources
- Models developed to delineate and classify isolated wetlands

- Use of Geographic Object Based Image Analysis (GeOBIA) along with ancillary data to quantify extent of isolated wetlands
- Reconnaissance of wetlands identified as isolated to verify location and accuracy

1.7 Research questions:

In this investigation the following research questions are posed:

- How are isolated wetlands defined for mapping utilizing Geographic Information Systems?
- Can we map isolated wetlands based on an expanded version of the Tiner methodology using Geographic Object Based Image Analysis with an accuracy that is acceptable to the user community?
- What are the key distinctions of isolated wetlands and can these distinctions be used to help determine factors important in the development of rulesets?
- What ancillary data provides the most useful help in developing models to aid in identifying and mapping isolated wetlands?
- What is the spatial extent of isolated wetlands within the study area?
- How much time is saved utilizing automated methods verses traditional photointerpretation methods?

1.8 Methodology:

In this study GeOBIA methods for identifying isolated wetlands in the northern part of the state of Alabama were developed. Several ancillary datasets were evaluated in order to determine which would be most useful in identifying wetlands. These datasets contain information relating to soil composition, historical rainfall, and historical floodplain extent. Imagery datasets of the study area include single meter resolution, 4-band imagery from the National Agriculture Imagery Program (NAIP). All data have been preprocessed before being analyzed using eCognition's Object Based Image Analysis software. This software allows for images to be segmented into smaller image objects and then assigned various classifications based on both raster and thematic ancillary data. Due to the volume of data required for the study area, the datasets were broken up by location and analyzed using batch processing routines. Most significantly, the parallel processing capabilities of eCognition Server were utilized for the ability to tile the datasets into smaller projects and export them using a meaningful naming scheme. These individual project tiles are projected and then renamed using a separate batch function before being merged and dissolved according to their spatial location using GIS Python scripts.

The geodatabase that is created contains all the areas identified during the GeOBIA process as wetlands. The geodatabase is then analyzed for each area's geographic isolation from traditional navigable waterways. To accomplish this, the National Hydrography Dataset (NHD) was used in conjunction with the Federal Emergency Management Agency's (FEMA) Digital Flood Rate Insurance Map (DFIRM) which contains the Special Flood Plain Hazard Areas (SFHA) more commonly known as the 100 year floodplain. The spatial extents of these two datasets when combined represent the area of non-isolation. Any identified wetlands that fall within this area of non-isolation will not be included in the final isolated wetlands dataset.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

A review of recent literature reveals much of the background information necessary for this thesis' research and analysis. It begins with the regulatory and legal background concerning wetlands in the United States with an emphasis on recent changes to the federal government's regulatory authority over isolated wetlands. This section also covers the new regulations implemented by the Environmental Protection Agency (EPA) in response to these changes in authority. The next section describes the ways in which wetlands have traditionally been mapped in the United States as well as describing the classification system that was implemented to organize the resulting dataset. The next section describes geographically isolated wetlands and the role they play in our environmental ecostabililty as well as some estimates of their spatial extent in Alabama. Next, a section describes the composition and function of hydric soils according to the Natural Resource Conservation Service (NRCS) and how they contribute to wetland delineation.

Another section describes the major types of digital soil data available today, the differences between them, and why this thesis includes it. Following that there is a discussion of traditional remote sensing techniques for mapping wetlands in the United

States and some of the historical limitations of this technology. Finally, there is a section which introduces the concept of Geographic Object Based Image Analysis (GeOBIA) as a new technique in the Remote Sensing subdiscipline of Geography.

2.2 Regulation:

In the United States areas defined as wetlands are regulated by the U.S. Army Corps of Engineers and the Environmental Protection Agency (EPA). Determining what defines a wetland and where the boundary between regulated and non-regulated land can be a hot button issue between federal agencies and private landowners. In the 2001 case of *Solid Waste Agency of Northern Cook County (SWANCC) vs. U.S. Army Corps of Engineers*, the U.S. Supreme Court issued a ruling on the requirement of permits for the discharge of dredged or fill materials into "navigable waters." SWANCC, a consortium of Chicago-area cities and villages, sought to develop a landfill for baled nonhazardous solid waste on a 533-acre parcel in Illinois. The parcel had been used for sand and gravel mining until about 1960. Since then, the excavation trenches from the mining had evolved into ponds ranging in size from a few feet across to several acres. SWANCC obtained the needed local and state permits, but the Corps denied a permit on the basis that the ponds were used by migratory birds. The Court held that the Corps of Engineers' use of the "migratory bird rule," adopted by the Corps and Environmental Protection Agency (EPA) to interpret the reach of their section 404 authority over discharges into "isolated waters" (including isolated wetlands), exceeded the authority granted by The Clean Water Act (531 U.S. 159 (2001). The "migratory bird rule" asserted that the Clean Water Act covers federal regulation of isolated waters "which are or would be used as habitat by... migratory birds that cross state lines" (33 U.S.C. § 1251). In a majority opinion the Court stated:

> In order to rule for [the Corps], we would have to hold that the jurisdiction of the Corps extends to ponds that are not adjacent to open water. But we conclude that the text of the statute will not allow this. (33 U.S.C. § 1251)

Later, in the 2006 case of *Rapanos v. United States,* the court issued rulings that voided fines against a real estate developer who filled 22 acres of wetlands with sand in order to build shopping malls and condos. He argued that the land was not a wetland and that he was not breaking the law because the land was up to 20 miles away from any navigable waterway (547 U.S. 715 (2006). In its ruling, the Court remanded the case to the Sixth Circuit Court of Appeals for reconsideration, but only four of the justices agreed with the underlying reasoning for such a ruling. This is referred to as a “plurality opinion,” which lacks authority as a precedent. In this case the lower courts are left to decide whether to follow the plurality opinion, or consider the opinion of the fifth judge as controlling. In the Court’s plurality opinion the term "waters of the United States," "includes only those relatively permanent, standing or continuously flowing bodies of water 'forming geographic features' that are described in ordinary parlance as 'streams, oceans, rivers, and lakes'.” Justice Kennedy agreed that the case should be remanded, but ruled that the lower courts should apply a “significant nexus” test. Wherein wetlands would be “waters of the United States” “if the wetlands, either alone or in combination with similarly situated lands in the region, significantly affect the chemical, physical, and biological integrity of their covered waters more readily understood as “navigable.” When, in contrast, wetlands affects on water quality are speculative or insubstantial, they fall outside the zone fairly encompassed by the statutory term “navigable waters”. The next year the Eleventh Circuit Court of Appeals ruled that Justice Kennedy's "significant nexus" test should be the sole method for determining federal jurisdiction (129 S.Ct. 627 (2008). After the Supreme Court denied an attempt at an appeal via writ of certiorari the Eleventh Circuit's ruling was effectively endorsed.

To summarize, wetlands can now be considered to fall into one of three categories relative to the Clean Water Act: 1) wetlands that fall under federal jurisdiction due to their adjacency to navigable waters or abut relatively permanent tributaries of those waters; 2) wetlands that might fall under federal jurisdiction, providing there is a finding of "significant nexus" between that wetland and a traditionally navigable waterway; and 3) wetlands that are not jurisdictional because no "significant nexus" can be established. This means that all wetlands not "readily understood as "navigable" must be given site specific inspection of "significant nexus" in order to determine jurisdiction.

In 2007 (and updated in 2008) the EPA issued a guidance memorandum to all its regional offices addressing the recent rulings (EPA, 2008). The document describes first that the agencies will assert jurisdiction over the following waters:

- Traditional navigable waters
- Wetlands adjacent to traditional navigable waters
- Non-navigable tributaries of traditional navigable waters that are relatively permanent where the tributaries typically flow year-round or have continuous flow at least seasonally (e.g., typically three months)
- Wetlands that directly abut such tributaries

It then goes on to describe that agencies will decide jurisdiction over the following waters based on a fact-specific analysis to determine whether they have a significant nexus with a traditional navigable water:

- Non-navigable tributaries that are not relatively permanent
- Wetlands adjacent to non-navigable tributaries that are not relatively permanent
- Wetlands adjacent to but that do not directly abut a relatively permanent non-navigable tributary

Specifically, the agencies will not assert jurisdiction over the following features:

- Swales or erosional features (e.g., gullies, small washes characterized by low volume, infrequent, or short duration flow)
- Ditches (including roadside ditches) draining only uplands that do not carry a relatively permanent flow of water

The agencies will apply the significant nexus standard as follows:

- A significant nexus analysis will assess the flow characteristics and functions of the tributary itself and the functions performed by all wetlands adjacent to the tributary to determine if they significantly affect the chemical, physical and biological integrity of downstream traditional navigable waters
- Significant nexus includes consideration of hydrologic and ecologic factors

In this memorandum various wetlands are defined based on their physical descriptions. Traditional navigable waters are defined as:

- Waters defined as navigable under section 9 or 10 of the Rivers and Harbors Act
- Waters determined by a federal court to be navigable-in-fact
- Waters currently being used for commercial navigation, which includes commercial water recreation such as chartered fishing

Wetlands can be considered adjacent wetlands if they satisfy any one of the following:

- An unbroken surface or shallow subsurface connection, which may be intermittent, to a jurisdictional water body
- A physical separation from jurisdictional water consisting only of man-made dikes or barriers, natural river berms, beach dunes, etc.
- Reasonable proximity supporting a science-based inference of ecological interconnection

The term adjacent is defined as meaning “bordering, contiguous, or neighboring.” Wetlands separated from other waters of the United States by man-made dikes or barriers, natural river berms, beach dunes and the like are “adjacent wetland.” A non-navigable tributary is also explicitly defined as a non-navigable water body “whose waters flow into a traditional navigable water either directly or indirectly by means of other tributaries.” Also, non-navigable waterways usually flow year round with the exception of drought and the EPA will not apply a significant nexus test on those waters meeting this criteria.

In applying Justice Kennedy’s significant nexus test the EPA states that:

- The agencies will assert jurisdiction over non-navigable, not relatively permanent tributaries and their adjacent wetlands where such tributaries and wetlands have a significant nexus to traditional navigable water.
- A significant nexus analysis will assess the flow characteristics and functions of the tributary itself and the functions performed by any wetlands adjacent to the tributary to determine if they significantly affect the chemical, physical and biological integrity of downstream traditional navigable waters.
- "Similarly situated" wetlands include all wetlands adjacent to the same tributary. Significant nexus includes consideration of hydrologic factors including the following:
    - Volume, duration, and frequency of flow, including consideration of certain physical characteristics of the tributary
    - Proximity to the traditional navigable water size of the watershed
    - Average annual rainfall
    - Average annual winter snow pack

Significant nexus also includes consideration of ecologic factors including the following:

- Potential of tributaries to carry pollutants and flood waters to traditional navigable waters
- Provision of aquatic habitat that supports a traditional navigable water potential of wetlands to trap and filter pollutants or store flood waters maintenance of water quality in traditional navigable waters

2.3 Mapping of Wetlands

There have been many attempts at mapping U.S. wetlands over the past few decades. One of the first attempts occurred when the United States Fish & Wildlife Service (FWS) conducted an inventory in an attempt to map all wetland habitats considered to be important to waterfowl (Shaw and Fredine, 1956). This inventory was conducted first by each state's fieldsmen identifying areas of the state most likely to contain a high percentage of wetlands important to waterfowl. Once these areas were identified, a field sampling of these locations was performed to determine the wetland type and extent. These figures were then extrapolated to include areas not sampled. These findings were known as Circular 39 and were published in a book titled "Wetlands of the United States." While not extremely comprehensive these results did serve as a starting point for inventorying the nation's wetlands. Wetlands were then, as they are now, undergoing changes from both natural and man-made influences which over time caused this already non-comprehensive dataset's usefulness to diminish. In response to Circular 39's limitations the National Wetlands Inventory (NWI) project was created in 1974 with the expressed purpose to: (1) produce maps of the characteristics and extent of the Nation's wetlands; (2) construct the national digital wetlands database; (3) disseminate NWI and other wetland products; (4) summarize the results of the inventory; (5) assess the status and trends of the Nation's wetlands.

The NWI's wetland classification system (Figures 2.1 and 2.2) was titled "Classification of Wetlands and Deepwater Habitats of the United States" and was developed by wetland ecologists with assistance from local, state, and federal agencies (Cowardin et al., 1979). The author of this thesis enrolled in the Advanced Wetland Photo/Imagery Interpretation Workshop by the United States Geological Survey (USGS) in Lafayette, Louisiana in order to become familiar with the Cowardin Classification System. During this multi-day course numerous wetland delineations were conducted in the presence of instructors. These delineation maps were later verified by students and instructors using boats to access the remote areas. Each participant was then tested by instructors before receiving documentation verifying that they had passed the course.

The Cowardin Classification System groups together ecologically similar wetlands using a hierarchical framework. The top level is the broadest with five major systems: marine, estuarine, riverine, lacustrine, and palustrine. Each system is divided into subsystems that reflect their hydrological conditions. These subsystems are further divided into subclasses that reflect an area's physical structure. Also included are modifiers which allow for further description of water chemistry, hydrology, and even special modifiers like whether a wetland is impounded or partially drained (Cowardin et al., 1979).

The NWI project sought to establish a method for delineating wetlands using available imagery and expert photointerpretation coupled with necessary field checking. At the time there were two commonly used sources of imagery in the United States. These were the LANDSAT Multi-Spectral Scanner and the aerial photography produced by federal agencies. It was decided that aerial photography would give interpreters the best chance of properly delineating these areas (Wilen and Pywell, 1992). Early in the project, the 1:80,000 scale black and white photography acquired by the United States Geological Survey (USGS), gave the best overall coverage for large portions of the country. These were later replaced by the 1:58,000 scale color infrared images collected during the operation of the USGS National High Altitude Photography Program (NHAPP). This type of imagery was replaced in 1987 by the 1:40,000 scale color infrared imagery of the National Aerial Photography Program (NAPP).

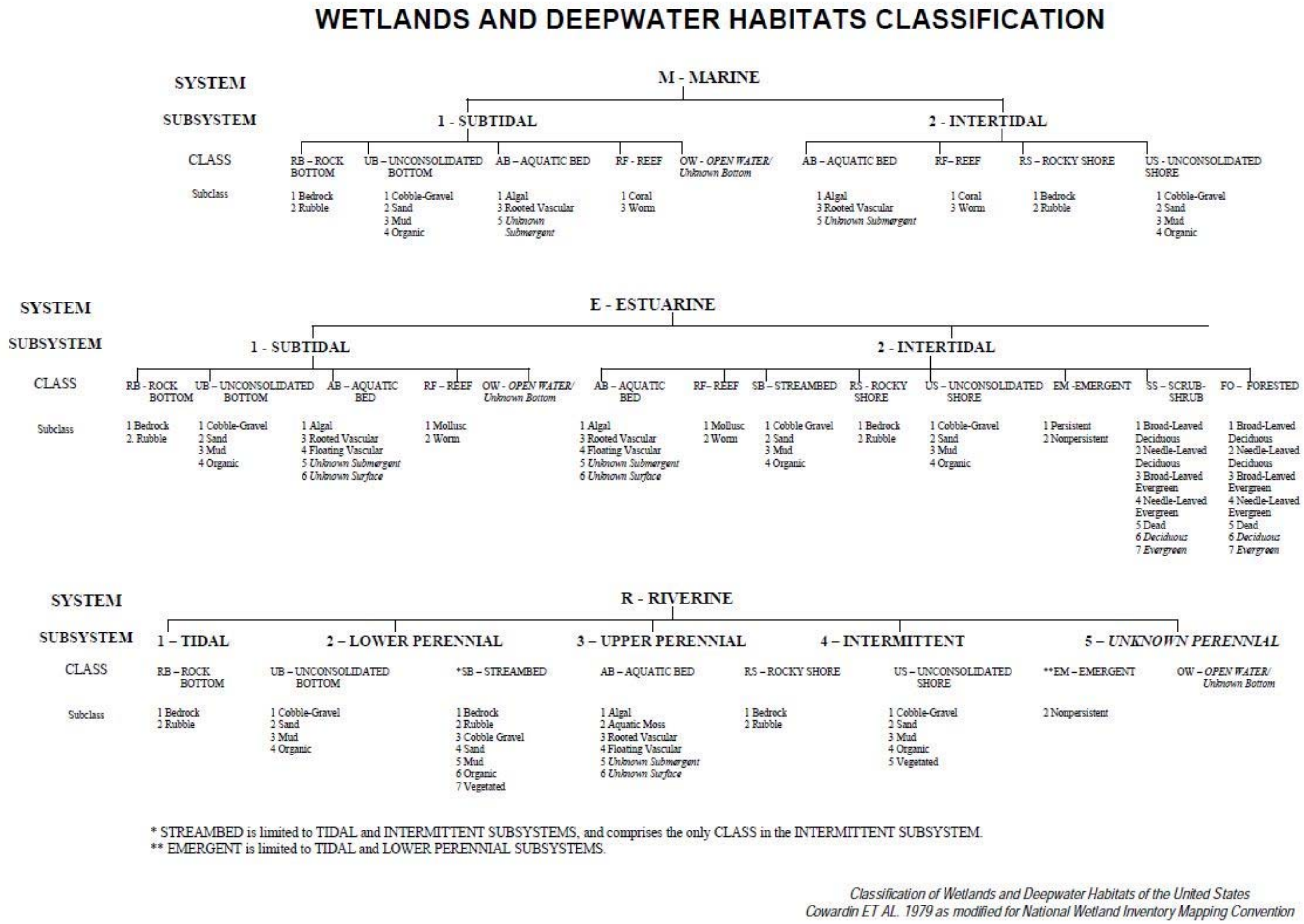


Figure 2.1 Flowchart of the Cowardin Classification System

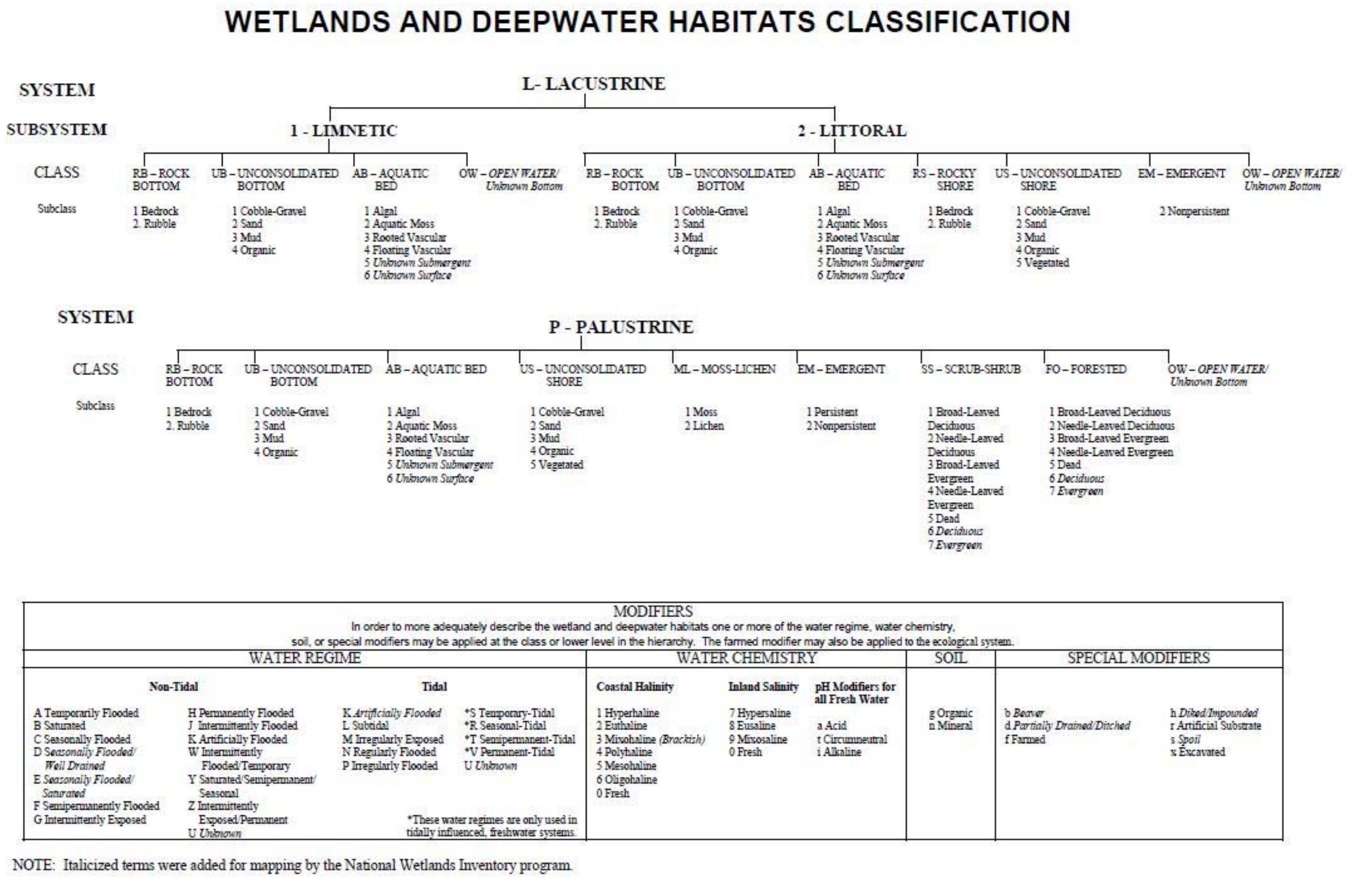


Figure 2.2 Flowchart of the Cowardin Classification System

The primary product of the NWI program was the 1:24,000 scale maps showing all delineated wetlands and their corresponding Cowardin Classification System code. The one exception to this was the state of Alaska whose wetland maps were primarily 1: 63,360 scale (Peters, 1991).

The NWI mapping procedures consist of seven major steps. First, a review of aerial photography and collateral data to become familiar with the area was done. Sites for possible field checking were identified with a focus on problematic areas. Second, researchers conducted a field review of the study area. The length and detail of this review was dictated by the complexity and density of the wetlands that were present. While field checking is usually done by ground vehicle, helicopters were commonly used in the state of Alaska. Throughout the project it was discovered that private ownership often limited access to field sites.

Third, stereoscopic interpretation of the aerial photography was performed with wetland boundaries delineated on photo overlays by means of using at least 4X magnification (USFWS, 1990a). Collateral information sources (e.g., soil surveys, USGS maps, navigation charts, local inventories, and previous wetland maps) were used where available. Occasionally, follow-up field work was necessary to resolve problems encountered during this phase. Fourth, quality control measures were assessed for the delineated wetland areas. A photo interpretation team leader ensured that delineations were as accurate as possible. Regional quality control brought local expertise into the review process. National quality control ensured that wetlands were classified similarly throughout the United States.

The fifth step in the process involved the preparation of local-scale draft wetland maps. NWI cartographic conventions were used to ensure consistency in wetland map codes and linework (USFWS, 1990b). The sixth step was the field verification of draft wetland maps. These maps were provided to local, state, and/or federal agencies' staffs for review based on their familiarity with wetland resources in the mapping area.

The seventh and final step in this process was the production of the final NWI wetland maps in analog format. These maps received final quality control for labeling and linework before being distributed to field offices across the country. This entire process took between 2 to 3 years (Hefner and Storrs, 1995). For the majority of the United States the aerial photography used for the project was flown in the mid 1980's (Peters, 1991). This means that two decades worth of change could have occurred since the original maps were produced leading some to speculate the dataset is outdated (Tiner, 2003a). New mapping efforts using modern GIS and remote sensing technology could possibly provide a way to produce wetland maps with similar accuracies as the photointerpretation maps of the 1980's, but at a fraction of the cost.

The classification system that was used to produce the NWI was based solely on the physical appearance and structure of a wetland (Cowardin et al., 1979). While classifications exist for describing a wetland's interconnectivity with other wetlands these were mostly limited to the marine, estuarine, and riverine systems in the final dataset. Palustrine and lacustrine systems, which are found inland from coastal areas, have special modifiers for their water regime but do not have classifications describing their geographic position relative to other wetlands and waterways. This is important because given the recent court rulings discussed earlier there is an increased interest in identifying a wetland's relationship with other wetlands that the existing NWI dataset cannot satisfy.

2.4 Geographically Isolated Wetlands:

With the SWANCC and Rapanos decisions, a sudden surge in interest emerged in identifying isolated wetlands due to the possibility of them falling outside of federal regulation. However, isolation can be viewed in different ways and based on different criteria. For instance, they can be viewed in a statutory sense which is controlled by recent legislation and court decisions. This position can shift greatly in a short period of time due to regulatory changes or a shift in court interpretation. However, isolated wetlands can also be viewed using purely scientific criteria which tend to vary little over time.

The term isolated can be most easily defined as a wetland or water body without a downstream surface outlet. These wetlands form in depressions and are isolated from traditional waters due to the higher elevation of the surrounding land (Leibowitz, 2003; Tiner, 2003a). However, more in depth definitions of this term require examining a wetland's ecological and hydrological interactions more closely. The simplest example of an isolated wetland is one that is not hydrologically connected to other wetlands or waterbodies. Wetlands with no surface connection to other waters can still interact via groundwater connections (Winter and LaBaugh, 2003). These interactions, however, depend upon the geological structure of the particular setting (Sutter and Kral, 1994). It should also be noted that intermittent surface water connections typically occur among isolated wetlands during flood stages. Leibowitz and Vining (2003) observed that 28 percent of the wetlands within an area of North Dakota experienced intermittent surface water connection during the high water stage. This has prompted some to define isolated wetlands as "depressions wetlands that under average surface-water levels are not connected to other aquatic habitats by surface waters" (Snodgrass et al., 1996).

The National Research Council defined isolated wetlands as “a wetland not adjacent to another body of water” (NRC, 1995). Others defined them as “highly disjunct” (Godt et al., 1995) or as “rare and highly dispersed habitats” (Pearson, 1994). Ralph Tiner’s use of the term “geographically isolated” limits the scope of these wetlands to those “that are completely surrounded by upland (e.g., hydrophytic plant communities surrounded by terrestrial plant communities or undrained hydric soils surrounded by nonhydric soils)” (Tiner, 2003a). In general, geographic isolation is the easiest to define since it describes the position of a wetland on the landscape and is the criteria most widely used for this reason (Tiner, 2003b). Since the definition used here is not a regulatory one, some of these types of wetlands may fall outside of the jurisdiction of the Clean Water Act (CWA) of 1972 and its subsequent amendments (Tiner, 2003b; FWPCA, 1972).

Geographically isolated wetlands serve similar roles to non-isolated wetlands in terms of function and benefit. There have been numerous studies examining the water quality (Dunson et al., 1997; Neely and Baker, 1989; Moore and Larson, 1979) and hydrologic function (Winter, 1989; Zedler, 1987; Stichling and Blackwell, 1957) of isolated wetlands. By definition isolated wetlands are cutoff from the local surface water system; therefore the water that collects in them must return to the atmosphere by evapotranspiration or enter the ground-water system (Leibowitz, 2003). Some may contain underlying layers of impervious soils which prevent penetration into the ground-water system and in these areas evapotranspiration would be expected to dominate. Conversely, wetlands located on highly permeable soils can expect the majority of their water losses to come through ground-water loss (Bolen et al., 1989).

Water quality for these wetlands could differ greatly from that of traditional riverine systems. These isolated wetlands would focus water from a large watershed into several depressions rather than funneling the runoff into a river or stream. This would mean that on average isolated wetlands would have smaller pollutant and nutrient loading when compared to riverine wetlands (Leibowitz, 2003). This is, however, a generalization and it should be noted that the geochemistry and water-quality function of each wetland can be highly variable due to climatic and geologic settings (Leibowitz, 2003).

Isolated wetlands serve a number of other environmental functions such as: surface-water storage, flood water protection, nutrient transformation, water quality maintenance, aquatic productivity, shoreline stabilization, and wildlife habitat (Tiner, 2003a). Low lying areas are better served by the numerous upstream depressional wetlands that serve as storage for precipitation. This storage capacity prevents the runoff from being directly introduced into regional riverine systems that can cause local or regional flooding (Neely and Baker, 1989). One study found that the Devil's Lake Basin of North Dakota's pothole wetlands have the ability to store 72% of total runoff due to a 2-year frequency storm and 41% total runoff due to a 100-year storm (Ludden et al., 1983). This storage capacity can also facilitate these wetlands contribution to the stream flow maintenance and groundwater recharge of a system. Other benefits include creating habitat for waterfowl and native fish and serving as water sources for domestic livestock, and humans (Tiner, 2003a).

The slow nature of release of these wetland's stored water into regional aquifers translates into a dependable input that many natural systems appear to rely on (Stone and Lindley Stone, 1994). In these cases the majority of input appears to occur during periods of high rainfall when the high water reaches more permeable adjacent soils.

Historical loss of isolated wetlands is difficult to quantify due to a lack of specific information such as The National Wetlands Inventory (NWI) which does not list isolated wetlands as a type (Cowardin et al., 1979, Tiner 2003a). Without baseline supporting data resource managers must rely on general wetland trends and the best professional judgment of experts to assess trends in wetland loss.

For instance, a study of the Carolina Bays of South Carolina estimate that 97% of isolated wetlands have been disturbed (Bennett and Nelson, 1991). Another study focused on playa lakes of the southern Great Plains and found that the majority were experiencing sedimentation from agriculture (Haukos and Smith, 2003; Haukos and Smith, 1994). In southern California there are estimates that as much as 97% of vernal pool habitat has been lost (King, 1998).

Another example of isolated wetland loss includes the Prairie Pothole Region states of Iowa, Minnesota, Montana, North Dakota, and South Dakota where half of these wetland types have been lost between the 1780s and 1980s (Dahl, 1990; Leibowitz, 2003). Most of this loss has come as the result of agricultural drainage (Tiner, 1984; Galatowitsch and van der Valk, 1994). Because these wetlands are generally smaller than more expansive traditional wetlands it may be thought that the ecological impact of their loss will be of less significance, but this is not the case since it can be shown that ecological importance is not proportional to a wetland's size (Naugle et al., 2000; Semlitsch and Bodie, 1998; Robinson, 1995; Gibbs, 1993).

For all of these reasons there is a great ecological need in establishing the extent of Alabama's isolated wetlands. While local geography can have a great impact on the number of isolated wetlands there is reason to believe that they represent a large percentage of the number of Alabama's wetlands. In a study of 72 sites throughout 44 states nearly 70% of the sites had over 50% of their wetlands designated as geographically isolated; nine of them had over 90% of their wetlands classified as geographically isolated (Tiner, 2003a). The lone area of study in

Alabama occurred near the city of Trinity in Morgan County. In this area the number of wetlands that were classified as isolated accounted for over 60% of all wetlands (Tiner, 2003a).

2.5 Hydric Soils

Many factors are used to determine wetland location and extent, but one of the leading factors is the presence of hydric soils (USACE, 1987). Since a soil's characteristics are not given to seasonal variation like hydrophytic vegetation canopy structure using the presence hydric soils to identify wetlands can be very useful. The jointly recognized methodology and characteristic requirements of the Natural Resources Conservation Service (NRCS) and the Environmental Protection Agency (EPA) for identifying hydric soils are found in the United States Army Corps of Engineers Wetland Delineation Manual in accordance with section 404 of the Clean Water Act.

Soil characteristics play a large role in both the function of a wetland as well as its classification. A hydric soil is defined as "a soil that formed under conditions of saturation, flooding or ponding long enough during the growing season to develop an anaerobic condition that supports the growth and regeneration of hydrophytic vegetation" (7 CFR 12.2). These anaerobic conditions cause hydric soils to experience accumulation or loss of many compounds which makes their identification easier and more scientific.

Within the anaerobic environment of hydric soils, microbes reduce iron from the ferric (Fe^{3+}) to the ferrous (Fe^{2+}) form and manganese from the manganic (Mn^{4+}) to the manganous (Mn^{2+}) form (NRCS, 2010). Areas where this has occurred can experience iron depletions where the insoluble ferric iron, being reduced to soluble ferrous iron, enters the soil solution and is translocated to other areas of the soil. This causes the soil to appear gray or reddish gray and is known as redox depletion. The areas where the ferrous iron is deposited may experience aerobic conditions later which cause the iron in the solution to oxidize in what are known as redox concentrations. This is the most common indicator of a hydric soil, but this phenomenon cannot occur in soils with parent materials low in iron or manganese (NRCS, 2010).

Another indicator of hydric soils is those that may experience sulfur reduction where microbes convert sulfates like SO_4^{2-} into H_2S or hydrogen sulfide. When this occurs in an area whose soil is saturated for extended periods of time a pungent “rotten egg” odor can be detected (NRCS, 2010). Also, these soils experience organic matter buildup due to the reduced speed at which soil microbes consume carbon when exposed to anaerobic conditions compared to aerobic conditions (Megonigal et al., 1996). These soils tend to have a thick peat layer of organic rich material in surface layer horizons.

Difficulties occur, however, in classifying hydric soils due to factors like: soils with black, gray or red parent material, soils with high pH, soils that are low in organic matter, recently developed hydric soils, and soils that are high in iron input (NRCS, 2010). The list of indicators in the soil survey handbook for the NRCS are mostly suited for delineating soils along the margins of hydric soils where anaerobic and aerobic conditions tend to alternate.

Information regarding the location and spatial extent of hydric soils is gathered though soil surveys carried out by the NRCS. These surveys compile data about soil characteristics such as color and drainage regime as well as examinations of basic chemical composition. Most of these data were collected by the National Cooperative Soil Survey by expert soil scientists who walked the land and observed the soil taking laboratory samples when needed (NRCS, 2013).

This information created the two most widely used datasets today which are the State Soil Geographic (STATSGO) database and the Soil Survey Geographic (SSURGO) database. The primary difference between the two is that STATSGO is a less detailed dataset that is derived and generalized from more detailed datasets for the purpose of “regional, multistate, river basin, state and multicounty resource planning, management, and monitoring”. STATSGO data are not detailed enough to make interpretations at a county level. (USDA, 2007). SSURGO data are much more detailed and are intended to provide information at the landowner level.

2.6 Remote Sensing Image Analysis for Wetlands Mapping

Image analysis includes the extraction of meaningful information from an image. For decades the only way of obtaining detailed geoinformation for wetlands mapping relied upon aerial photography and manual visual inspection (Lang, 2008). Standard raster images are collected by optical sensors and produce a matrix of pixels for a user’s mind to interpret. For each of these pixels, a corresponding wavelength along the electromagnetic spectrum is recorded as a Digital Number (DN), also commonly referred to as a Brightness Value (BV). For wavelengths that fall within the human visual spectrum the pixel is a direct interpretation of what was captured by the sensor. For wavelengths that fall outside of the visible spectrum the pixel must be reprojected into a color that the interpreter can visually observe by the image processing software. Common forms of this are images captured in the near infrared spectrum and displayed as False Color Composites (FCC) for improved mapping of vegetation.

Traditionally, remote sensing has utilized pixel based methods of classification which relied on pixel BVs from multiple bands of the electromagnetic spectrum to determine a pixels classification. This tends to produce reasonably acceptable results while using relatively coarse imagery (e.g. Landsat), but has not been as successful when dealing with the rich information of high resolution data such as sub-meter aerial photography (Oruc, 2004). Also, with the rapid increase in availability of large, high resolution data it has become more necessary to establish automated methodologies to better deal with processing (Hay and Castilla, 2006).

2.7 Geographic Object Based Image Analysis (GeOBIA)

Image analysis automation began with pixel level interpretation in order to assign each pixel to a particular class. Two widely-used methods are known as supervised and unsupervised classification. Each is distinct in its classification process, but they share the same basic premise which was the analysis had to be performed at the pixel level. With the increasing spatial resolution of aerial imagery this caused classification problems from the increasingly small pixels being too complex for simple pixel classifiers to handle (Baatz and Schape, 2000). In GeOBIA, this limitation is overcome by grouping pixels together into increasingly larger image primitives until meaningful image objects are created using parameters assigned by the user (Stow et al., 2008; Myint et al., 2008). Specifically, the multiresolutional segmentation algorithm, which has become the most widely recognizable aspect of eCognition’s software, groups pixels together that appear to be a single meaningful object using the Fractal Net Evolution Approach (Baatz & Schape, 2000). The exact nature of the multiresolutional segmentation algorithm, however, is proprietary information of the Definiens Corporation and their parent company Trimble Navigation, but its success has brought eCognition and GeOBIA to the forefront in the remote sensing community.

This approach to image feature extraction incorporates analysis of heterogeneity similar to human visual perception according to the gestalt principles (Lang, 2008). Among other things, these principles attempt to describe the way humans create conceptual boundaries around areas of perceived pattern also known as the “Orchard problem” wherein the patterns of evenly spaced trees are detected and the entire orchard is regarded as a single object (Lang, 2008).

The three key parameters utilized are compactness, shape, and scale. Shape and compactness are assigned a value between 0 and 1 which can then be applied at different scales (Myint et al., 2006). Assigning a higher number to the scale parameter will generate larger and more homogeneous objects while lower numbers assigned in the scale parameter will produce smaller and more detailed objects. These parameters can also be weighted to individual bands for increased accuracy and flexibility (Definiens, 2008).

Utilizing segmentation effectively shifts the basic unit of the classification process from pixels to objects. This allows for analysis beyond spectral reflectance to include linearity, texture, as well as contextual relationships to other image objects (Corcoran and Winstanley, 2008). GeOBIA also opens up the possibility for creating methodologies that could replicate or exceed human interpretation of remotely sensed imagery in an automated fashion (Hay and Castilla, 2008). The result of which would mean more repeatable methods with reduced subjectivity and labor time costs. Classification within eCognition offers two distinct options in assigning segmented objects into classes: Membership Function and the Nearest Neighbor Classifier. Membership Function relies on user defined constraints consisting of intervals to which a particular class’ features must fall to determine classification. This type of classification relies on the user’s expert knowledge of the characteristics of each class (Myint et al., 2011). Nearest Neighbor Classifier uses sample areas or training sites to “teach” the classifier algorithm the characteristics of a particular class (Myint et al., 2011; Definiens, 2008). The user will continue to select appropriate training sites until an acceptable classification has been achieved.

The two options within the Nearest Neighbor Classifier also allow for either the program to automatically use mean values for all object features or the user can limit the scope of classification to specific object features (e.g., size, shape, texture) (Myint et al., 2011).

Some drawbacks to GeOBIA include that the use of high resolution imagery in modern remote sensing has created very large datasets that require the use of many processors as well as efficient/complex tiling solutions. There are several object based platforms capable of performing these algorithms, however, in order to provide such flexibility and functionality the software tends to be complicated and currently has a steep learning curve that requires substantial time. Also, given that GeOBIA is a relatively new and quickly changing method of analysis there are discrepancies in terminology to describe image objects as either primitives or actual objects depending on their level of meaningfulness (Hay and Castilla, 2008; Corcoran and Winstanley, 2008). Even the name of this type of analysis has been a source of debate with some preferring the term GeOBIA (Geographic Object Based Image Analysis) compared to OBIA (Object Based Image Analysis) in order to create a distinction between spatial analysis in traditional remote sensing versus medical imaging technologies (Hay and Castilla, 2008).

There have been few attempts at mapping isolated wetlands using GeOBIA currently, but those that have taken place have shown some promising results. One study conducted in the St. Johns River Water Management District of Alachua County, Florida attempted to map isolated wetlands at a minimum spatial extent of 0.5 acres using Landsat-7 imagery with a spatial resolution of 30 meters. Since satellite data are available for a given area several times a month the researchers were able to select the scene with the greatest amount of water present which allowed them to reach an accuracy of 88% (Frohn et al., 2009). This thesis seeks to identify isolated wetlands at a spatial extent 80% smaller than that of the Frohn study using imagery thirty times higher in spatial resolution.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This thesis focuses on the mapping of geographically isolated wetlands in north Alabama using Geographic Object Based Image Analysis (GeOBIA). Recent changes in wetland regulation have brought increased interest in determining the spatial extent of geographically isolated wetlands due to their possible loss of federal protection. The first section of this chapter describes the various data that were acquired, compiled, and used for analysis. Also discussed are the various geospatial methods tested to delineate and classify these isolated wetlands using GeOBIA automated algorithms in conjunction with traditional GIS analysis. Finally, this chapter discusses how accuracy was determined using manual inspection in conjunction with field verification.

3.2 Data:

3.2.1 NAIP Imagery

The National Agriculture Imagery Program (NAIP) is funded by the United States Department of Agriculture's (USDA) Farm Service Agency (FSA) through the Aerial Photography Field Office (APFO). This program's primary objective is to acquire digital aerial photography during the agricultural growing season of the continental United States. Beginning in 2003 the imagery was collected on a 5 year cycle but this was changed to a 3 year cycle beginning in 2009 (USDA, 2011). NAIP imagery has a spatial resolution of one meter and a horizontal accuracy of six meters as determined by photo-identifiable ground control points which are used during image inspection. The spectral information includes the natural color bands of red, green, and blue and the dataset also includes an additional band at the near infrared (NIR) spectrum which is highly useful for extracting water bodies from imagery. The imagery is organized and distributed using the existing United States Geological Survey (USGS) 7.5 minute topographic quadrangles grid system. Each NAIP digital image corresponds to one quarter quadrangle or 3.75x3.75 minute with a 300 meter buffer on all sides. These tiles are projected in the Universal Transverse Mercator (UTM) coordinate system using the North American Datum (NAD) of 1983 (USDA, 2011; Campbell, 2002). These data are utilized for the GeOBIA process to segment the imagery into wetland polygons for the inventory.

3.2.2 Soil Survey Geographic Dataset (SSURGO)

Soil composition was determined using the Soil Survey Geographic (SSURGO) Dataset, specifically those soils defined as being fully hydric and therefore very likely to contain wetlands. The basic definition of a hydric soil is any soil that is sufficiently wet in the upper part to develop anaerobic conditions during the growing season (NRCS, 2012) SSURGO soil surveys are performed by the Natural Resource Conservation Service's (NRCS) National Geospatial Management Center (NGMC) and is made available to the public through the United States Department of Agriculture's (USDA) Geospatial Data Gateway (USDA, 2013). Soil surveys identify soil types based on many factors including parent material, climate, vegetative zones, and local topography. Chemical and physical data are obtained from horizon samples analyzed in a laboratory to determine exact physical characteristics such as color, texture, and pH (USDA, 2012). The hydric soils data layer is used to delineate wetlands in conjunction with those identified using the GeOBIA automated algorithms.

3.2.3 FEMA DFIRM

Floodwater extent is assessed using floodplain data from the Federal Emergency Management Agency's (FEMA) Digital Flood Rate Insurance Map (DFIRM). These data are created through hydraulic and hydrological floodplain insurance studies (FIS) that are mandated in the National Flood Disaster Protection Act of 1973. The DFIRM shows the spatial extent of Special Flood Hazard Areas (SFHA). SFHAs are areas that have a one percent chance of inundation by floodwaters on any given year and are sometimes known as one hundred year floodplains. These types of floodplains are the national standard for which floodplain data and insurance requirements of the National Flood Insurance Program (NFIP) are based. These floodplain data are used in determining geographic isolation by using a 40-meter buffer analysis of both the floodplain and the existing waterbody information within the National Hydrography Dataset (NHD).

3.2.4 National Hydrography Dataset

The current extents of known waterways are gathered from the National Hydrography Dataset (NHD) (USGS, 2013). The NHD is funded by the USGS and serves as the surface water component of that agency's National Map of the United States. The NHD is a vector dataset that delineates surface water features such as rivers, lakes, and ponds and also contains watershed boundary information from the Watershed Boundary Dataset (WBD). These data provide more insight into potential boundaries of current wetlands.

3.3 Methods

3.3.1 Segmentation and Classification

Image segmentation is the process of “breaking up” an image into less complex image primitives. Once these primitives have become meaningful in the sense that they embody complete items in space they become image objects (Lang, 2008). It is this shift from individual pixels, which only offer spectral reflectance information, to more meaningful objects that allows for rule-oriented image analysis based on image object relationships and spatial attributes (Hay and Castilla, 2006). The parent/child relationship allows for the link between initially created image objects and their attributes with image object layers that are created from them. For instance, if a coarse segmentation were run followed by a finer segmentation on the objects created by the coarse segmentation the link between the attributes of both sets of objects would remain intact. Figure 3.1 provides an example of the NAIP imagery being segmented using the multi resolutional segmentation ruleset.

Figure3.1 This image shows the Multi-Resolutional Segmentation on a section of NAIP Imagery

As image primitives are merged with other primitives they produce hierarchies of "levels" that while now spatially joined still retain their statistical discontinuity which can be utilized for advanced analysis (Lang, 2008). This analysis will produce image objects that can be assigned to class values that correspond to real-world objects such as land cover classifications or vegetation types based on their relationships to other hierarchies as well as spatial attributes like shape, extent, and proximity to other objects. For the purposes of this thesis those attributes are an extension of the methodology used for isolated wetland identification (Tiner, 2003a). Figure 3.2 shows an example of the NAIP imagery being segmented further using the spectral difference segmentation ruleset.


Figure 3.2 This image shows the Spectral Difference Segmentation's ability to group large, similar objects together.

Much of the difficulty in identifying isolated wetlands stems from the fact that these types of wetlands are typically small and ever changing in extent due to seasonal variation and hydrological input (Tiner, 2003a). This also means that in many instances there will be no visible sign of a wetland in a given aerial dataset, but that does not mean these wetlands are not present in other datasets. For that reason the segmentation and classification algorithms focus on the presence of surface water while existing datasets, such as the ones listed earlier, are merged into the newly created isolated wetland dataset.

The NAIP imagery, while already tiled into DOQQs, needed to be further tiled into 3000 x 3000 (9000 pixel maximum) projects and executed using eCognition Server's parallel processing environment in order to increase processor efficiency. The study area consists of 714 DOQQs with each being broken into 8 smaller project tiles for a total of 5,712 individual project tiles. Each tile is then subjected to iterative segmentations including eCognition's multiresolutional segmentation and spectral difference segmentation. Multiresolutional segmentation has been used in a number of studies and has been found to accurately delineate meaningful image objects (Myint et al., 2011; Tian and Chen, 2007; Kressler et al., 2005; Wei et al., 2005; Darwish et al., 2003). Furthermore, for this study through trial and error it was shown that an efficient way of obtaining further segmentation (i.e. larger, more meaningful image primitives), was to utilize the spectral difference segmentation which groups larger objects with similar spectral and textural characteristics together.

The first step in creating a segmentation is assigning scale, compactness, and shape which are specified by the user. Scale is generally considered the most important parameter since it directly determines the resulting image object scale (Myint et al., 2011). Currently, determining the most effective parameter settings within eCognition relies upon a trial and error approach on the part of the researcher. For this project the optimal size parameter was determined to be 10 with shape and compactness remaining at their defaults which resulted in an average image object size of 300 to 500 pixels at the multiresolutional level and 3000 to 8000 at the spectral difference level. Figure 3.3 shows the parameters for multiresolutional segmentation and how they are set within eCognition's process tree.

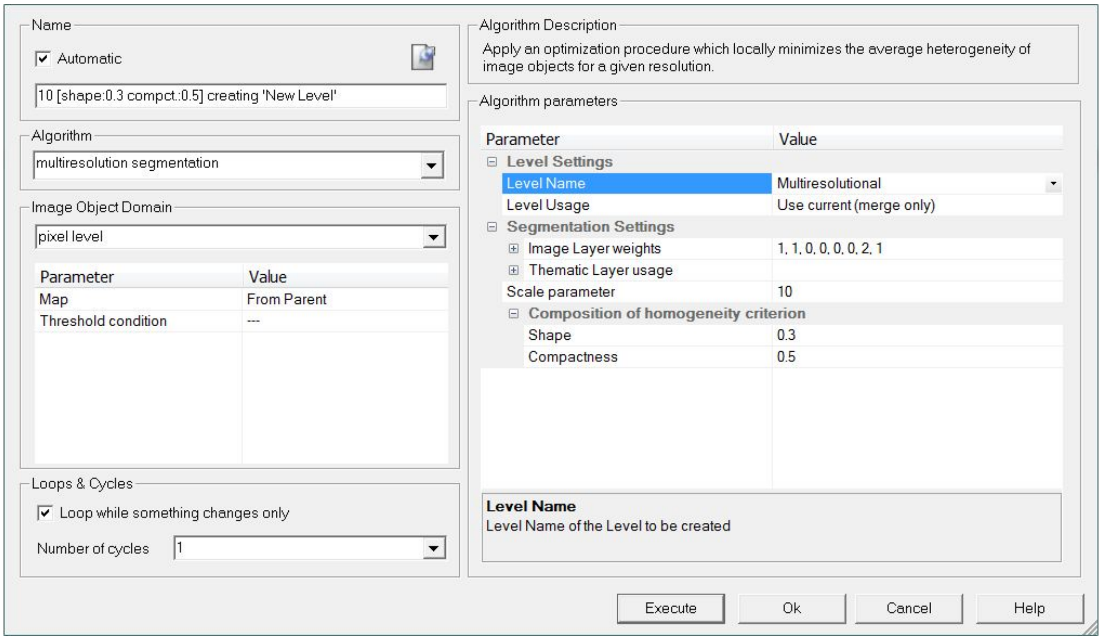


Figure 3.3 The parameters for multiresolutional segmentation within eCognition.

In addition to these parameters, eCognition also allows the user to assign weighted values to individual image bands. By default each band is given a value of 1 meaning that each band holds equal weight in the segmentation process. However, given that water has low reflectance in the NIR portion of the electromagnetic radiation spectrum, the corresponding Band 4 was given the value of 2 meaning it was assigned a double weight. Each of the iterations of segmentation resulted in the new class of image primitives being arranged in a parent/child hierarchy until meaningful water body image objects were created.

Classification is achieved using spatial and textural logic such as spectral reflectance in the NIR band, homogeneity, and asymmetry. These rulesets were developed using a trial-and-error approach which has become common when using this type of analysis (Myint et al., 2011). Open water spectral signature was analyzed by averaging each image object's value in Band 2 (Green) and Band 4 (Near Infrared). The average of Band 2 minus the average of Band 4 was then divided by the average of Band 2 plus the average of Band 4.

[Avg. Band 2] – [Avg. Band 4] / [Avg. Band 2] + [Avg. Band 4]

Upon visual inspection these attributes were found to very clearly delineate open water bodies while eliminating vegetation. A homogeneity rule was employed to identify objects with lower variance in pixel values. This meant that objects were “smoother” and were therefore more likely to be open water than vegetation. Figure 3.4 below shows the eCognition dialog for creating the water candidate class.

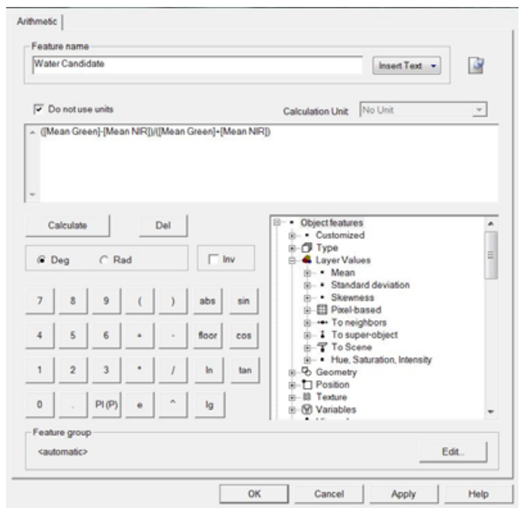


Figure 3.4 Shows the rule as setup for water extraction.

Next, a rule was used for restricting the geometry of objects that could be identified as water. This was achieved by using eCognition’s Asymmetry attribute assigned to accept only objects between .07 and 0.9. Visual inspection of several areas showed that this interval captured most water bodies while eliminating most areas of shadow. Finally, it was noticed that many small objects (<0.13 acres) remained which were beyond the accuracy abilities of this ruleset and were therefore removed by applying a spatial extent rule to remove all otherwise qualifying image objects that contained less than 500 pixels. In figure 3.5 below are examples of wetland delineation using eCognition.

Figure 3.5 Shows the classification of water (in blue) based on size, shape, and spectral information.

The final class that met all the necessary criteria was auto-exported into subfolders with appropriate naming schemes as georeferenced shapefiles. Initial plans were to merge the many thousands of shapefiles using an ArcGIS supported Python script to simplify data handling, but it was later noticed that the auto-export functionality employed by eCognition installed several “dot” characters within the naming scheme. This resulted in errors during the merging process due to unique character restrictions within the Arcpy toolbox which had to be corrected by collecting the directory names for all the subfolders and parsing them in order to isolate the “dot” characters. Using the Microsoft Disk Operating System (MS-DOS) Command Line Interface the shapefiles and their associated files (.prj, .dbf, .xml, etc.) were copied and updated with underscores which are supported within the toolbox. The resulting files were then able to be merged using the toolbox’s arcpy.ListFeatureClasses command to create a listing of each shapefile and its associated file. This listing was then merged using the file management tool Merge_management with the listing name as a wild card identifier. Figure 3.6 below shows an example of the files being batch renamed in MS-DOS.

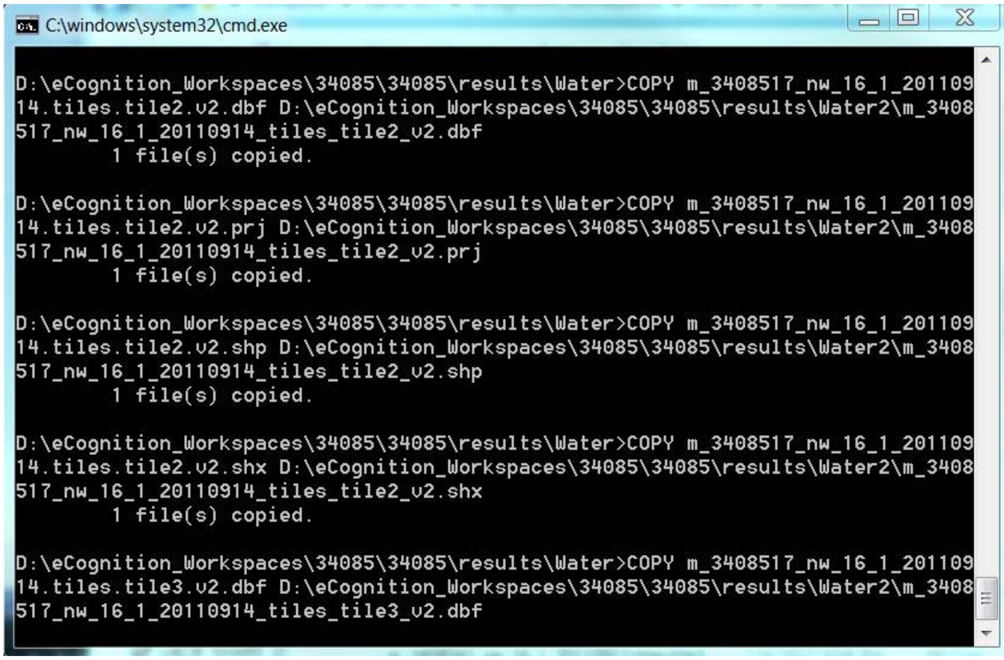


Figure 3.6 Shows an example of the MS-DOS Commands for renaming.

These resulting water polygons were merged with existing hydric soils data as an ESRI File Geodatabase. They were then buffered relative to existing datasets of known waterways and existing 100 year floodplain data by 40 meters in order to determine geographic isolation in accordance with the Tiner methodology (Tiner 2003a). Figure 3.7 below shows an example of non-isolated wetlands (in green) falling within the waterway and floodplain buffer causing them to be removed leaving only the geographically isolated wetlands (in blue). These resulting areas were then analyzed using ArcToolbox’s Cluster and Outlier Tool to identify if any areas contained a statistically significant ($p > 0.05$) number of large wetlands.

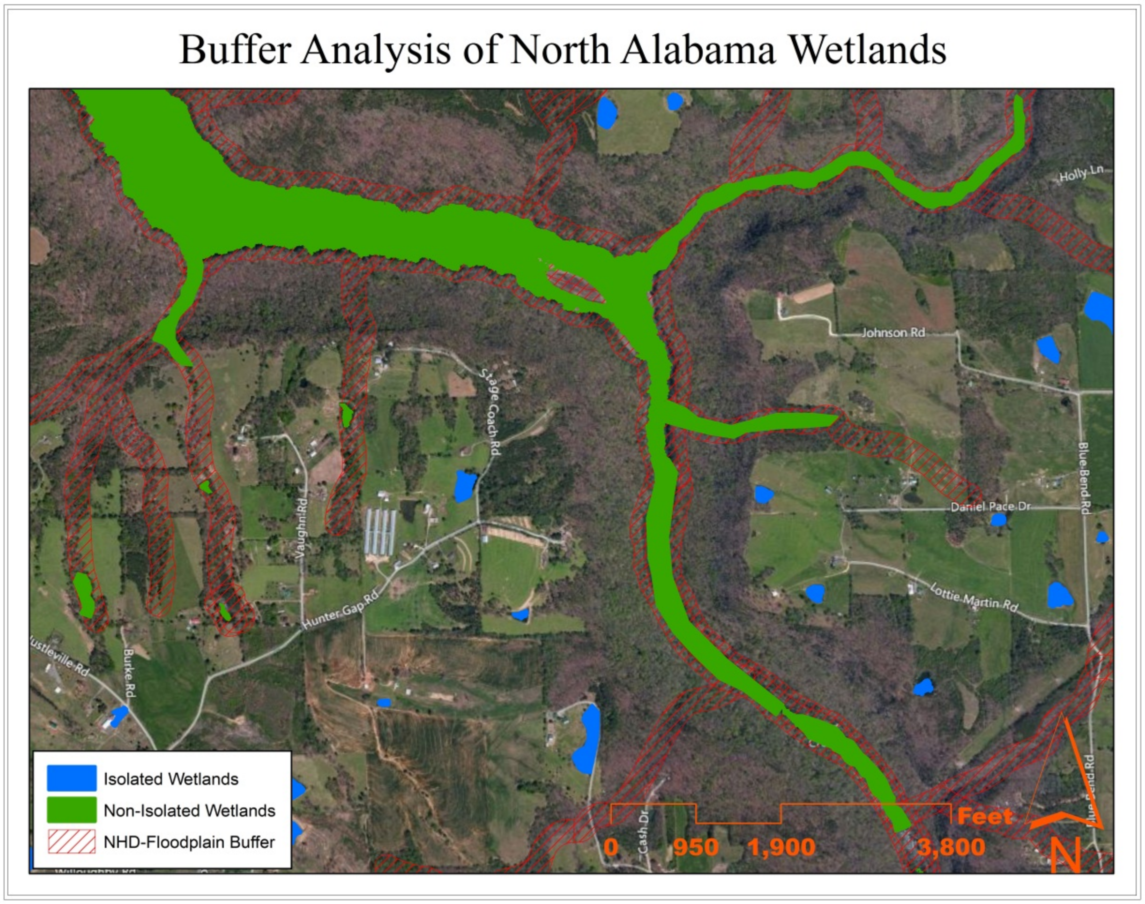


Figure 3.7 Example showing the areas identified as isolated and non-isolated using GeOBIA

3.3.2 Field Work and Verification

During the course of this study a retired NRCS State Resource Conservationist (Norton, 2013) with 35 years of experience was interviewed concerning past wetland mapping projects including the National Wetlands Inventory (NWI). Wetland mapping efforts originally consisted of expert photo-interpreters manually delineating and classifying wetlands onto analog maps (Norton, 2013). This was a particularly tedious process that required each interpreter to devote approximately one week to each 7.5 minute USGS quadrangle. The preliminary maps were then field verified by federal, state, and local officials, sometimes several times in particularly complex areas, until a final map was created. This process was both labor intensive and time-consuming which caused the projects to require large amounts of public funds and many years to complete. This stands in stark contrast to this study in which significance of the project is derived from the ability to automate and batch process large wetland mapping projects.

For this study the verification process was broken into remote verification and field verification. Remote verification was done by randomly selecting one percent of the overall wetlands delineated by GeOBIA across the entire study area and manually inspecting the imagery for obvious errors. This resulted in 191 areas being investigated and classified as either correct or incorrect. Field verification methods, however, required physical inspection of delineated wetlands for accuracy assessment.

Intermittent field trips to assess accuracy occurred from June 2012 through February 2013. During these trips maps were produced of areas identified as isolated wetlands by the GeOBIA algorithms. Also, certain areas that were either familiar to the author or known to be public lands were preferred to limit landowner interaction. The more accessible sites were visited in order to maximize the overall number of verifications with 57 sites being visited overall across Jackson and Marshall County. Visual inspection was used to determine the validity of the site's classification as a wetland. These site's GPS locations were then collected with a Topcon WAAS corrected DGPS. Figure 3.7 below shows a general location map of the field verification sites that were visited from June 2012 through February 2013. Figure 3.1 below shows the GPS coordinates and database ID numbers for all of the field verification sites of the study. Each site was accuracy assessed based on field maps with the isolated wetland classification overlayed. Figures 3.8 and 3.9 below show examples of isolated wetland verification sites.

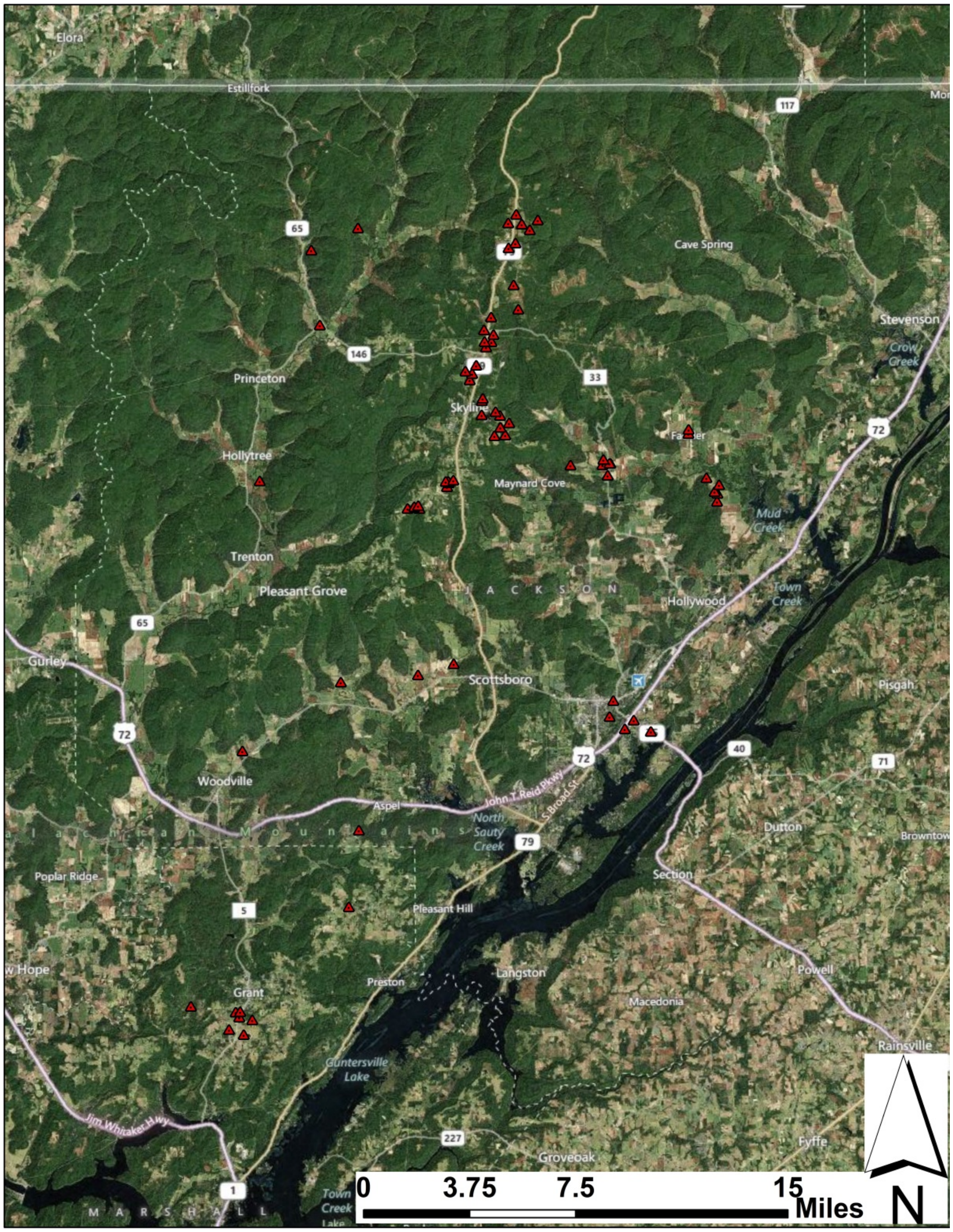


Figure 3.7 Shows the general location of the field verification sites throughout the study area.


Figure 3.8 Photo of a wooded verification site in Jackson County, AL


Figure 3.9 Photo of an open verification site in Jackson County, AL

Database Identification #	Longitude	Lattitude
18845	-86.1810	34.9169
18880	-86.0823	34.9231
18869	-86.0690	34.9202
18853	-86.0789	34.9181
18840	-86.0740	34.9151
18859	-86.0874	34.9188
18814	-86.0830	34.9085
18797	-86.0873	34.9060
18688	-86.0844	34.8870
18634	-86.0817	34.8745
18528	-86.0972	34.8616
18539	-86.1031	34.8640
18608	-86.0986	34.8706
18483	-86.1027	34.8580
18482	-86.0985	34.8579
18467	-86.1018	34.8553
18419	-86.1081	34.8459
18389	-86.1107	34.8417
18395	-86.1149	34.8430

18369	-86.1122	34.8385
18321	-86.1042	34.8289
18311	-86.1048	34.8277
18259	-86.1051	34.8204
18274	-86.0963	34.8220
18256	-86.0936	34.8201
18230	-86.0879	34.8163
18208	-86.0935	34.8140
18173	-86.0935	34.8140
18169	-86.0971	34.8097
17893	-86.1277	34.7864
17888	-86.1262	34.7866
17873	-86.1257	34.7857
17850	-86.1269	34.7838
17895	-86.1230	34.7871
17673	-86.1516	34.7728
17682	-86.1474	34.7736
17687	-86.1450	34.7742
17681	-86.1443	34.7728
18020	-86.0257	34.7951

18018	-86.0252	34.7950
18006	-86.0301	34.7943
18051	-86.0295	34.7969
18008	-86.0500	34.7943
17931	-86.0269	34.7888
18177	-85.9764	34.8099
18196	-85.9764	34.8120
17913	-85.9655	34.7870
17855	-85.9577	34.7834
17795	-85.9606	34.7799
17781	-85.9588	34.7790
17720	-85.9591	34.7749
16866	-86.0122	34.6631
16822	-86.0178	34.6587
16798	-86.0017	34.6572
11377	-86.2608	34.5149
11384	-86.2577	34.5152
11354	-86.2586	34.5124

Table 3.1 Shows the GPS locations of field verification sites that were inspected.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This thesis seeks to estimate the spatial extent of geographically isolated wetlands within the study area. To achieve this, existing wetland datasets were compiled from various sources to provide supplemental and historical information for assisting in the development of automated rulesets. Next, an automated process of tiling, segmenting, and classifying image objects by GeOBIA in eCognition Developer v.8 were coupled with traditional GIS analysis using ArcInfo 10.1. These analyses include overlay procedures such as buffer and merge as well as descriptive statistical analysis. Afterwards, the results of this analysis were assessed for accuracy through remote and field verification. A comparison is made between the automated process developed here and traditional methods that have been done in the past.

4.2 Identification Using GeOBIA

An automated GeOBIA process was utilized to identify isolated wetlands in north Alabama. This was done by using an eCognition Developer v.8 Customized Import algorithm to create individual workspaces for 1°x1° sections of 1-meter resolution imagery from the National

Agricultural Imagery Program (NAIP). Within each workspace the algorithm assigned each Digital Orthographic Quarter Quad (DOQQ) to an individual project file. Each of those individual project files were then partitioned into 3000x3000 pixel tiles resulting in the creation of 5,712 project tiles across the entire study area. Each project tile then had a ruleset applied to it that is described in more detail in Chapter 3. The resulting classified areas were then merged into a single geodatabase and buffered against existing water body and stream data within the National Hydrography Dataset (NHD) as well as the Federal Emergency Management Agency's (FEMA) Digital Flood Rate Map (DFIRM) to determine geographic isolation. Figure 4.1 below shows the distribution of results across all of north Alabama with identified isolated wetlands shown in yellow. Large groupings of isolated wetlands can be seen in Lawrence and Morgan County to the south of the Tennessee River as well as in Jackson County to the west of the Tennessee River/Lake Guntersville. This large number of wetlands in Lawrence and Morgan County are just to the north of the Tennessee River Divide which prevents surface runoff from flowing to the south. Also the large groupings of isolated wetlands in Jackson County lie between Lake Guntersville and the southern Appalachian Mountain Range.

Maps below show identified isolated wetlands in yellow for each of the 17 north Alabama counties. Included in the county figures are statistics for the number of isolated wetlands, the range in size of the wetlands, the total area, the average area, and the standard deviation of the areas. It should be noted that remotely sensed wetlands were bounded at a minimum size of .13 acres, however the hydric soils dataset contained smaller delineations therefore some minimums were below the bounded limit.

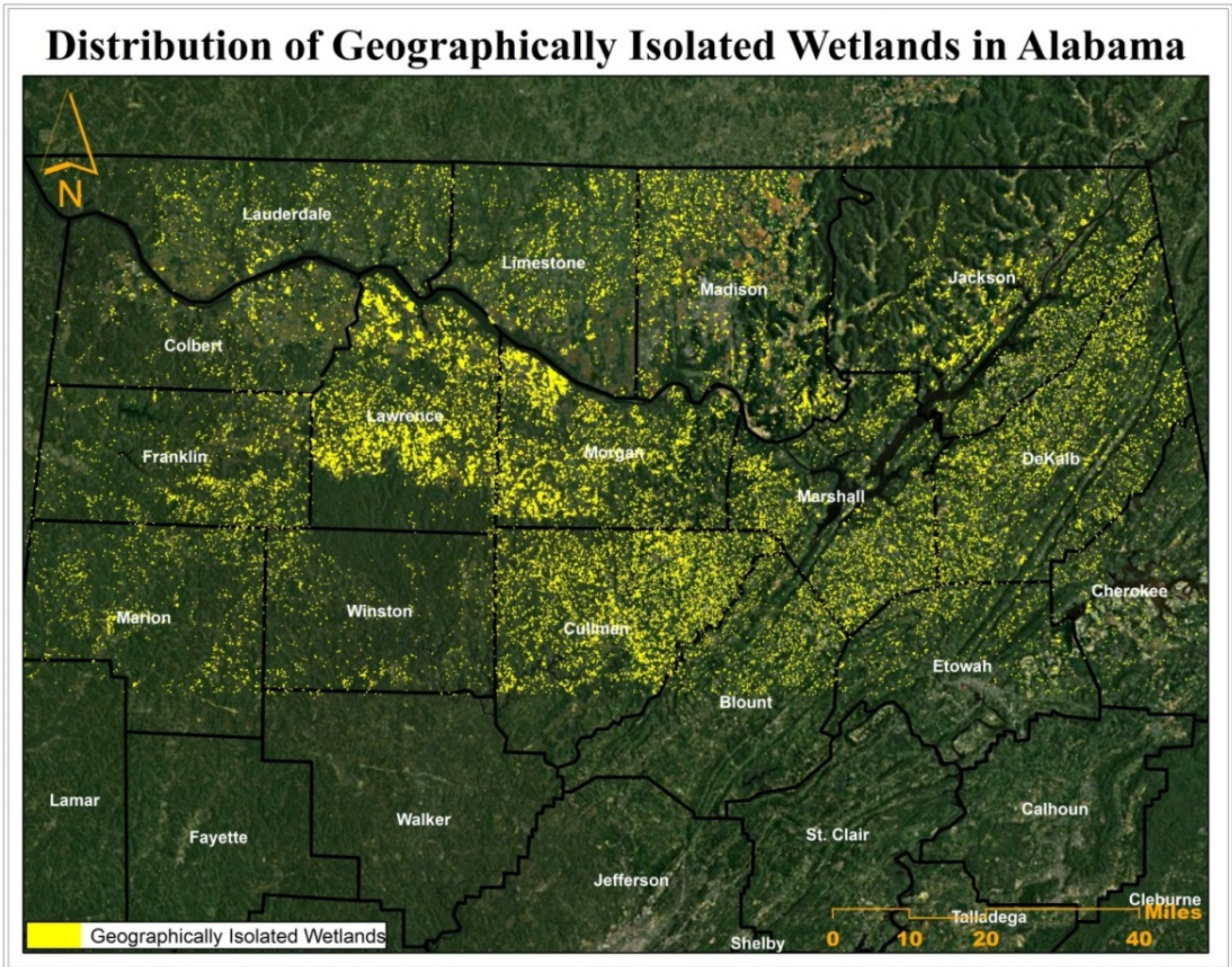
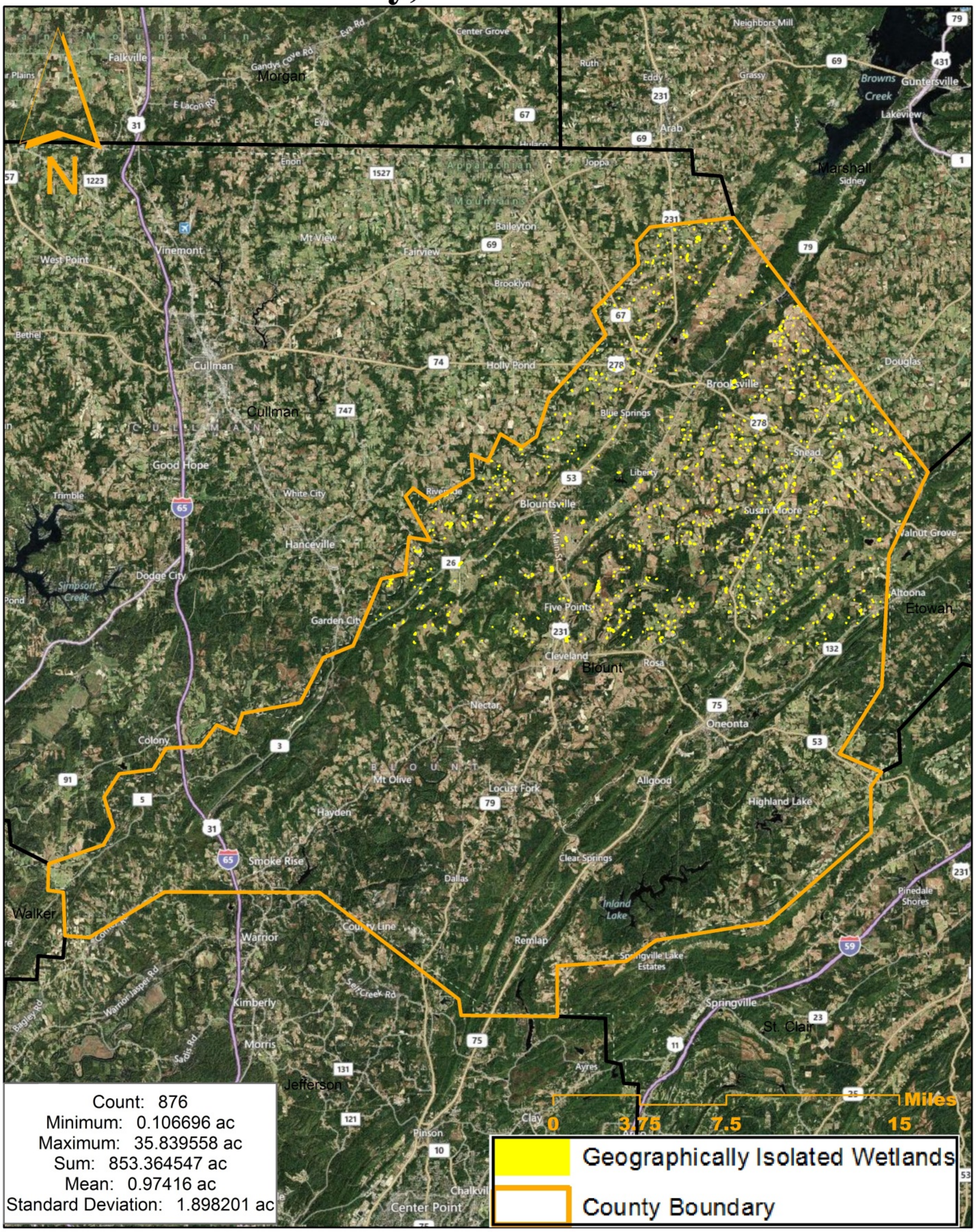
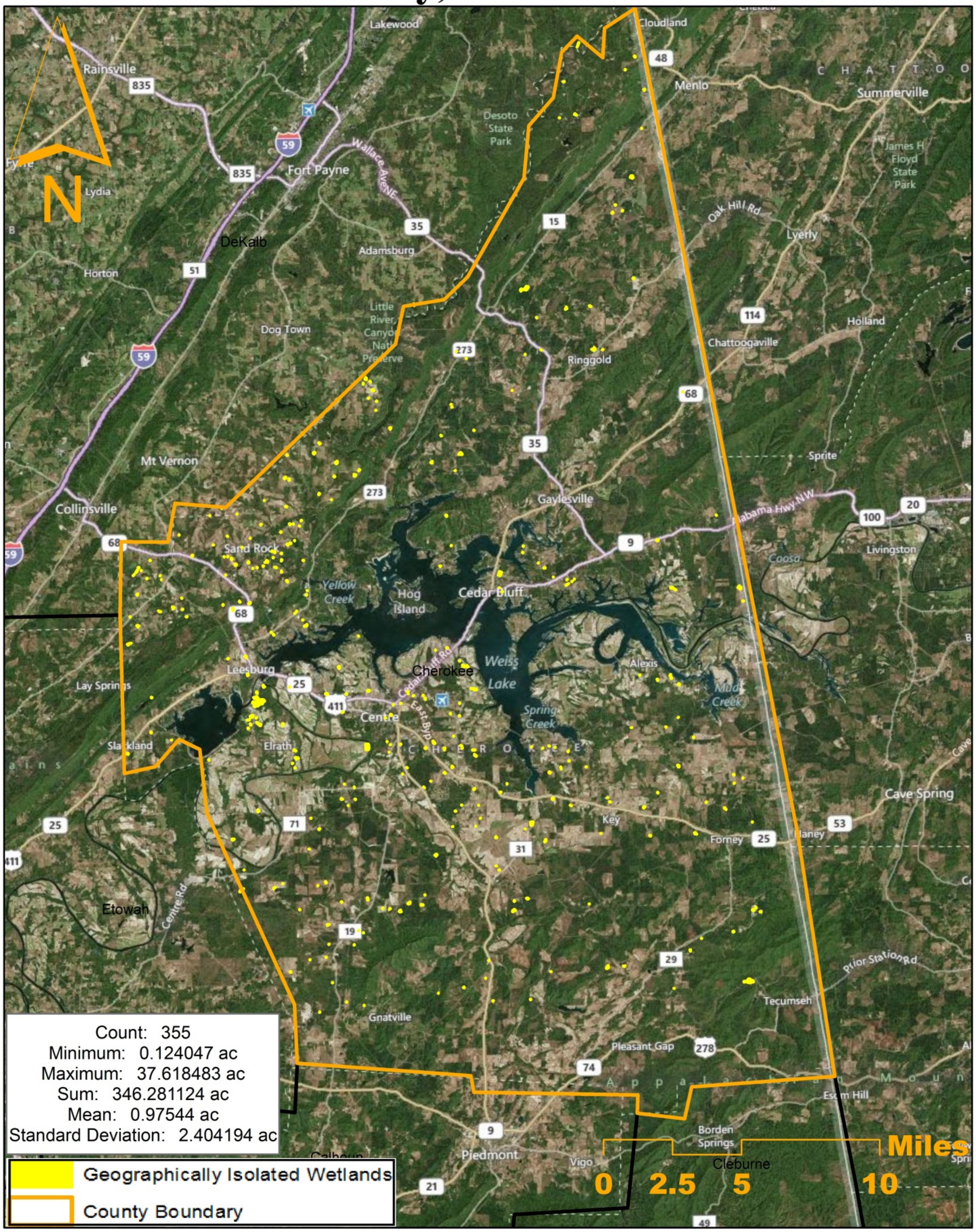


Figure 4.1 An overview of identified geographically isolated wetlands

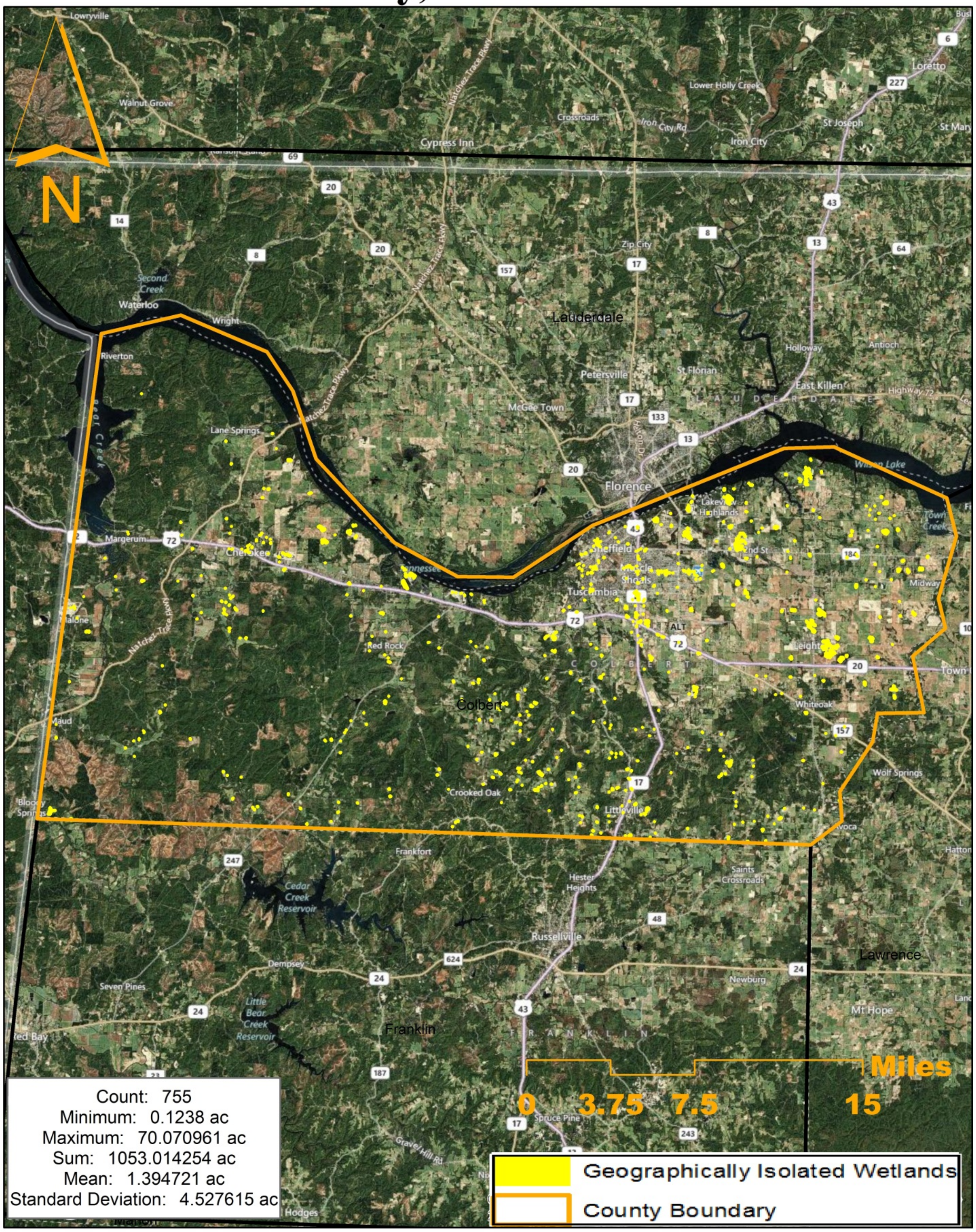
Blount County, AL Isolated Wetlands



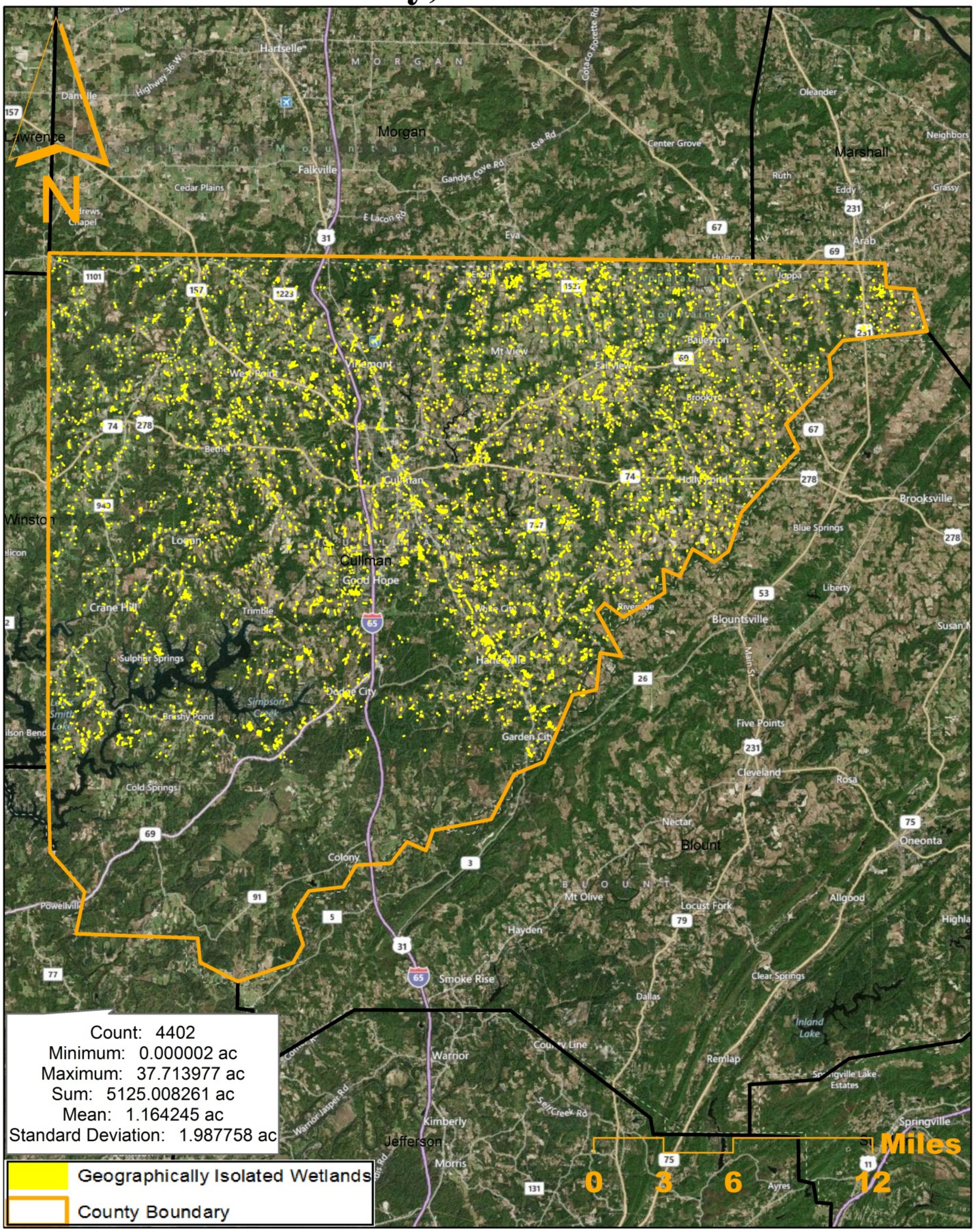
Cherokee County, AL Isolated Wetlands



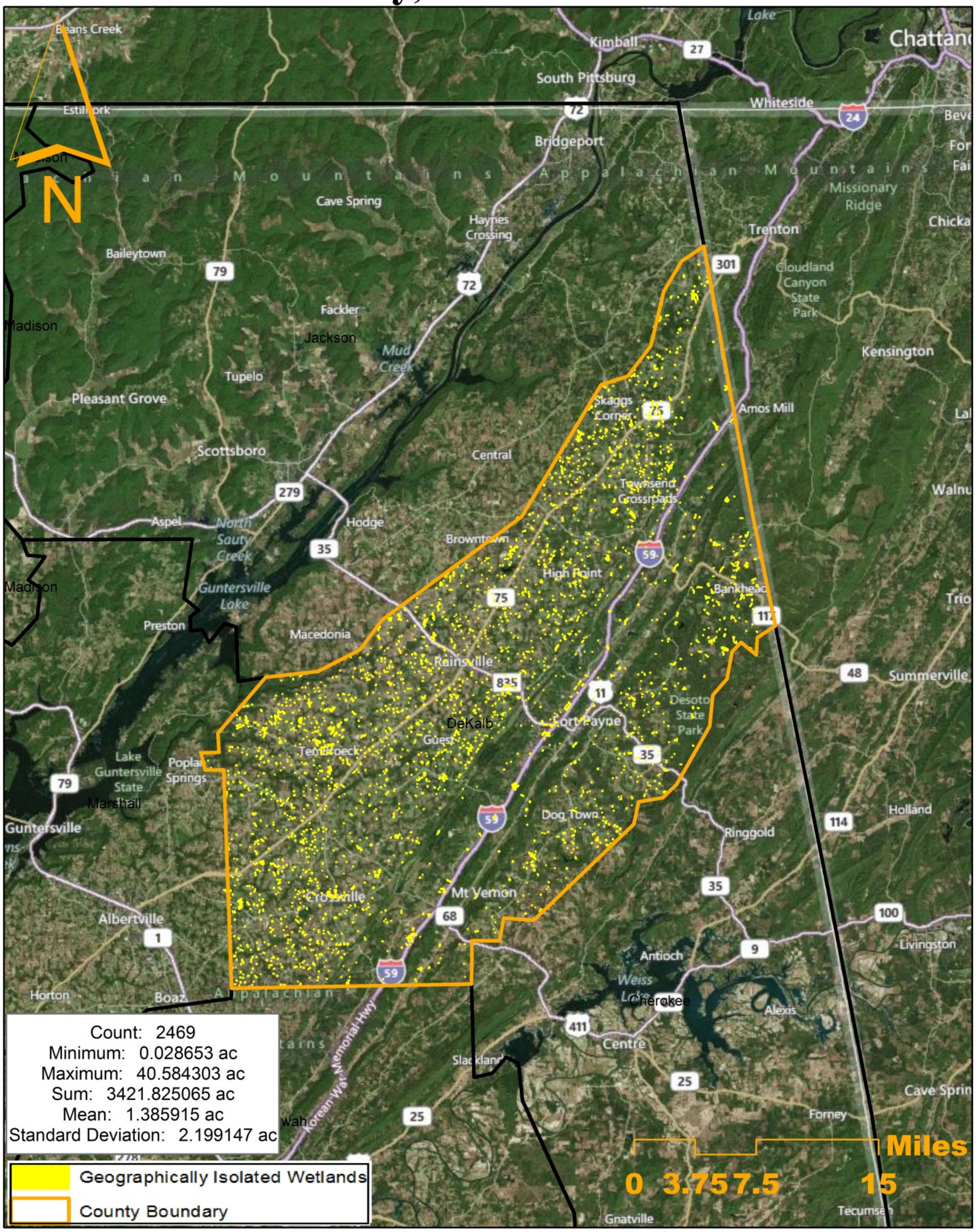
Colbert County, AL Isolated Wetlands



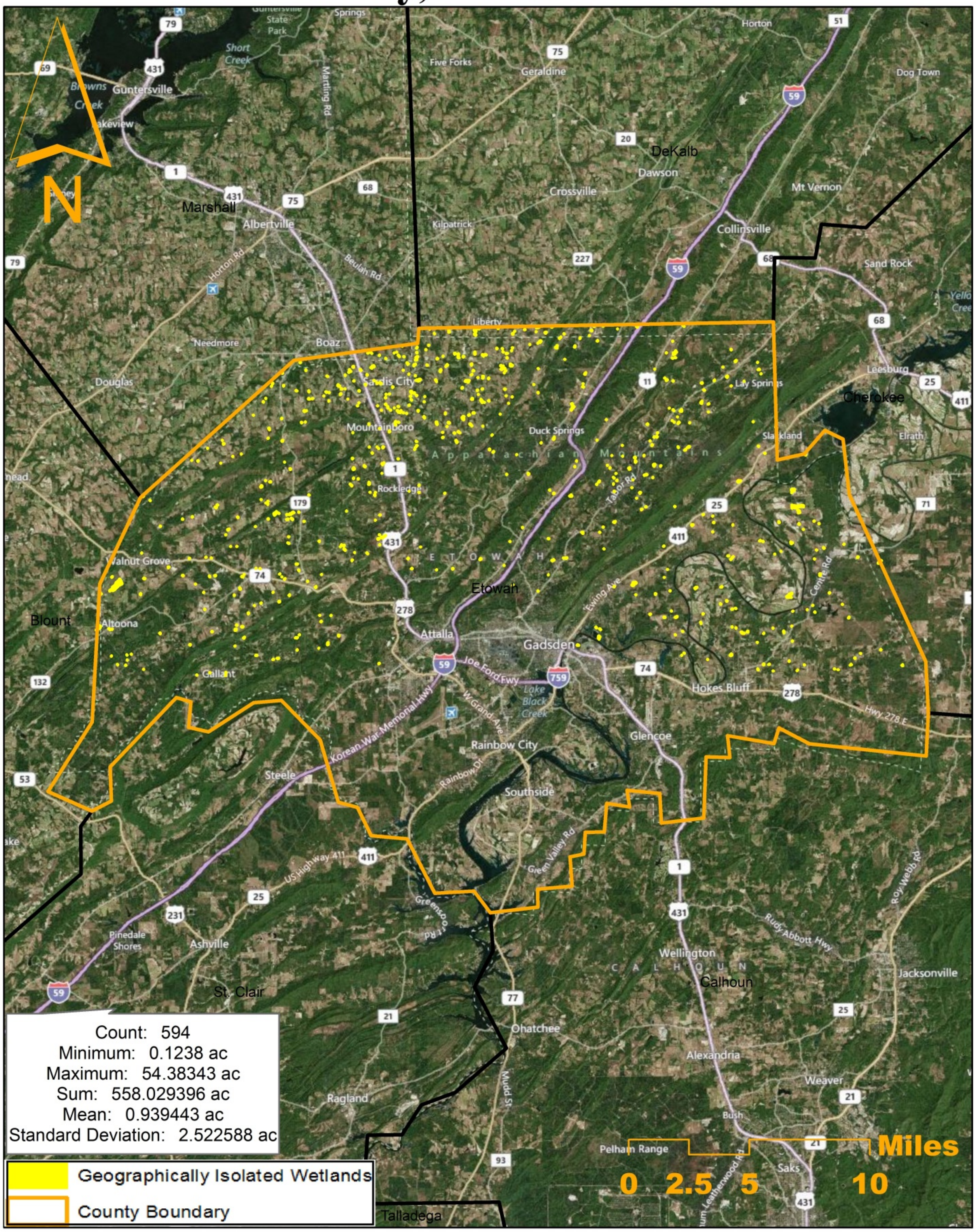
Cullman County, AL Isolated Wetlands



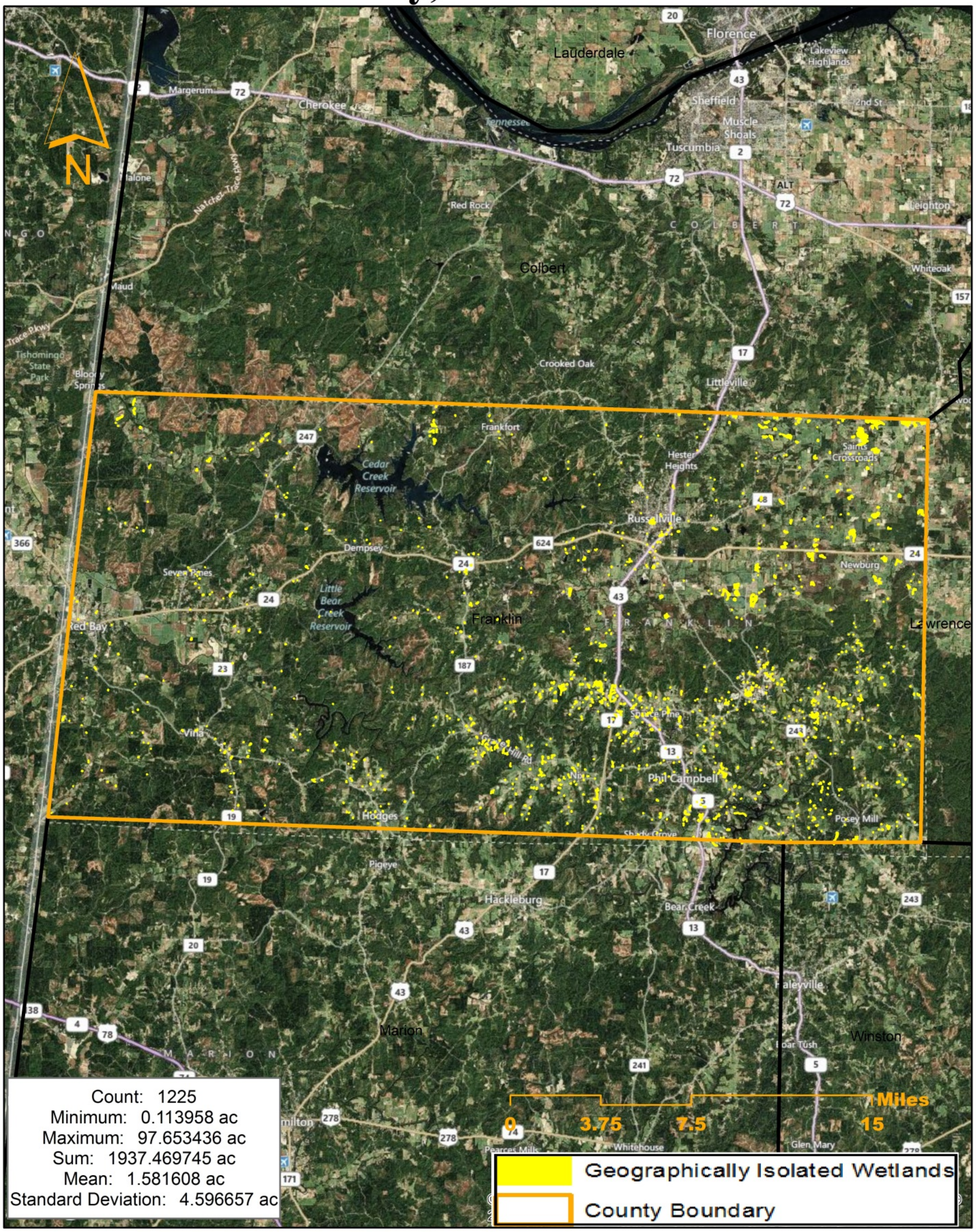
Dekalb County, AL Isolated Wetlands



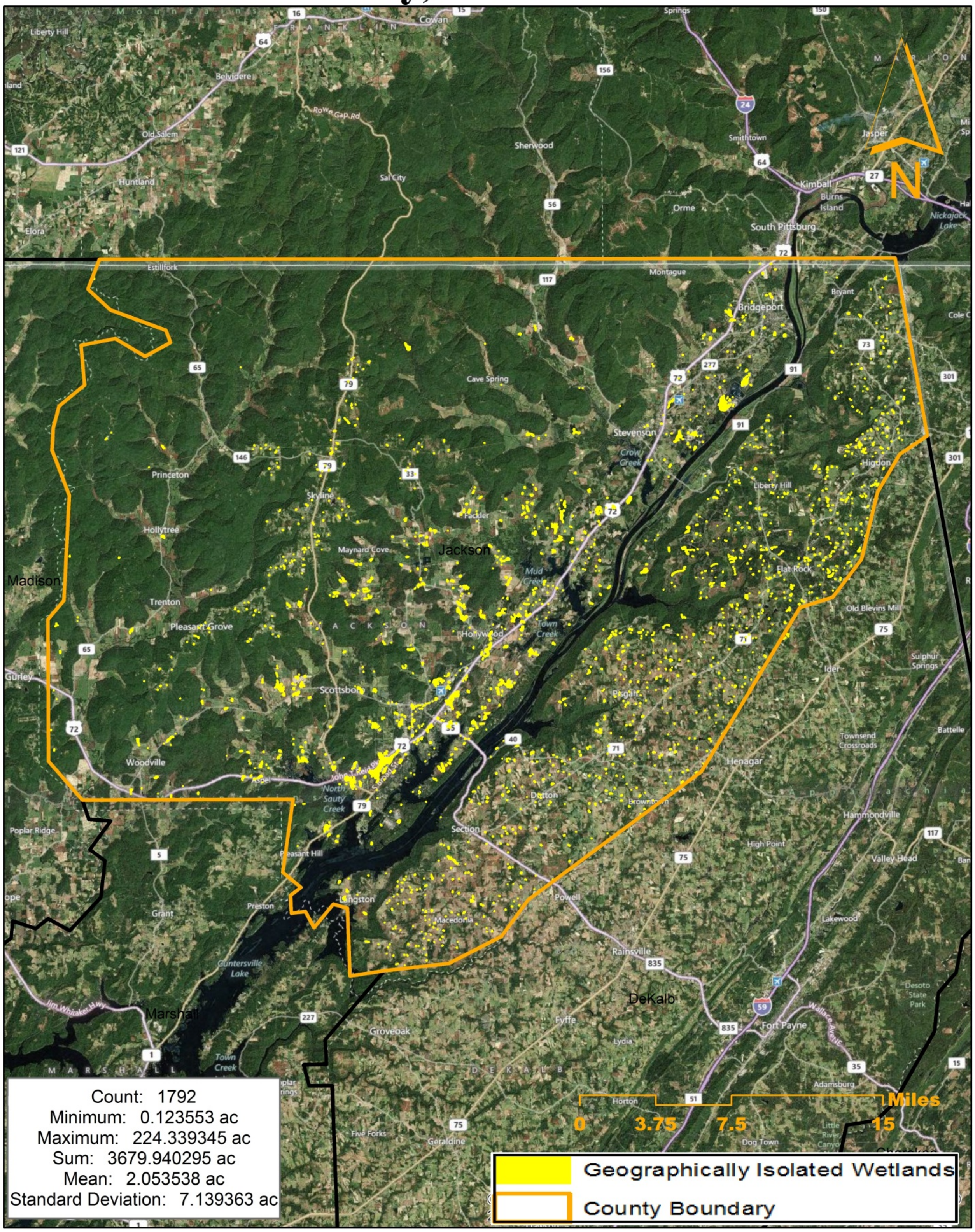
Etowah County, AL Isolated Wetlands



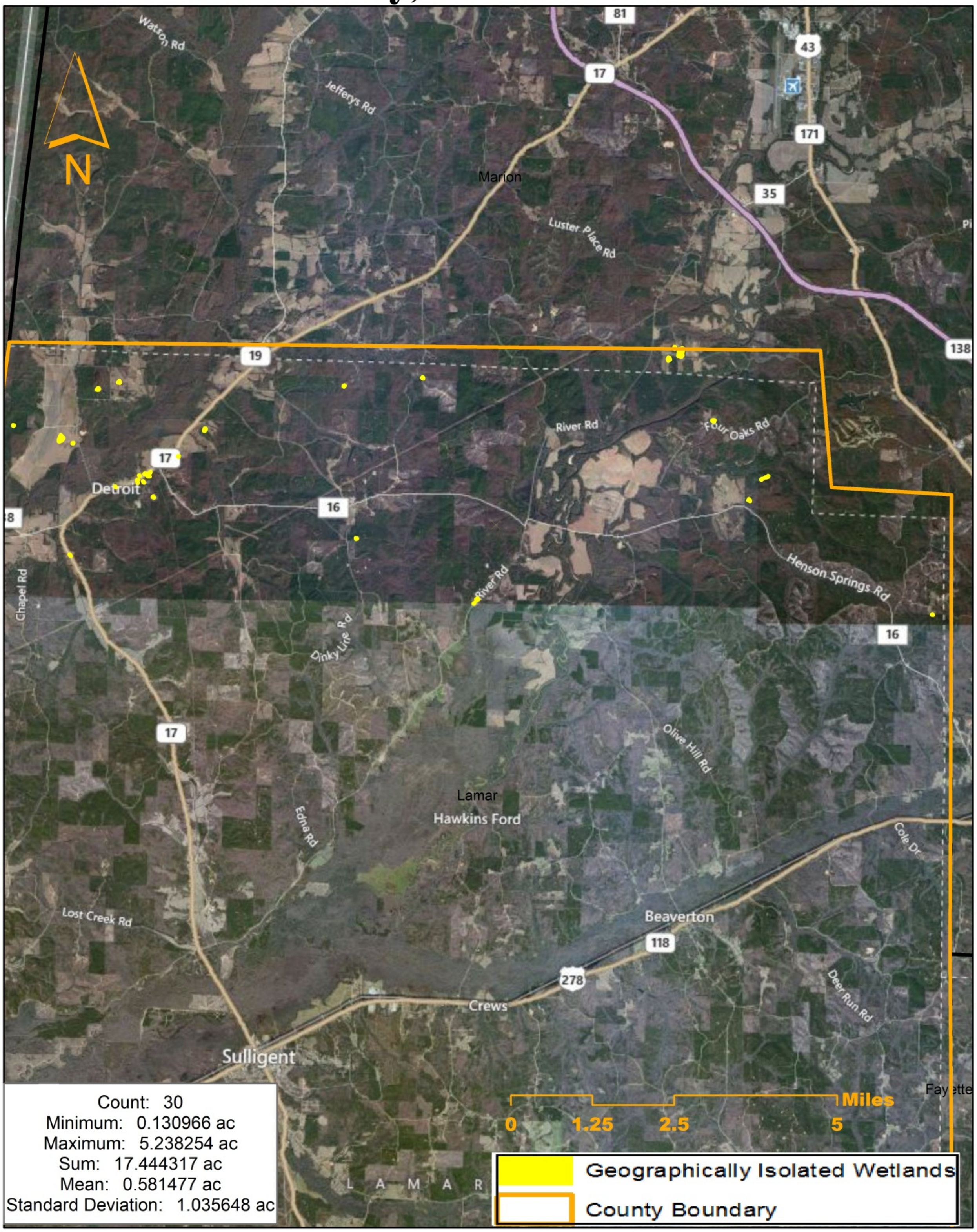
Franklin County, AL Isolated Wetlands



Jackson County, AL Isolated Wetlands

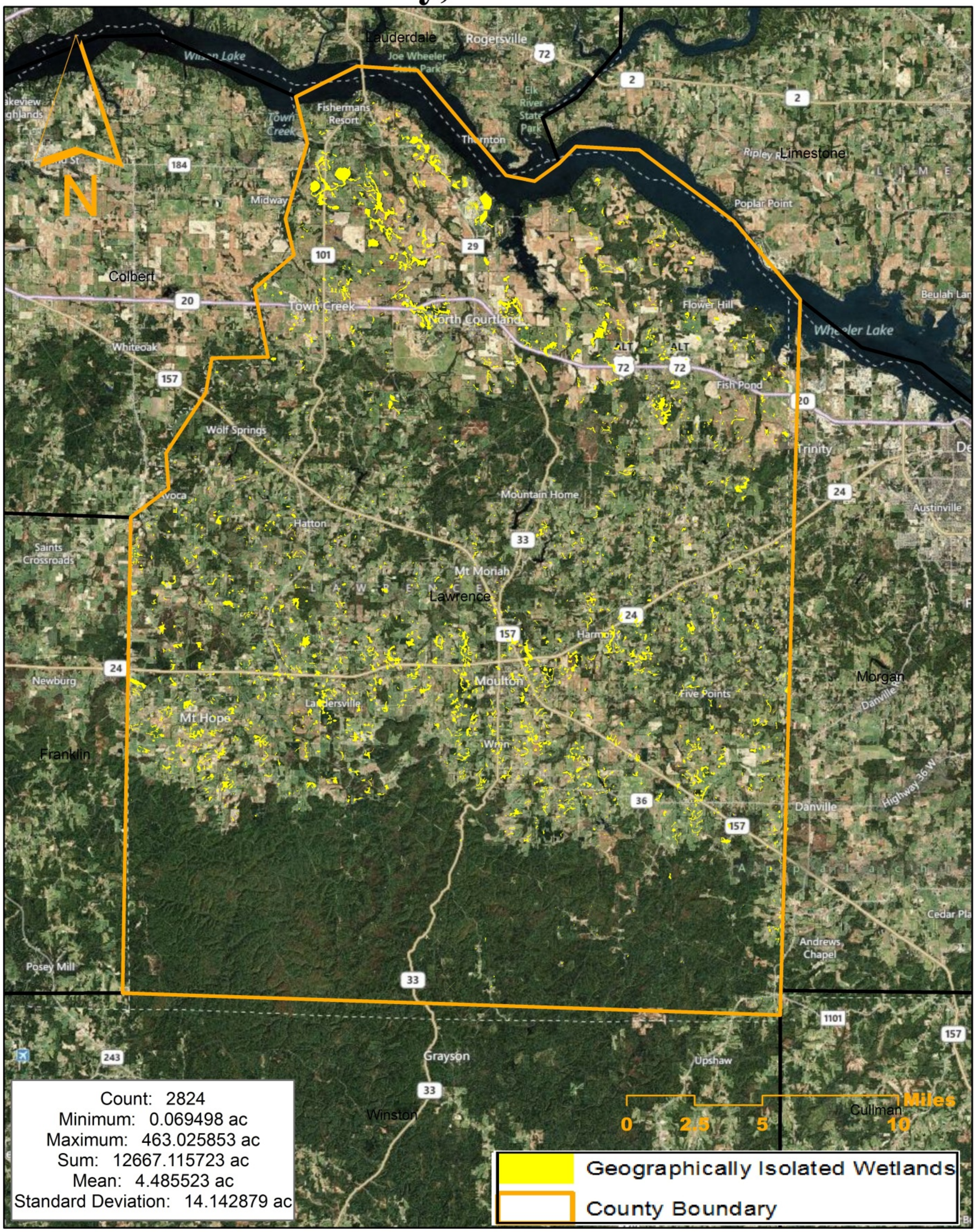


Lamar County, AL Isolated Wetlands

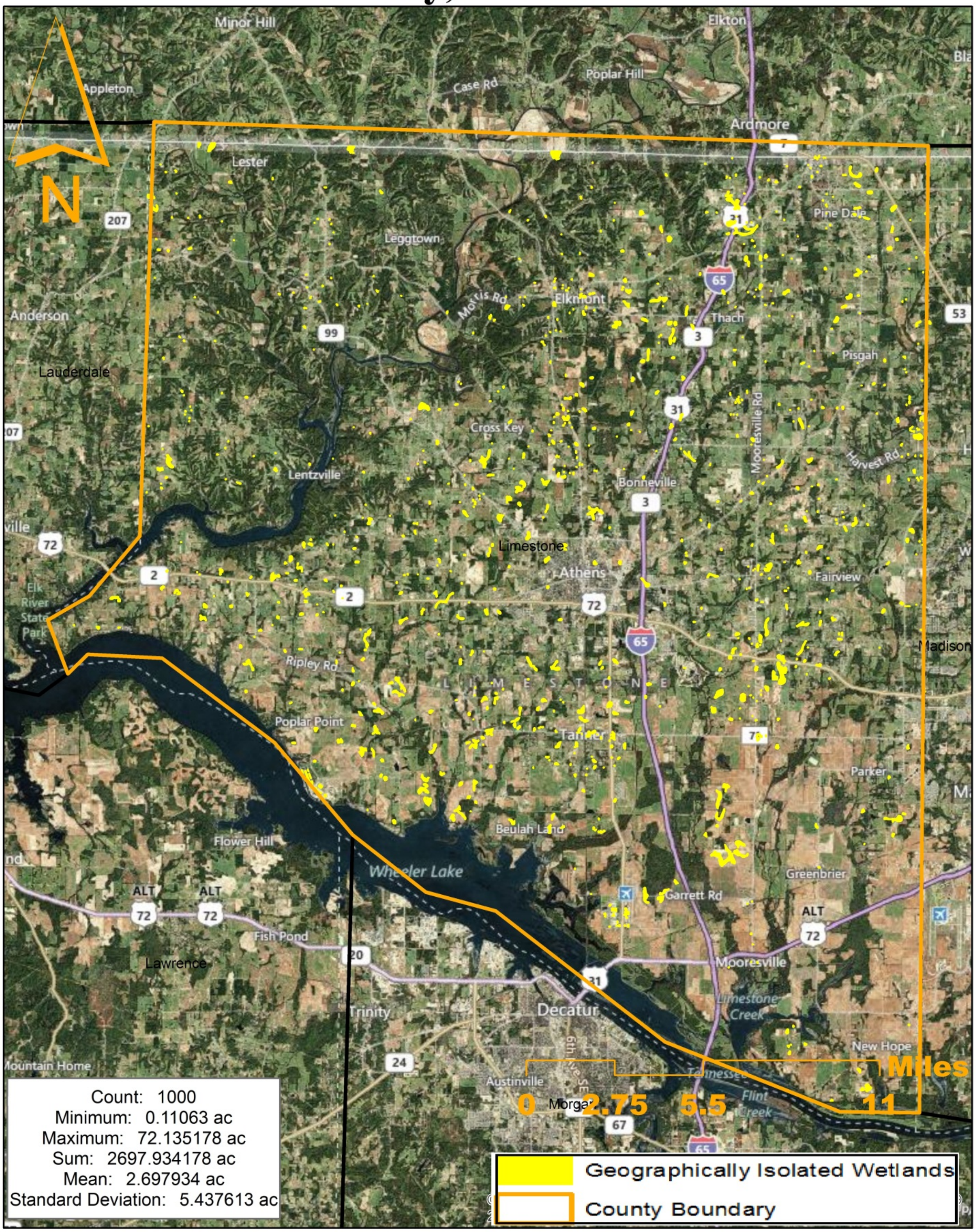


Lauderdale County, AL Isolated Wetlands

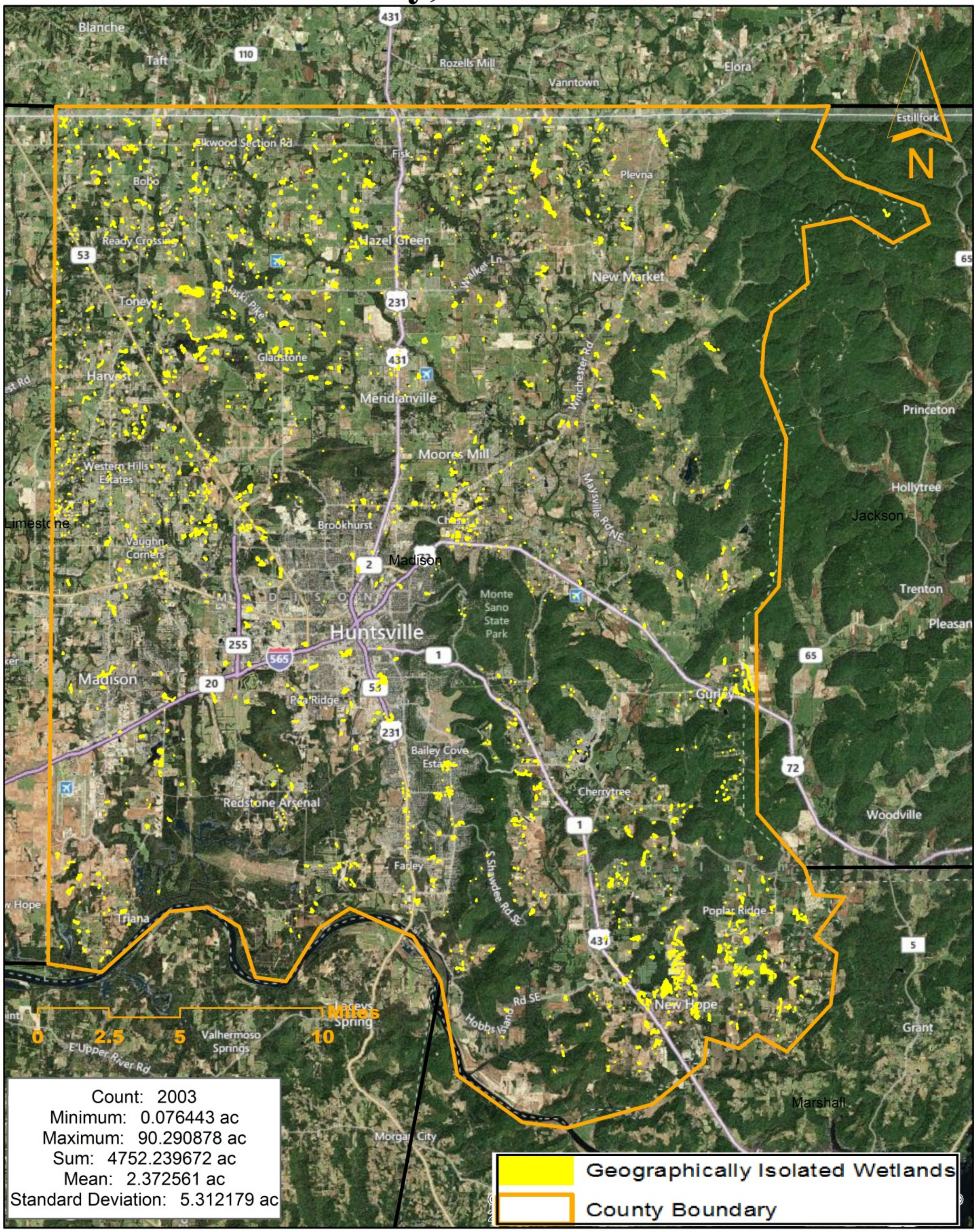
Lawrence County, AL Isolated Wetlands



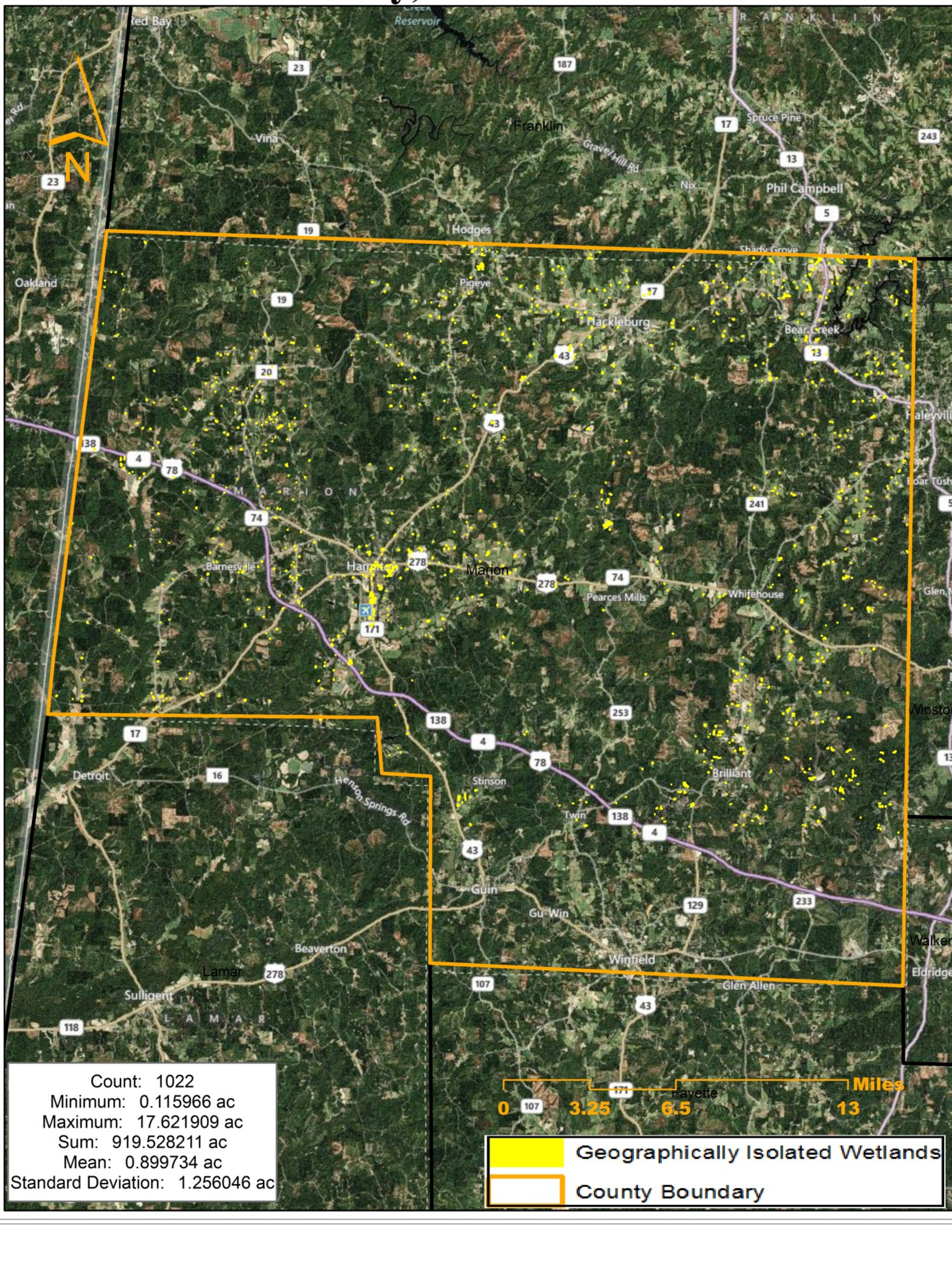
Limestone County, AL Isolated Wetlands



Madison County, AL Isolated Wetlands

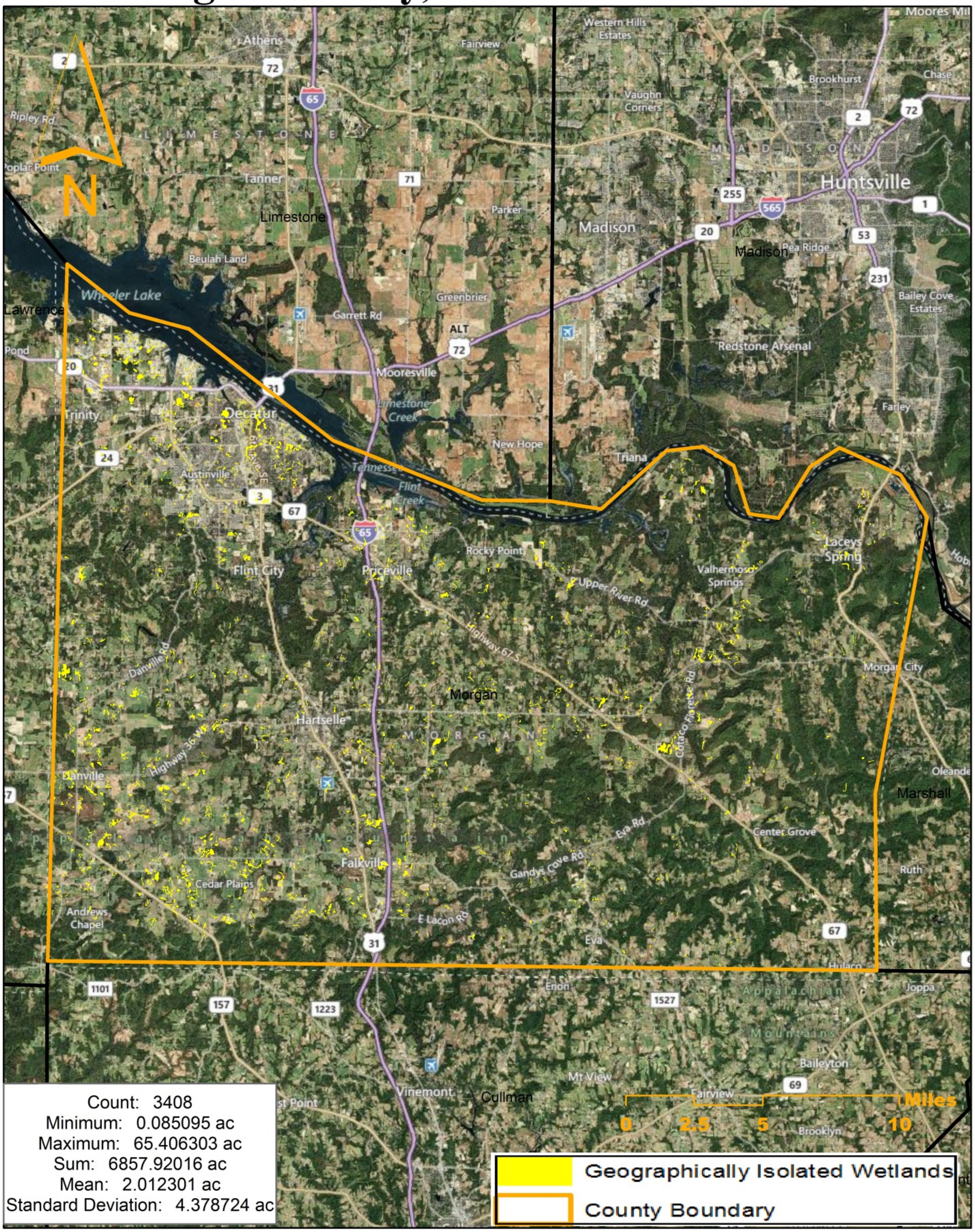


Marion County, AL Isolated Wetlands

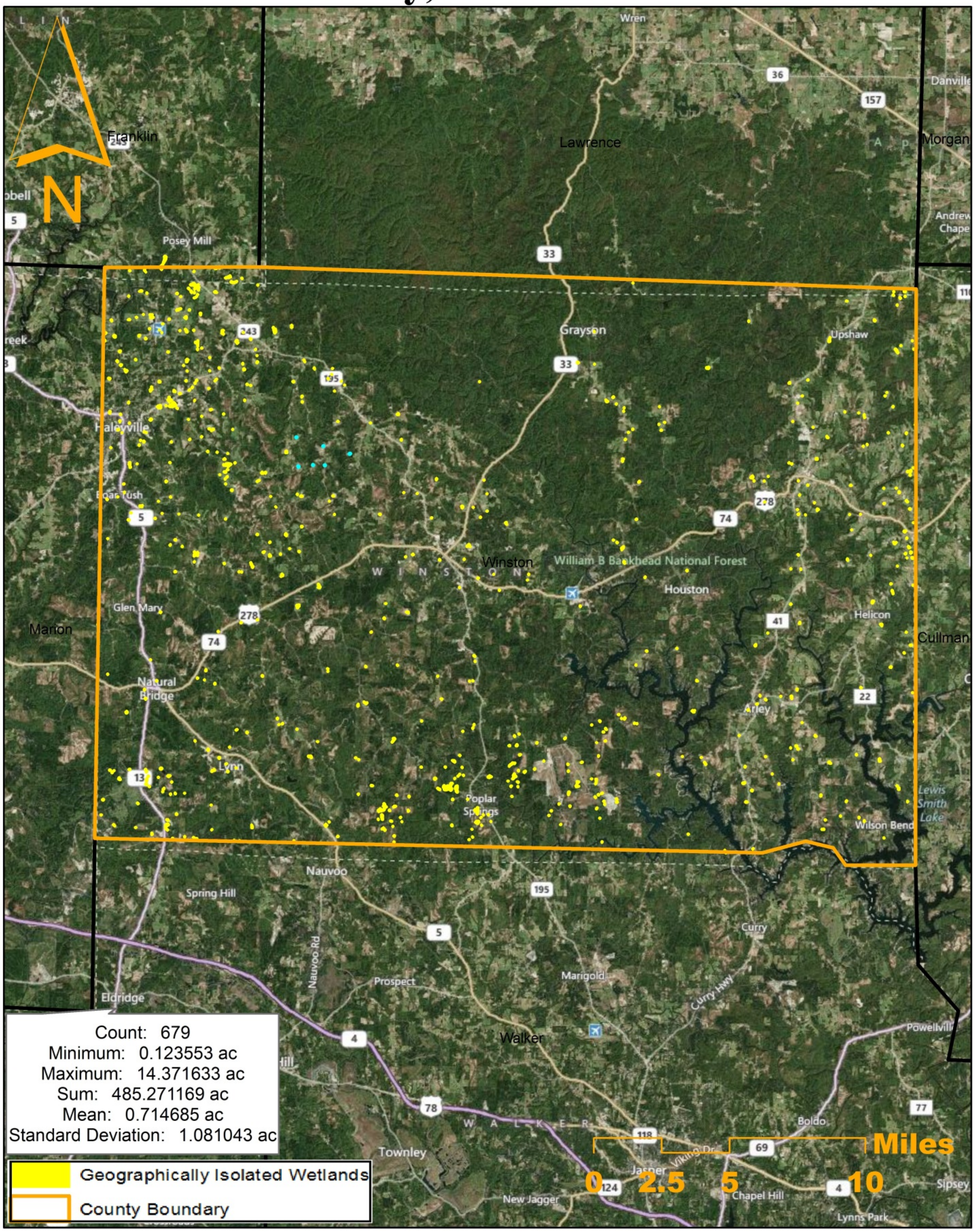


Marshall County, AL Isolated Wetlands

Morgan County, AL Isolated Wetlands



Winston County, AL Isolated Wetlands



4.3 Statistical Summary

The results across the entire study area are shown below in Table 4.1 with the minimum, maximum, average, and total extent of wetlands identified as geographically isolated. Table 4.2 shows these figures for each county as well as overall number and standard deviation of areas identified as geographically isolated wetlands.

Min. Extent	0.0286 acres
Max. Extent	463.02 acres
Avg. Extent	1.859 acres
SUM	49,139.5 acres

Table 4.1 Shows largest, smallest, and average size as well as the sum of all areas identified as isolated wetlands.

County	Count:	Minimum:	Maximum:	Sum:	Mean:	Standard Deviation:
Blount	876.000	0.107	35.840	853.365	0.974	1.898
Cherokee	355.000	0.124	37.618	346.281	0.975	2.404
Colbert	755.000	0.124	70.071	1053.014	1.395	4.528
Cullman	4402.000	0.000	37.714	5125.008	1.164	1.988
DeKalb	2469.000	0.029	40.584	3421.825	1.386	2.199
Etowah	594.000	0.124	54.383	558.029	0.939	2.523
Franklin	1225.000	0.114	97.653	1937.470	1.582	4.597
Jackson	1792.000	0.124	224.339	3679.940	2.054	7.139
Lamar	30.000	0.131	5.238	17.444	0.581	1.036

Lauderdale	936.000	0.124	39.366	1550.282	1.656	3.451
Lawrence	2824.000	0.069	463.026	12667.116	4.486	14.143
Limestone	1000.000	0.111	72.135	2697.934	2.698	5.438
Madison	2003.000	0.076	90.291	4752.240	2.373	5.312
Marion	1022.000	0.116	17.622	919.528	0.900	1.256
Marshall	2091.000	0.104	47.450	2418.779	1.157	2.081
Morgan	3408.000	0.085	65.406	6857.920	2.012	4.379
Winston	679.000	0.124	14.372	485.271	0.715	1.081

Table 4.2 Statistical analysis for each north Alabama County's identified isolated wetlands.

4.4 Cluster Analysis

An analysis was run on the final results in order to determine if there were any spatial patterns to the distribution of geographically isolated wetlands. Upon inspection it was noticed that there were portions of the study area that appeared to contain a higher number of large wetlands than others. A cluster analysis was performed across the entire study area to determine if these areas were larger by a statistically significant amount. Figure 4.2 below shows the spatial distribution of areas with larger than average isolated wetland polygons as determined by the Cluster and Outlier Analysis Tool in ArcGIS. In Figure 4.2 these areas are marked as "cluster". These areas mostly include Lawrence, Limestone, Morgan, Madison, and Jackson County.

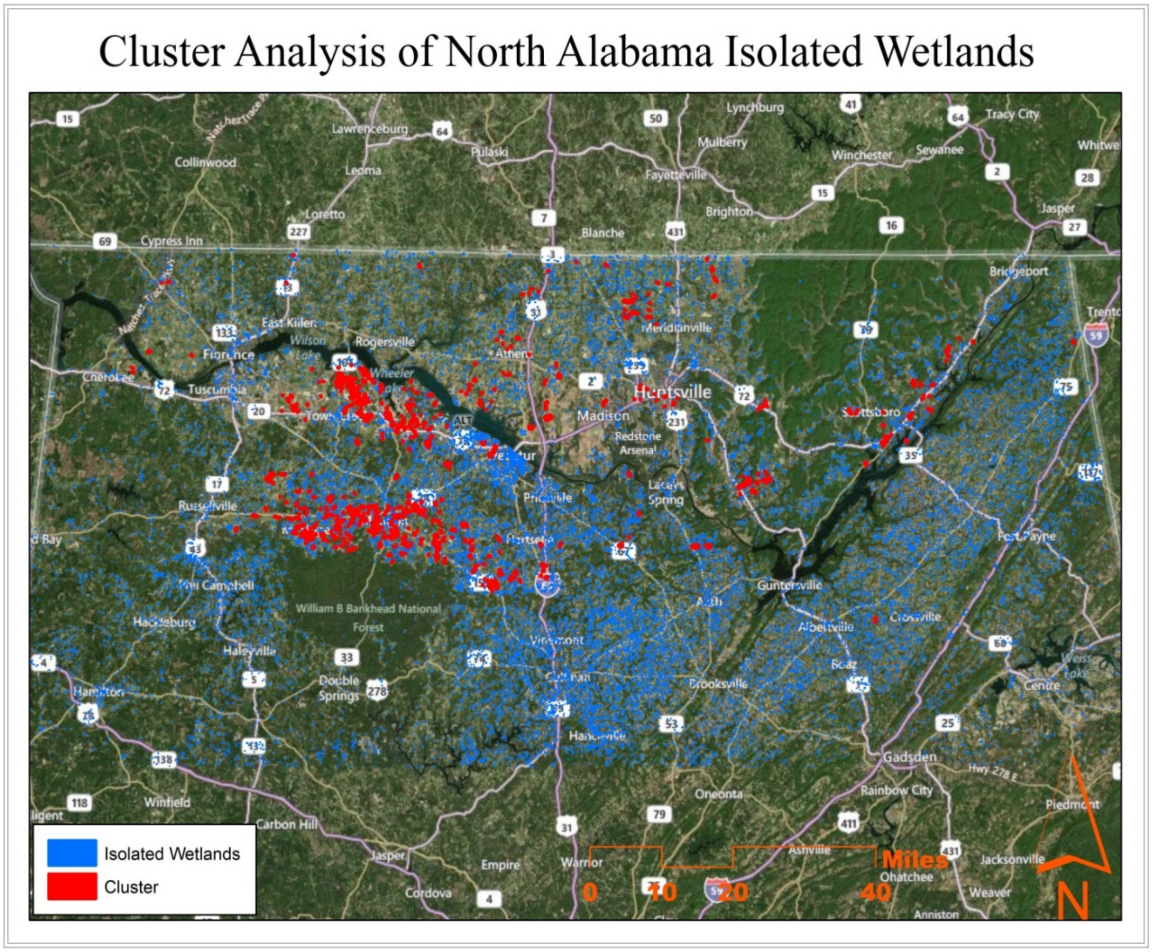


Figure 4.2 Shows the cluster analysis for isolated wetlands based on acreage.

4.5 Accuracy Assessment of Randomly Selected Polygons through Manual Inspection

Accuracy was assessed for geographically isolated wetlands delineated using GeOBIA by manually inspecting 191 randomly selected polygons within the dataset. Polygons were randomly selected using the National Park Service's Alaskapak v.3.0 for ArcGIS 10.x random number selection tool (NPS, 2013). Accuracy was determined using visual inspection NAIP Imagery and each polygon was assigned either a status of correct or incorrect. Table 4.3 below shows the full results of this analysis. Because SSURGO soils data are delineated using methods that are not dependent on remote sensing and the NAIP imagery, all hydric soils polygons were removed prior to random polygon generation. This reduced the number of polygons from 26,400 to 19,198 of which 1% were inspected for accuracy or 191 total inspection polygons. Figure 4.3 shows the locations of the 191 randomly selected polygons used for accuracy assessment.

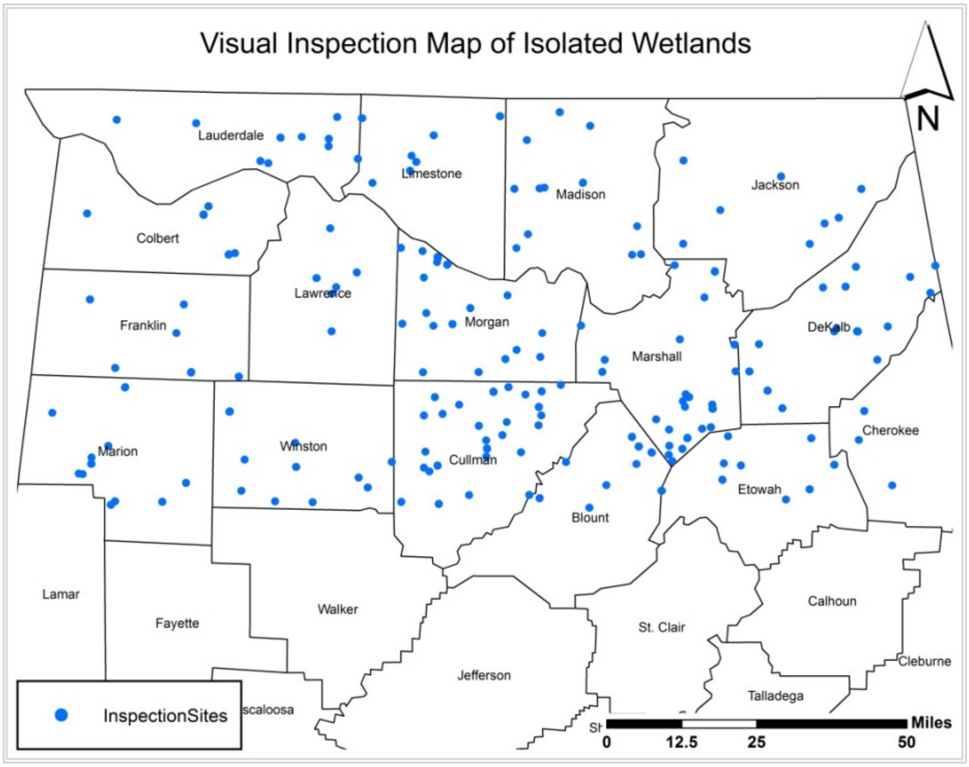


Figure 4.3 A location map for the visual inspection sites

Accuracy_ID	Database_ID	Acres	Status
0	127	1.912341	**CORRECT**
1	151	1.74085	**CORRECT**
2	188	0.261684	**CORRECT**
3	197	0.708201	**CORRECT**
4	202	1.019059	**CORRECT**
5	205	1.416649	**CORRECT**

6	205	1.416649	**CORRECT**
7	354	0.406981	**CORRECT**
8	442	0.334579	**CORRECT**
9	496	0.532757	**CORRECT**
10	555	0.601205	**CORRECT**
11	619	0.309869	**INCORRECT**
12	657	0.252294	**CORRECT**
13	659	0.281946	**CORRECT**
14	682	0.134425	**CORRECT**
15	740	0.605406	**CORRECT**
16	754	0.854487	**CORRECT**
17	774	0.870549	**CORRECT**
18	785	0.347923	**CORRECT**
19	796	0.77146	**INCORRECT**
20	826	0.258471	**CORRECT**
21	861	0.628881	**CORRECT**
22	907	0.145792	**CORRECT**
23	922	0.350888	**INCORRECT**
24	1032	0.18607	**CORRECT**
25	1123	0.247104	**CORRECT**
26	1176	0.704	**CORRECT**
27	1254	0.135413	**INCORRECT**
28	1302	0.1621	**INCORRECT**
29	1609	0.373869	**CORRECT**
30	1861	0.539676	**CORRECT**

31	1894	0.475182	**CORRECT**
32	1922	0.153699	**CORRECT**
33	1956	2.938813	**CORRECT**
34	2123	0.232525	**CORRECT**
35	2285	0.871784	**CORRECT**
36	2381	1.124819	**CORRECT**
37	2386	1.878735	**CORRECT**
38	2468	1.598765	**CORRECT**
39	2498	0.22956	**CORRECT**
40	2623	0.495444	**CORRECT**
41	2692	0.372139	**CORRECT**
42	2699	0.439105	**CORRECT**
43	2704	2.800434	**CORRECT**
44	2804	0.730688	**CORRECT**
45	3505	0.138378	**CORRECT**
46	3566	0.162348	**INCORRECT**
47	3681	0.261189	**CORRECT**
48	3740	4.040898	**CORRECT**
49	3748	0.219923	**INCORRECT**
50	4041	0.24488	**CORRECT**
51	4199	0.296278	**CORRECT**
52	4312	0.222641	**CORRECT**
53	4475	0.689668	**CORRECT**
54	4607	0.164819	**CORRECT**
55	4782	0.358796	**CORRECT**

56	4963	0.171985	**CORRECT**
57	4993	5.00164	**CORRECT**
58	5056	1.157684	**CORRECT**
59	5153	1.752217	**CORRECT**
60	5180	1.11963	**CORRECT**
61	5282	0.154687	**CORRECT**
62	5286	0.418101	**CORRECT**
63	5446	1.568619	**CORRECT**
64	5774	0.344464	**CORRECT**
65	5795	0.639012	**CORRECT**
66	5815	0.176927	**CORRECT**
67	5829	0.170749	**CORRECT**
68	5870	0.36695	**CORRECT**
69	5897	0.146533	**CORRECT**
70	6102	0.149251	**CORRECT**
71	6185	0.149498	**INCORRECT**
72	6186	1.976094	**CORRECT**
73	6299	0.600711	**CORRECT**
74	6376	1.0198	**CORRECT**
75	6398	0.744031	**CORRECT**
76	6611	0.828294	**CORRECT**
77	6689	1.005221	**CORRECT**
78	6705	1.831044	**CORRECT**
79	6745	1.734179	**CORRECT**
80	6758	0.830765	**CORRECT**

81	6796	0.143815	**INCORRECT**
82	7036	0.650626	**CORRECT**
83	7073	0.456896	**CORRECT**
84	7125	0.652108	**CORRECT**
85	7184	1.996851	**CORRECT**
86	7305	0.129977	**INCORRECT**
87	7410	0.174456	**CORRECT**
88	7569	0.356077	**CORRECT**
89	7681	26.522209	**CORRECT**
90	7732	0.545606	**CORRECT**
91	7826	0.137637	**CORRECT**
92	7846	0.815444	**CORRECT**
93	7892	0.673607	**INCORRECT**
94	7898	0.642719	**CORRECT**
95	7980	0.455908	**CORRECT**
96	8105	0.124294	**CORRECT**
97	8249	0.386224	**CORRECT**
98	8337	0.310363	**CORRECT**
99	8346	0.177174	**CORRECT**
100	8449	0.633823	**INCORRECT**
101	8488	1.226132	**CORRECT**
102	8644	0.411429	**CORRECT**
103	8707	0.291089	**CORRECT**
104	9197	0.452942	**INCORRECT**
105	9210	0.386224	**CORRECT**

106	9216	0.191506	**CORRECT**
107	9599	0.344464	**CORRECT**
108	9603	0.228819	**CORRECT**
109	9628	0.169019	**CORRECT**
110	9688	0.343475	**CORRECT**
111	9881	0.30888	**CORRECT**
112	10020	1.000279	**CORRECT**
113	10035	0.425761	**CORRECT**
114	10104	0.926641	**CORRECT**
115	10131	0.550796	**CORRECT**
116	10300	0.214981	**CORRECT**
117	10343	0.311599	**CORRECT**
118	10350	3.094983	**INCORRECT**
119	10416	0.770719	**CORRECT**
120	10490	0.178409	**CORRECT**
121	10520	0.388942	**CORRECT**
122	11366	0.136155	**CORRECT**
123	11422	0.154687	**INCORRECT**
124	11490	0.591815	**CORRECT**
125	11623	0.131954	**CORRECT**
126	11915	0.949375	**CORRECT**
127	11942	0.659027	**CORRECT**
128	11980	0.124294	**INCORRECT**
129	12132	0.606641	**CORRECT**
130	12535	0.63407	**CORRECT**

131	12622	0.144803	**INCORRECT**
132	12829	0.714626	**CORRECT**
133	12865	0.162842	**INCORRECT**
134	12915	2.644758	**CORRECT**
135	12936	0.224124	**CORRECT**
136	12971	0.426996	**CORRECT**
137	12987	0.153946	**INCORRECT**
138	13062	0.488525	**INCORRECT**
139	13401	0.9899	**CORRECT**
140	13533	2.126333	**INCORRECT**
141	13543	0.445282	**CORRECT**
142	13717	1.223167	**CORRECT**
143	14151	0.160618	**CORRECT**
144	14331	1.214518	**CORRECT**
145	14442	0.5078	**CORRECT**
146	14454	0.306657	**CORRECT**
147	14475	0.68102	**CORRECT**
148	14509	0.68868	**CORRECT**
149	14544	0.258718	**CORRECT**
150	14679	0.236973	**CORRECT**
151	14771	0.232278	**CORRECT**
152	14785	0.556726	**CORRECT**
153	14793	0.156664	**INCORRECT**
154	14812	0.554749	**CORRECT**
155	15018	0.420325	**CORRECT**

156	15061	0.182116	**CORRECT**
157	15090	0.809514	**INCORRECT**
158	15099	0.500881	**CORRECT**
159	15587	0.293313	**CORRECT**
160	15595	0.198425	**INCORRECT**
161	15634	1.512773	**CORRECT**
162	15691	0.149004	**CORRECT**
163	15699	0.159877	**CORRECT**
164	15784	0.166054	**CORRECT**
165	15802	0.375104	**CORRECT**
166	15994	0.307151	**CORRECT**
167	16108	2.467832	**CORRECT**
168	16186	0.247846	**CORRECT**
169	16205	0.717838	**CORRECT**
170	16213	0.356077	**CORRECT**
171	16436	0.202378	**CORRECT**
172	16446	0.330379	**CORRECT**
173	16552	0.125282	**INCORRECT**
174	16653	0.12973	**CORRECT**
175	16657	0.212016	**CORRECT**
176	16904	0.142332	**INCORRECT**
177	17081	0.140108	**CORRECT**
178	17140	0.161359	**CORRECT**
179	17239	0.74502	**CORRECT**
180	17347	0.131212	**CORRECT**

181	17716	0.95407	**CORRECT**
182	17718	0.168772	**INCORRECT**
183	17728	0.253035	**INCORRECT**
184	17754	0.141838	**INCORRECT**
185	17957	0.490255	**INCORRECT**
186	18136	0.347182	**CORRECT**
187	18412	0.158147	**CORRECT**
188	18736	0.589591	**CORRECT**
189	18914	0.134672	**INCORRECT**
190	18997	1.546874	**CORRECT**
191	19032	0.872031	**CORRECT**

Table 4.3 The results of the accuracy assessment using manual inspection

Accuracy assessment reveals that of the 191 polygons that were visually inspected, 160 were correct or an overall accuracy of 83.77%. Incorrectly identified areas consisted mostly of rooftops, pavement, and shadows. It should be noted that the time required identifying any obviously incorrect areas the way it was performed here was significantly less than the time required to manually delineate correct areas from the imagery. This could perhaps be incorporated into a functional workflow for correcting remotely identified areas using GeOBIA in which the process while not yet fully automated would still require significantly less time than manual interpretation. Field verification was also used due to the fact that this study was incorporated with another, larger study being funded by the Environmental Protection Agency (EPA) which as part of their standards for quality control requires field verification for accuracy assessment.

4.6 Accuracy Assessment of GeOBIA Classification via Field Verification

Field verification for areas digitized as isolated wetlands was conducted to determine accuracy of classification. In total there were 57 verification sites located in Jackson and Marshall County. This particular area was chosen because of the researcher's familiarity with the area and access to private and public lands. Field maps were prepared for areas containing identified isolated wetlands and were used during verification. Areas on the maps were assigned check marks when verified as correct or incorrect and entered into a spreadsheet afterwards as well as the areas latitude and longitude coordinates. Accuracy was determined by evaluating correctly classified sites with respect to the total number of classified polygons. Table 4.4 shows the database identification number, geographic coordinates, and verification status of all 57 sites. Figure 4.4 shows an example of identified isolated wetlands and Figure 4.5 shows an example of areas identified as geographically isolated.

Database ID	Longitude	Latitude	Status
18845	-86.1810	34.9169	Correct
18880	-86.0823	34.9231	Correct
18869	-86.0690	34.9202	Correct
18853	-86.0789	34.9181	Correct
18840	-86.0740	34.9151	Correct
18859	-86.0874	34.9188	Correct
18814	-86.0830	34.9085	Correct
18797	-86.0873	34.9060	Correct

18688	-86.0844	34.8870	Correct
18634	-86.0817	34.8745	Correct
18528	-86.0972	34.8616	Correct
18539	-86.1031	34.8640	Correct
18608	-86.0986	34.8706	Correct
18483	-86.1027	34.8580	Correct
18482	-86.0985	34.8579	Correct
18467	-86.1018	34.8553	Correct
18419	-86.1081	34.8459	Correct
18389	-86.1107	34.8417	Correct
18395	-86.1149	34.8430	Correct
18369	-86.1122	34.8385	Correct
18321	-86.1042	34.8289	Correct
18311	-86.1048	34.8277	Correct
18259	-86.1051	34.8204	Correct
18274	-86.0963	34.8220	Correct
18256	-86.0936	34.8201	Correct
18230	-86.0879	34.8163	Correct
18208	-86.0935	34.8140	Correct
18173	-86.0935	34.8140	Correct
18169	-86.0971	34.8097	Incorrect
17893	-86.1277	34.7864	Correct
17888	-86.1262	34.7866	Correct

17873	-86.1257	34.7857	Correct
17850	-86.1269	34.7838	Correct
17895	-86.1230	34.7871	Incorrect
17673	-86.1516	34.7728	Correct
17682	-86.1474	34.7736	Correct
17687	-86.1450	34.7742	Incorrect
17681	-86.1443	34.7728	Correct
18020	-86.0257	34.7951	Correct
18018	-86.0252	34.7950	Correct
18006	-86.0301	34.7943	Correct
18051	-86.0295	34.7969	Correct
18008	-86.0500	34.7943	Correct
17931	-86.0269	34.7888	Correct
18177	-85.9764	34.8099	Correct
18196	-85.9764	34.8120	Correct
17913	-85.9655	34.7870	Correct
17855	-85.9577	34.7834	Correct
17795	-85.9606	34.7799	Correct
17781	-85.9588	34.7790	Correct
17720	-85.9591	34.7749	Correct
16866	-86.0122	34.6631	Incorrect
16822	-86.0178	34.6587	Incorrect
16798	-86.0017	34.6572	Incorrect

11377	-86.2608	34.5149	Correct
11384	-86.2577	34.5152	Incorrect
11354	-86.2586	34.5124	Correct

Table 4.4 GPS coordinates of the field verification sites with verification status

Figure 4.4 Areas classified as isolated wetlands by GeOBIA and hydric soil data

These results show that of the 57 verification sites 50 were confirmed as wetlands which yield an overall accuracy of 87.7%. These errors are of commission rather than omission where those mapped as isolated wetlands were revealed to be incorrect. This study makes no attempt to discern accuracy with respect to errors of omission. The sites revealed as incorrect were mixed between incorrectly classified rooftops, asphalt, and shadows as well as incomplete wetland polygons.

Figure 4.5 Shows an example of a correct and incorrect verification site

4.7 GeOBIA vs. Traditional NWI Methods

The most distinct difference between traditional wetland mapping and GeOBIA is the expandability and automation that GeOBIA can potentially provide. During the course of this project an area of approximately 12,000 square miles (750,000 acres) was evaluated which required an active processing time of 60 hours. By comparison it required a single photo-interpreter a full 40 hour workweek to evaluate a single USGS 7.5 minute orthoquad for the creation of the National Wetlands Inventory (NWI) (Norton, 2013). Extrapolating these figures for further comparison it could be said that in order to obtain the detail of this study, which admittedly lacks the Cowardin classification complexity of the NWI, GeOBIA outperformed traditional wetland analysis by a 99.26% reduction in analysis time required. While this figure does not include time required for pre-processing, post-processing, and ruleset development it still demonstrates the potential of large reductions in time required to complete wetland mapping projects. This type of reduction in time and manpower required would also significantly reduce the financial requirements of large wetland mapping projects from tens of millions of dollars (NWI) to possibly as low as only a few hundred thousand dollars for a study area of the same size.

4.8 Results

The total number of areas identified as geographically isolated wetlands within the study area was 26,461 with an average extent of 1.859 acres. There was a total wetland area of 49,139.5 acres identified as geographically isolated with the largest single area consisting of 463 acres and the smallest consisting of .028 acres. Lawrence County had the largest average wetland size at 4.48 acres per wetland and Lamar County had the smallest average wetland size at .58 acres per wetland. While there were over twenty six thousand areas identified in the study the entire area comprises less than 1% of the total overall area of the 17 north Alabama counties studied. Of the 26,461 areas identified as geographically isolated wetlands 19,191 were identified by GeOBIA and 7,270 were previously delineated areas of hydric soils or 73 percent to 27 percent respectively.

The cluster analysis shows that the areas that lie north of the Tennessee River Divide and west of the Appalachian Mountains contained a statistically significant ($p > .05$) number of large wetlands compared with the rest of the study area. These areas where mostly comprised of Lawrence and Morgan County either just south of the Tennessee River or just north of the Bankhead National Forest. Another area that appears to contain a statistically significant cluster of large wetlands was in Jackson County to the west of the Tennessee River/Guntersville Lake. These results suggest that the proximity of large water bodies to mountain ranges has an impact on the average size of geographically isolated wetlands.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary

Prior to the SWANNC ('01) and Rapanos ('06) decisions, isolated wetlands fell under the same regulatory jurisdictions as all other, more traditional wetlands within the United States. After these decisions though, there has been an increased interest in isolated wetlands due to their possible loss of federal regulatory protection. According to previous studies, isolated wetlands serve a vital role in the formation and maintenance of unique and highly variable ecosystems as well as water quality control for larger waterbodies located downstream (Leibowitz, 2003; Naugle et al., 2000; King, 1998; Robinson, 1995; Gibbs, 1993; Bennett and Nelson, 1991; Ludden, 1983; Moore and Larson, 1979). One study has shown that isolated wetlands have the potential to represent over 50 percent of the number of an area's wetlands and between 30 to 50 percent of an area's total wetland extent. However, there still remain no national estimates for isolated wetlands (Tiner, 2003a).

One of the main objectives of this thesis is to estimate the total number and spatial extent of geographically isolated wetlands in north Alabama. To accomplish this over a large study area, mapping efforts required the construction of automated Geographic Object Based Image Analysis (GeOBIA) algorithms which utilize image segmentation and classification in conjunction with traditional remote sensing techniques. The imagery used in this thesis was collected and prepared by the National Agricultural Imagery Program (NAIP) during the summer of 2011. This imagery acquisition program is funded by the United States Department of Agriculture's (USDA) Farm Service Agency (FSA) through the Aerial Photography Field Office (APFO) and is made available to the general public at no additional cost. This particular imagery dataset contained four spectral bands (Blue, Green, Red, Near-Infrared) at a spatial resolution of 1-meter (USDA, 2011). The NAIP imagery is received in a tiled file directory according to the United States Geological Survey (USGS) 7.5 minute topographic quadrangle grid system with each individual image corresponding to one quarter quadrangle or 3.75x3.75 minute with a 300 meter buffer on all sides. Each tile is projected in the Universal Transverse Mercator (UTM) coordinate system using the North American Datum (NAD) of 1983.

The NAIP imagery was imported into eCognition v.8 using a customized algorithm designed to assign each image an individual project folder and naming scheme which resulted in 714 files. The resulting files were then tiled further into arbitrary 3000x3000 pixel sub-tiles in order to increase computer processor efficiency upon batch processing which resulted in 5,712 individual project tiles. These project tiles were then iteratively segmented, classified, and exported using a customized automated algorithm and eCognition Server's batch processing functionality. The resulting dataset was merged with existing hydric soils data using the ArcToolbox to create the isolated wetlands layer.

The soils data used in this mapping study were from the Soil Survey Geographic Dataset (SSURGO) obtained from the Natural Resource Conservation Service's (NRCS) National Geospatial Management Center (NGMC) and made available through the United States Department of Agriculture's (USDA) Geospatial Data Gateway (USDA, 2013). Specifically, the investigation used the all hydric soils data layer which delineates soils that are wet enough to develop anaerobic conditions during the growing season.

In order to determine geographic isolation these datasets were buffered against existing datasets delineating traditional waters and streams as well as commonly accepted floodplains. The National Hydrography Dataset (NHD) is funded and distributed by the United States Geological Survey (USGS) and contains vector data for surface water features such as rivers, streams, and lakes. These data were merged with the Federal Emergency Management Agency's (FEMA) Digital Flood Rate Insurance Map (DFIRM) which delineates the Special Flood Hazard Areas (SFHA). The SFHAs are areas which have a one percent chance of inundation from floodwaters on any given year and are commonly known as the one hundred year floodplain. The two datasets together are buffered to a distance of 40 meters in accordance with the Tiner methodology and any identified wetlands that fall within or intersect this buffer are delineated as non-isolated wetlands and removed from the dataset. Remote accuracy assessment was conducted on one percent of the total number of areas identified as geographically isolated by GeOBIA. Of the 191 areas that were inspected, 160 were identified as correct or an overall accuracy of 83.77%. Field verification of this mapping effort was conducted during the fall and spring of 2012-2013. Overall assessments of the 57 sites visited showed there to be an accuracy of 87 percent with errors of commission coming through mislabeled pavement, rooftops, and shadows. For practical purposes, these errors can be removed through a manual process that would be much more efficient than having to use the traditional digitizing methods.

5.2 Research Question Conclusions

1. How are isolated wetlands defined for mapping utilizing Geographic Information Systems?

For this study isolated wetlands needed to be defined within quantifiable parameters for use within a Geographic Information System (GIS). This type of definition could then be used to extract information from within the database for classification and analysis. Geographic isolation was therefore chosen rather than definitions based on more complex parameters such as hydrological connectivity. This was done because while hydrological connectivity is important in explaining the creation and ecological function of wetlands it is not as easily observed as geographic isolation and is not workable with our current GIS software and computer hardware.

In this study the definition of geographic isolation was based on the methodology used by Tiner, namely the narrowest interpretation of wetlands used in that study where wetlands that were greater than 40 meters from a non-isolated waterbody were considered geographically isolated (Tiner, 2003a). Merging the surface water features that were present within the NHD dataset with the Special Flood Hazard Areas within the DFIRM produced the best available data layer that would then be used as non-isolated waterbodies within the study area. This was accomplished with the overlay and analysis tools within ArcToolbox, specifically the Merge, Union, and Dissolve tools for overlay and the Buffer tool for analysis. The non-isolated waterbodies data was then used to remove the features that fell within or intersected them. The remaining wetlands would then be considered geographically isolated.

2. Can we effectively map potential locations of isolated wetlands using Geographic Object Based Image Analysis?

Wetlands have traditionally been mapped using expert visual interpreters that inspect individual aerial photographs and delineate and classify wetlands either by hand or through heads-up digitizing. According to the gestalt principles, the human mind accomplishes this by using the visual cortex as a holistic and self organizing center of the brain that extracts information and features from imagery by interpreting the image as a whole rather than breaking it into parts (Lang, 2008). The use of automated GeOBIA is an attempt at mimicking this process by clustering pixels, which individually reflect only spectral reflectance, into more meaningful image objects. Given enough time and research perhaps GeOBIA will approach the accuracy of the human visual cortex while vastly increasing productivity over human interpreters. This study was able to achieve an overall accuracy ranging from 83 to 88 percent over an area of 13,000 square miles utilizing automated batch-processing algorithms.

3. What are the key distinctions of isolated wetlands and can this be used to help determine factors important in the development of rulesets?

The distinctions of isolated wetlands used in these algorithms were developed via trial and error as is common in GeOBIA. For this study the rulesets for segmentation were primarily focused on the spectral reflectance within the 4-band NAIP imagery with the rulesets for classification focusing on a combination of spectral reflectance and the size, shape, and texture of the subsequently created image objects. Initial segmentation utilized the multiresolutional algorithm with emphasis placed on Band-4 (Near-Infrared) due to water’s particularly low reflectance at this wavelength. A subsequent segmentation utilizing the spectral difference algorithm joined image primitives that shared similar textual characteristics and this step provided a substantial decrease in processing time required. Through trial and error it was shown that using both of these, consistently created the most meaningful objects that the classification rulesets could use. For classification, spectral reflectance was utilized by establishing a ratio of Band-2 (Green) to Band-4 (Near-Infrared) {[Avg. Band-2]-[Avg. Band-4]} / {[Avg. Band-2]+[Avg. Band-4]}. Also, shape and extent of image objects proved useful for classification with constraints on object asymmetry being applied first and constraints on minimum image object size being used second.

4. What data are most useful in developing models to aid in identifying and mapping isolated wetlands?

For this study the primary dataset was the 1-meter, 4-band NAIP imagery provided by the USDA. Within this dataset Band-4 (Near-Infrared) proved to be the most useful at identifying isolated wetlands due to water's low reflectance at this wavelength. Also useful was Band-2 (Green) because the ratio of this band to the near-infrared band was very useful at identifying wetland features. Other ancillary datasets were used beyond the primary imagery dataset for both, identification of wetlands as well as assisting in establishing geographic isolation. The hydric soils layer of the SSURGO soils dataset contains all the known hydric soils within the study area. This data proved useful because hydric soils are a very strong indicator of the presence of wetlands (NRCS, 2010).

For determining geographic isolation the National Hydrography Dataset (NHD) was used because it held the extent of the known rivers, streams, and lakes within the study area. This dataset appears comprehensive upon inspection, however, the extents of theses waterbodies floodplains were not contained within this dataset. To contribute to an accurate description of geographic isolation the Special Flood Hazard Areas (SFHA), also known as the 100 year floodplain, within the Federal Emergency Management Agency's (FEMA) Digital Flood Rate Insurance Map were used. This floodplain data were merged with the NHD data to create a comprehensive database that depicts the known extent of traditional waterways. This dataset was then buffered at a distance of 40 meters and all identified wetlands that fell within or intersected this area were removed from the isolated wetland dataset.

5. Are there any spatial patterns of isolated wetlands within the study area?

Those areas identified as isolated wetlands were analyzed using the Cluster and Outlier Analysis Tool in the ArcToolbox. This tool was configured to identify areas within the study area that had an unusually high number of large wetlands (in acres). Results showed that 634 isolated wetlands were within statistically significant clusters, in this case statistical significance was determined to be a p-value of .05 or higher, spread mostly across the 5 counties of Lawrence, Limestone, Madison, Morgan, and Jackson. Upon inspection it was noticed that these areas tended to follow the Tennessee River, the largest river in the study area. The likely explanation for this is due to the higher presence of open water and hydric soils that surround the river increased the likelihood that some of these areas would fall outside of the floodplain and its 40 meter buffer. Most of these areas fall within the Moulton Valley where the Tennessee Valley

Divide is directly south and prevents surface water from flowing as freely creating more hydric soils. The areas within Jackson County may be attributed to being bounded to the north by the Appalachian Mountains that also causes a larger number of open waters and hydric soils.

6. What is the spatial extent of isolated wetlands within the study area?

The total spatial extent of land within the study area that was identified as geographically isolated using GeOBIA and traditional GIS analysis is estimated to be 49,139.5 acres. The smallest isolated wetland that was identified was .028 acres and the largest was 463 acres. The average size of areas identified as geographically isolated wetlands was 1.859 acres.

7. How much time is saved utilizing automated methods verses traditional photointerpretation methods?

According to those familiar with past wetland mapping projects relying solely on human photo interpretation an experienced interpreter would only be able to complete a single 7.5 minute orthoquad per 40 hour work week (Norton, 2013). At that rate in order to examine the same area as this study would require 7,120 hours or almost three and a half years for a single interpreter. By comparison, using the automated algorithms and through the batch-processing available within eCognition Server the entire study area within this thesis required only 60 hours of active processing time or 99.26% less time than visual interpretation.

5.3 Importance of Study and Future Work

This study examined the feasibility of mapping isolated wetlands using automated remote sensing techniques. Traditionally, wetland mapping projects have used manual photointerpretation by wetlands experts who were only capable of examining a finite area in a given amount of time. These limitations meant that large wetland mapping projects required very large budgets and years to complete. This also meant that the routine updating of these manually-created datasets was not economically feasible. Mapping wetlands, and anything else for that matter, using automation such as GeOBIA offers the possibility of updating existing wetland datasets as new imagery becomes available and that the speed in which this can be accomplished is limited only by the ever expanding processer capabilities of the modern computer. For this project the amount of time required to complete delineation of isolated wetlands was reduced by approximately 99.2% over that of traditional photointerpretation. Though the overall accuracy was lower than that of traditional wetland maps it could still be possible to correct obvious errors using manual inspection while maintaining a marked improvement of efficiency. Also, given that many of the errors identified in the dataset were building rooftops if statewide availability of airborne LiDAR were to become available many of those errors could be easily avoided. Future studies should examine these potentials and develop appropriate workflows to accommodate these advances.

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