The Extent Of Wetland Vegetation And Wetness Change At Eufaula National Wildlife Refuge From 1984-2012 Examined Using Landsat Thematic Mapper And Enhanced Thematic Mapper Plus Imagery

Jeremy M. Henning
Fort Hays State University, jmhenning@mail.fhsu.edu

Follow this and additional works at: https://scholars.fhsu.edu/theses
Part of the Geology Commons

Recommended Citation
https://scholars.fhsu.edu/theses/86

This Thesis is brought to you for free and open access by the Graduate School at FHSU Scholars Repository. It has been accepted for inclusion in Master's Theses by an authorized administrator of FHSU Scholars Repository.
THE EXTENT OF WETLAND VEGETATION AND WETNESS CHANGE
AT EUFAULA NATIONAL WILDLIFE REFUGE FROM 1984-2012
EXAMINED USING LANDSAT THEMATIC MAPPER AND
ENHANCED THEMATIC MAPPER PLUS IMAGERY

being

A Thesis presented to the Graduate Faculty
of the Fort Hays State University in
Partial Fulfillment of the Requirements for
the Degree of Master of Science

by

Jeremy M. Henning
B.A., University of Alabama

Date_____________________        Approved________________________________

Major Professor

Approved________________________________

Chair, Graduate Council
GRADUATE COMMITTEE APPROVAL

Committee Chair

Chair

Dr. John Heinrichs, Department Chair
Fort Hays State University

Professor

Dr. Greg Farley, Biology
Fort Hays State University

Associate Professor

Dr. Richard Lisichenko, Geosciences
Fort Hays State University

Associate Professor

Dr. Tom Schafer, Geosciences
Fort Hays State University
ABSTRACT

Wetlands provide functions such as reducing flooding of surrounding areas and acting as a rest stop for migrating birds. Eufaula National Wildlife Refuge in Alabama has a natural wetland and six artificial wetlands that are differentiated by how they are drained. Remote sensing derived normalized difference vegetation index and normalized difference wetness indexes were used to obtain information about vegetation and wetness at the wetlands from 1984-2011. A correlation analysis was performed to assess the degree of association between vegetation and wetness as a function of management practices. An ANOVA and agglomerative hierarchical clustering were performed to assess the degree of similarity among the different wetlands based on vegetation and wetness. From the results of the correlation analysis, it was found that there is a statistically significant association between vegetation and wetness. The ANOVA and agglomerative hierarchical clustering suggest that wetlands that are managed similarly have a similar association between vegetation and wetness.
ACKNOWLEDGMENTS

I would like to thank several people for their help and support throughout the research and writing of this thesis. First and foremost, I thank my advisor, Dr. John Heinrichs, for guiding me through the process of graduate school and thesis writing from beginning to end. I would also like to thank Dr. Tom Schafer for helping with cartographic issues, Dr. Richard Lisichenko for his expertise and assistance in GIS, and Dr. Greg Farley for his insight into the biological aspects of wetlands. I thank all four of these professors for their continued support during the thesis-writing process and for always making themselves available to me.

Next, I would like to express my appreciation for the staff at Eufaula National Wildlife Refuge, particularly refuge manager John Earle. Mr. Earle provided me with access to the refuge as well as maps outlining the different wetland areas. I would also like to thank the staff for showing me the best places to visit inside the refuge and their congeniality when I visited.

Third, I thank my parents, William Henning and Jeannie Henning, and my daughter, Emma Henning, for their help and encouragement throughout the graduate school process. Lastly, I would like to thank Sarah Rages for her patience, encouragement, love, and assistance.
## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRADUATE COMMITTEE APPROVAL</td>
<td>i</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vi</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Site Description</td>
<td>1</td>
</tr>
<tr>
<td>Background Information on Wetlands</td>
<td>3</td>
</tr>
<tr>
<td>Degradation of Wetlands</td>
<td>3</td>
</tr>
<tr>
<td>Conservation of Wetlands</td>
<td>5</td>
</tr>
<tr>
<td>Objectives and Hypotheses</td>
<td>6</td>
</tr>
<tr>
<td>METHODS</td>
<td>7</td>
</tr>
<tr>
<td>Remote Sensing of Wetlands</td>
<td>7</td>
</tr>
<tr>
<td>Data Selection</td>
<td>9</td>
</tr>
<tr>
<td>Image Processing</td>
<td>10</td>
</tr>
<tr>
<td>Statistical Analysis</td>
<td>12</td>
</tr>
<tr>
<td>RESULTS</td>
<td>16</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Time Series</td>
<td>16</td>
</tr>
<tr>
<td>Correlation Analysis</td>
<td>18</td>
</tr>
<tr>
<td>Dendrogram</td>
<td>18</td>
</tr>
<tr>
<td>Analysis of Variance</td>
<td>19</td>
</tr>
<tr>
<td>CONCLUSION</td>
<td>21</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>24</td>
</tr>
<tr>
<td>LITERATURE CITED</td>
<td>26</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Map of Eufaula National Wildlife Refuge outlined in yellow. The refuge is located in both Alabama and Georgia. The Chattahoochee River is the boundary between the states of Alabama and Georgia. South of the Refuge is the city of Eufaula, AL. Note the large size of the Chattahoochee River in comparison with Eufaula.</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>Map of Eufaula National Wildlife Refuge outlined in yellow. The refuge is located in both Alabama and Georgia. The Chattahoochee River is the boundary between the states of Alabama and Georgia. South of the Refuge is the city of Eufaula, AL. Note the large size of the Chattahoochee River in comparison with the Eufaula NWR.</td>
<td>33</td>
</tr>
<tr>
<td>3</td>
<td>Map of wetlands included in Eufaula National Wildlife Refuge. Eufaula National Wildlife Refuge is outlined in yellow, gravity drained wetlands have red boundaries, pump drained wetlands have purple boundaries, and natural wetland sections have blue boundaries.</td>
<td>34</td>
</tr>
<tr>
<td>4</td>
<td>NDVI time-series graphs by month. Each graph covers a time series of 1984-2011 and includes all seven wetland areas.</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>NDWI time-series graphs by month. Each graph covers a time-series of 1984-2011 and includes all seven wetland areas.</td>
<td>36</td>
</tr>
<tr>
<td>6</td>
<td>Months of each year for which cloud free Landsat images were available.</td>
<td>37</td>
</tr>
<tr>
<td>7</td>
<td>Correlation coefficient between NDVI and NDWI values by wetland and month. Row colors indicate management practices; boldface values indicate a significant correlation.</td>
<td>38</td>
</tr>
<tr>
<td>8</td>
<td>Graph of average correlation coefficient between NDVI and NDWI values over each month by wetland unit.</td>
<td>39</td>
</tr>
<tr>
<td>9</td>
<td>Dendrogram chart. The shorter the connecting line the more similar the wetlands are in their biomass and wetness relationship.</td>
<td>40</td>
</tr>
</tbody>
</table>
INTRODUCTION

Site Description

Eufaula National Wildlife Refuge (NWR) (Figure 1) was established by the U.S. Army Corp. of Engineers and local communities in 1964 (US Fish and Wildlife Service, 2008). Eufaula NWR was originally established as a habitat for wintering waterfowl (Figure 2) and other migratory animals (US Fish and Wildlife Service, 2008). Eufaula NWR provides a habitat for endangered species as well as a “resting and nesting” place for migratory birds including the American Bald Eagle (US Fish and Wildlife Service, 2008).

The refuge contains 4,526 ha of land and water and is located on and around the Chattahoochee River in both Alabama and Georgia (US Fish and Wildlife Service, 2008). The Alabama portion of the Refuge includes 3,218 ha in Barbour and Russell counties, while the Georgia portion only has 1,307 ha in the counties of Stewart and Quitman (US Fish and Wildlife Service, 2008). Eufaula NWR contains several different habitats that account for 4,496 ha of the land at the refuge and include: 1,440 ha of wetlands, 313 ha of croplands, 1,052 ha of woodlands, 70 ha of grasslands, and 1,618 ha of open water (US Fish and Wildlife Service, 2008). The remaining 29 ha are dedicated to administration (US Fish and Wildlife Service, 2008).

The wetland portion of the refuge is located on the banks of the Chattahoochee River and extends into the Walter F. George Reservoir, and also includes six artificially created wetlands that are managed by the refuge. Controlling soil moisture and planting row crops creates food for wintering waterfowl. Activities such as prescribed burning, reforestation, timber thinning, and controlling the amount of invasive plants, helps to expand the habitat for species living at the refuge and for migratory species (US Fish and
Wildlife Service, 2008). Annual precipitation is approximately 129 cm, March receives the largest amount of precipitation, while October receives the lowest amount (National Oceanic and Atmospheric Administration, 2006). Precipitation typically comes from thunderstorms, however, due to its location near the Gulf of Mexico, tropical storms and hurricanes can also bring precipitation to the refuge (National Oceanic and Atmospheric Administration, 2006). From April through September, high temperatures can exceed 37°C, while the fall and winter months rarely drop below -6°C (National Oceanic and Atmospheric Administration, 2006). On average, the area receives less than 1.5 cm of snowfall per year (US Fish and Wildlife Service, 2005).

Water areas at Eufaula NWR compose approximately 36 percent of the refuge area. Lake Eufaula forms the largest naturally occurring wetland portion of the refuge, containing 837 ha of wetland area. Eufaula NWR contains six wetlands that are managed by the refuge (Figure 3). These managed wetlands can be classified into two different types. Both types are filled with water using inlet pumps, however, the types differ on how their water is drained. Water in type A is drained with outlet pumps while water in type B is drained by gravity-flow. The three wetland units included in type A are: Bradley (303 ha), Houston (84 ha), and Kennedy (182 ha). Type B also has three wetland units including: Uplands (16 ha), Davis-Clark (6 ha), and Molnar (10 ha). The design of artificial wetlands as well as drainage strategy can influence several aspects of a wetland's hydrology including: rate of drainage, water body depth, and water quality (Mitsch, 1992).
**Background Information on Wetlands**

Wetlands are critically important environments, which provide several functions for humans and a variety of species (Lee and Yeh, 2009). Wetlands present at Eufaula NWR act as a habitat for wintering waterfowl, as well as providing necessary water for agriculture (US Fish and Wildlife Service, 2008). Lee and Yeh (2009) concluded that wetlands provide boundary areas between different environments (such as land and water). The roles of wetlands include: (1) acting as a control by reducing flooding and erosion of surrounding land areas; (2) protecting the water quality of surrounding water bodies by retaining nutrients and particulate matter in the water; (3) adding necessary nutrients and minerals into surrounding agricultural areas which help to replenish soils, and (4) existing as areas where diverse animal species live, visit, and reproduce (Cui et al., 2009; Nielsen et al., 2008; Lee and Yeh, 2009; Wright and Gallant, 2006). Wetlands located at Eufaula NWR have similar roles. Wetlands provide flood control for the surrounding area, filter out pollutants in the local hydrology, as well as add nutrients to it, provide water for agriculture, and provide habitats for species living at and visiting the refuge (US Fish and Wildlife Service, 2008).

**Degradation of Wetlands**

The amount of wetland acreage on earth is declining and that roughly half of the world’s natural wetlands have been lost due to human activity (Cui et al., 2009). Wetland area and distribution at Eufaula NWR has been altered due to humans since the Muscogee Creek Native Americans lived there (US Fish and Wildlife Service, 2008).

Prior to the 1800s Muscogee Creek Native Americans inhabited what is currently Eufaula NWR (US Fish and Wildlife Service, 2008). Muscogee Creek Native Americans
built several villages along the banks of the Chattahoochee River (US Fish and Wildlife Service, 2008). In the 1800s Europeans built the port city of Irwinton, later changed to Eufaula (US Fish and Wildlife Service, 2008). In order for the city to expand, large areas of hardwood forest were cleared and the wetlands present were drained for agricultural use (US Fish and Wildlife Service, 2008).

Flood control projects have affected the distribution and composition of wetlands at the refuge (US Fish and Wildlife Service, 2005). These changes also negatively influence the biodiversity of the wetlands and surrounding area. Pollution from agriculture, urbanization of surrounding lands, and industrial waste from surrounding cities also degrade the environmental health of wetlands at Eufaula NWR (US Fish and Wildlife Service, 2008). Fragmentation of habitats at the refuge is also responsible for the degradation of wetlands at the refuge (US Fish and Wildlife Service, 2008). Excessive sedimentation is also impacting the water area and water depth of wetlands present at the refuge and wetland-dependent species (US Fish and Wildlife Service, 2008).

Several animals listed by the US Fish and Wildlife Service rely on wetland habitats to survive (Wright and Gallant, 2006). Bortels et al., (2011) concluded that migrating birds use wetlands as stopping points along their migration routes and that the success or failure of a migration may depend on wetlands. A narrative report conducted by the US Fish and Wildlife Service in 1964 determined that animals native to the area were not observed in the Eufaula NWR area (US Fish and Wildlife Service, 2008). Refuge employees of the time did not observe any signs of deer or wild turkey (US Fish and Wildlife Service, 2008).
**Conservation of Wetlands**

Conservation of wetlands is necessary for the survival of many species (Wright and Gallant, 2006). In order to create standards for conservation an inventory of wetlands was compiled (Wright and Gallant, 2006). The United States National Wetland Inventory (NWI) program was initiated to supply information for the continental United States (Nielsen et al., 2008). In order to be included in the NWI inventory, wetlands “must satisfy at least one of the following conditions: (1) at least periodically, the site supports predominantly hydrophytic vegetation; (2) the substrate is predominantly un-drained hydric soil; (3) the substrate is not soil and is saturated or covered by shallow water at some time during the growing season of each year” (Wright and Gallant, 2006:1).

The United States Fish and Wildlife Service (operating on behalf of the United States Department of the Interior) maintain the National Wildlife Refuge System (NWRS). The NWRS holds several pieces of public land that are devoted to protecting fish, wildlife, and water systems in the United States (US Fish and Wildlife Service, 2008).

In 1963 the Corp. of Engineers impounded parts of the Chattahoochee River for navigation purposes (US Fish and Wildlife Service, 2008). In 1964 the Eufaula NWR was established to help conserve the wetlands, forests, and hydrology of lands around the Chattahoochee River.
Objectives and Hypotheses

The objective of this study is to assess the degree of association between vegetation change and wetness change at the six managed wetlands and one naturally occurring wetland at Eufaula NWR. The hypothesis for this objective is that there is a statistically significant association between vegetation and wetness because vegetation is dependent on water (Roy and Ravan, 1996). A secondary objective is to assess the degree of similarity between vegetation and wetness at the two types (pumped and gravity) of wetlands located at Eufaula NWR. The hypothesis for the secondary objective is that the two different types of wetlands have a dissimilar relationship between vegetation and wetness. This hypothesis is based on the idea that gravity drained wetlands may more closely approximate naturally drained wetlands than pump drained wetlands.
**METHODS**

Remote sensing was used to examine vegetation and wetness of wetlands located at Eufaula NWR. NDVI and NDWI were utilized to estimate the amount of vegetation and wetness. These methods are based on a study done by Lee and Yeh (2009), who used NDVI to study vegetation at wetlands located in Taiwan. In addition, studies conducted by Kleinod et al., (2005) and Jackson et al., (2004) used NDWI to assess moisture and wetness at wetlands.

Next, a time series analysis was used in this study to assess the degree of similarity between vegetation and wetness from 1984 through 2011. In previous years, studies performed by Sonnenschein et al., (2011) and Roder et al., (2008) used time series analyses to gauge vegetation change in the Mediterranean.

The third part of this study was to perform a correlation analysis to evaluate the degree of association between vegetation and wetness. Finally, an ANOVA and a hierarchical agglomerative cluster analysis were used to estimate the degree of similarity between the different wetlands based on vegetation and wetness.

**Remote Sensing of Wetlands**

Satellite remote sensing is an effective tool for collecting and analyzing images of wetlands and has been used since the 1970s (Nielsen et al., 2008, Wright and Gallant, 2006). Satellite remote sensing allows researchers to compare wetlands from one point in time to another point in time (Lee and Yeh, 2009). Landsat 5 TM was chosen for this study because of its spatial and spectral resolution, as well as being free to the public. Landsat 5 TM was launched in March of 1984 and Landsat 7 ETM+ was launched in April of 1999 (Kovalskyy and Roy 2013). Kovalskyy and Roy (2013) state that both
Landsat 5 TM and Landsat 7 ETM+ have a 15’ field of view and are located approximately 705 km above the Earth, in sun-synchronous orbits (Figure 4).

Landsat images the same area of Earth every 16 days (Fuller et al., 1998). Landsat 5 TM has seven detectors, with a spatial resolution of 30m x 30m so each pixel represents 900m$^2$ of land (Conroy et al., 2012). Landsat images with a spatial resolution of 30m x 30m are adequate for detecting wetlands larger than 1.0 ha, such as those examined in the present study (Huang et al., 2011; Wright and Gallant, 2006). Platforms such as SPOT have sensors that have a higher spatial resolution (20m) but the advantage of Landsat is that it includes sensors that detect in the Near Infrared region of the electromagnetic spectrum (EMS); this region is necessary for investigating vegetation change (Fuller et al., 1998). Landsat 7 ETM+ has an eighth band which is panchromatic and has a spatial resolution of 15m x 15m (Fuller et al., 1998). Band one is used for measuring blue radiance, band two is used for measuring green radiance, band three is used for measuring red radiance, and band four is used for measuring near infrared (NIR) radiance (Goward et al., 2003, Maxwell and Sylvester, 2012). Bands five through seven extend further into the infrared part of the EMS (Goward et al., 2003). Landsat Bands one through four can be used identify areas of vegetation because plants absorb blue and red wavelengths and reflect green and near infrared wavelengths (Lee and Yeh, 2009).

Lee and Yeh (2009) concluded that the Normalized Difference Vegetation Index (NDVI) is an effective tool for indicating vegetation changes between time periods. NDVI can be used to indirectly indicate the amount of vegetation of an area but the sensitivity of NDVI to vegetation fluctuates depending on the environment under investigation (Du et al., 2010). Raynolds (2006) determined that NDVI is sensitive to
several factors including the satellite angle and cloud cover over the study site but both problems can be overcome. NDVI was calculated with equation (1), where NIR stands for detectable near infrared radiance and RED stands for detectable red radiance (Lee and Yeh, 2009, Maxwell and Sylvester, 2012).

\[
\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})}
\]

NDVI places vegetation on a decimal scale from -1.0 to 1.0 (Lee and Yeh, 2009). NDVI values at or below 0.2 indicate that there is no vegetation in that pixel, but other land cover classes such as soil, water, or clouds (Maxwell and Sylvester, 2012). Green vegetation, which is dense, typically has an NDVI value of 0.6 or higher (Maxwell and Sylvester, 2012).

The Normalized Difference Wetness Index (NDWI) is an effective tool for indicating wetness in materials such as: soil, water, and vegetation (Kleinod et al., 2005). In combination with satellite remote sensing, this method has provided a way to indirectly indicate if wetness has changed over time (Kleinod et al., 2005, Jackson et al., 2004). NDWI is less sensitive to atmospheric interference than NDVI (Gao, 1996). The wetness index was calculated with equation (2), where NIR stands for detectable near infrared radiance and MIR stands for detectable mid-infrared radiance in the EMS (Kleinod et al., 2005, Jackson et al., 2004).

\[
\text{Wetness index} = \frac{(\text{NIR} - \text{MIR})}{(\text{NIR} + \text{MIR})}
\]

**Data Selection**

Landsat 5 TM and Landsat 7 ETM+ level 1B product images from 1984 through 2011 were acquired from the USGS’s GLOVIS and/or Earth Explorer sites. Level 1B images are terrain corrected and geo-referenced (Yang et al., 2012). In Alabama, the first
frost which is typically in February and last frost which is typically in November were
used to determine which months were most appropriate for this study (Richards and Hart,
2011; Grisso, 1993). One image from each of the following months has been collected for
each year: March, April, May, June, July, August, September, and October. These
months were selected to make sure that all stages of the vegetation cycle at the Eufaula
site could be investigated.

Due to cloud cover, some months in some years were omitted from this study
(Figure 7). Cloud cover over can distort the NDVI image and can give false NDVI values
(Raynolds, 2006). In a study of wetlands done by Julien et al., (2011) Landsat images
were removed from the study if any clouds were found in the image without impacting
the results. June and July are the only months that have greater than five-year intervals of
missing images. Landsat time series with intervals that span more than five years can
introduce an error rate between 10 to 15 percent (Jin and Sader, 2005).

**Image Processing**

The level 1B product images were downloaded as geotiff files and were
uncompressed and extracted using the Winzip program. Since Landsat has seven bands
with each band measuring radiance from a different part of the electromagnetic spectrum
the bands are loaded into ENVI as separate files. All seven bands for each Landsat image
were loaded into ENVI on an image by image basis. In ENVI the seven bands for each
image were layer stacked so that all of the information from each band was located in one
file.

Once the images were layer stacked the images were processed for NDVI and
NDWI. In order to create a derived NDVI and NDWI image, ENVI's band math function
was utilized. In ENVI's band math, the following equation was applied to create an NDVI derived image for every layer stacked image (Maxwell and Sylvester, 2012).

\[(\text{float}(b2)-\text{float}(b1))/(\text{float}(b2)+\text{float}(b1)).\]  

(3)

In equation (3), b2 was assigned to band 4 which represents Near Infrared Radiance and b1 was assigned to band 3 which represent Red radiance. Each pixel in the resulting image has a value between -1.0 and 1.0.

As with the NDVI, the following wetness index equation was entered into ENVI through the band math function and applied to each image to derive a wetness index image.

\[(\text{float}(b2)-\text{float}(b1))/(\text{float}(b2)+\text{float}(b1)).\]  

(4)

In equation (4), b2 was assigned to band 4 which represent Near Infrared Radiance and b1 was assigned to band 5 which is representative of Mid-Infrared radiance. Each pixel in the resulting image has value between -1.0 and 1.0.

After NDVI and NDWI images were derived from the layer stacked images, the images were layer stacked again, in order to establish the proper time series. For example an NDVI layer stack and an NDWI layer stack were created for March. Both stacks started with the 1986 March image and ended with the 2011 March image. Each monthly NDVI and NDWI layer stack only included the images that were available for that particular month. The March image was resized so that only the refuge was visible. Each subsequent monthly image was then resized using the March image file so that all images were resized exactly the same.

The refuge manager at Eufaula NWR provided a digital map of the refuge, compiled in 2012, that included the boundaries for all six managed units and the natural
wetland. The wetland boundaries are not static and overlap each other for the purposes of this study one set of boundaries was used to ensure that the same pixels were used. The map was loaded into Arcmap 10.1 and geo-referenced using known points such as road intersections. The geo-referenced map was then used as a basis for pixel selection.

In ENVI a Red, Green, Blue (RGB) image was produced. The image was resized based on the March resize file. The region of interest (ROI) tool was used to select pixels so that the NDVI and NDWI values of only those pixels selected could be exported. Every pixel in each managed wetland and the natural wetland were selected. Each monthly NDVI and NDWI image was then opened on an image by image basis and the ROIs were applied. The values of those pixels were then saved to ASCII as a text file and imported into Microsoft Excel.

Since the objective of this thesis was to study vegetation and water at Eufaula NWR, through NDVI and NDWI respectively, some data processing was necessary to remove any water-inundated pixel points. NDVI is a study of vegetation on the landscape. Vegetation has NDVI values of zero and above, while other features such as water and clouds can have a negative NDVI value (Raynolds, 2006). In Microsoft Excel, a filter was applied to the whole data set, which displayed any values less than zero. Those NDVI pixel values were then deleted from the entirety of the data set.

**Statistical Analysis**

Each wetland unit had several thousand NDVI and NDWI values. The average and standard deviation of those values for each wetland unit per month were calculated. The averages and standard deviations for each wetland per month were used to derive a trend analysis. Analysis was done on a by month basis for each individual wetland unit.
The equation for the trend analysis is as follows (Sonnenschein et al., 2011; Roder et al., 2008).

\[ Y_t = a \times t + b \]  

with

\[ Y_t = \text{Vegetation at date } t \]

\[ t = \text{date of the oldest image in the time series (March 1984)} \]

\[ a = \text{regression coefficient} \]

\[ b = \text{regression constant} \]

Microsoft Excel was used to determine the average and standard deviation for each month's time series based on each wetland unit. The averages and standard deviation for each wetland unit were copied and pasted into a monthly Excel sheet so that all of the averages and standard deviations by wetland unit were associated with their proper time series. For instance, the March sheet has a time series from 1986 through 2011 because the years 1984 and 1985 had too much cloud cover to obtain accurate NDVI values. A scatter plot was created based on the averages and standard deviations for each month for both NDVI and NDWI.

The secondary objective of this study was to establish if there was any association between vegetation (NDVI) and wetness (NDWI). A Pearson correlation coefficient test was utilized to determine the strength of the association between vegetation and wetness. This correlation is between -1 and 1 (McGrew, 2009). A value of one indicates a perfect correlation, meaning two variable values are perfectly associated (Mcgrew, 2009). For example, if NDWI values decline, then NDVI values would also decline. The Pearson
correlation was calculated for each month and for each of the managed wetland units and used to produce a time series graph.

In order to determine if the correlations were significant, a t-distribution test statistic was calculated for each of the correlation values. n-2 degrees of freedom were used. Degrees of freedom and the t-distribution values were used to reference the Mcgrew (2009) critical values table with a 95% level of confidence to determine if the Pearson correlation coefficient values were significant. For the two-tailed Pearson correlation test statistic, the null hypothesis \((H_0)\) is that the correlation coefficient is equal to zero, and the alternative hypothesis \((H_A)\) is that the correlation coefficient is not equal to zero. With a confidence level of 95%, the alpha was set at 5%. The Pearson correlation coefficient values that were outside the critical value range were displayed in boldface in the correlation table.

In order to determine how similar the two types of wetlands were, an agglomerative hierarchical clustering was performed on the correlation grid using XLSTAT add-in for Microsoft Excel. The output of the result is a dendrogram, which is a diagram that represents similarities between two or more variables (wetland units). The dendrogram clustered the wetland units based on similarity between the six managed wetland units and the one naturally occurring wetland unit. The similarity value ranging from 1.0 to 0 indicates the degrees of similarity between each grouping.

The tertiary objective was to determine if the wetland units in the two types of artificial wetlands (gravity and pumped) are similar or different. An analysis of variance (ANOVA) test was performed to determine the relationship between them. This test had a confidence level of 95% and alpha (the significance threshold) was assigned a value of
0.05. \( H_0 \) cannot be rejected if the p values are 0.05 or less. \( H_0 \) is that the three gravity
drained wetlands have similar NDVI and NDWI values per pixel over time and that the
three pump drained wetlands have similar NDVI and NDWI values per pixel over time.
\( H_A \) was that the wetlands in the two different types (pumped, gravity) are not similar. The
test was performed four times for each month. Once for the pump drained wetlands' 
NDVI values over the time series, once for the gravity drained wetlands' NDVI values 
over the time series, once for the pump drained wetlands' NDWI values over the time 
series, and once for the gravity drained wetlands' NDWI values over the time series.
RESULTS

Time Series

The March NDVI values for all units followed a similar trend over the study period. The NDVI trend was closely grouped for the wetland units except for the Davis-Clark unit (Figure 4). The NDVI values ranged from 0.39 to 0.15. NDVI values dropped from 2004 through 2011.

March NDWI values for each unit followed a similar trend. NDWI is grouped together except for the natural wetland (Figure 5). NDWI values ranged from 0.06 to -0.25. NDVI and NDWI values remained consistent throughout the time series with minor increases and decreases.

The April NDVI and NDWI values followed a similar trend. Both were closely grouped, with NDWI having a tighter grouping than that of the NDVI. NDVI values ranged from 0.2 to 0.6; while NDWI values ranged from -0.15 to 0.24. NDVI and NDWI values remained consistent throughout the time series with minor increases and decreases.

NDVI values for May followed a similar trend. They are loosely grouped with values ranging from 0.65 to 0.3. NDWI follows a similar trend. NDWI values are more tightly grouped with values ranging from .25 to -0.16. NDVI and NDWI values remained fairly constant throughout the time series with small increases that peaked in 1987 and remained constant until a decrease in values starting in 2000.

In June, both NDWI and NDVI followed a similar trend, and wetland units for both NDWI and NDVI are tightly grouped. NDVI had values that ranged from 0.6 to 0.3 and
NDWI had values ranging from 0.25 to -0.2. NDVI and NDWI values follow a similar trend to that of previous months.

NDVI and NDWI were tightly grouped and both followed a similar trend line for the month of July. NDVI values ranged from 0.59 to 0.35 and NDWI had values ranging from 0.25 to -0.2. Both NDVI and NDWI had slight increases in values from 1989 to 1992. Decrease in values was seen in both NDVI and NDWI from 1992 to 2000, where they leveled off and remained constant with small fluctuations until 2011.

August NDVI values followed a similar trend and are tightly grouped. NDWI values were also tightly grouped and wetland units also followed a similar trend to each other that differed from the NDVI trend. NDVI ranged from 0.65 to 0.35 and NDWI ranged from 0.25 to -0.15. NDWI stayed fairly consistent from 1986 to 2011 with only minor fluctuations. NDVI followed a similar trend to that of NDWI but with larger fluctuations.

In September, all wetland units except the Upland unit were tightly grouped. However all wetland units followed a similar trend for NDVI. Wetland units followed a similar trend and were tightly grouped together for NDWI values. NDVI values range from 0.6 to 0.35 and NDWI values range from 0.2 to -0.45.

All wetland units in October follow a similar NDVI and NDWI trend. Wetland units for this month are not closely grouped. NDVI values range from .54 to .25 and NDWI values range from 0.15 to -0.25. NDVI values consistently increase and decrease throughout the whole time series. NDWI follows a similar trend of increasing and then decreasing through the time series as well.
**Correlation Analysis**

For all three types of wetlands (natural, gravity, pumped), gravity drained wetlands have the highest level of correlation between vegetation and wetness (Figure 7). Gravity drained wetlands have four correlation values where $H_0$ could not be rejected: Molnar in August, and Davis-Clark in July, August, and October. The correlation between NDVI and NDWI ranges from 0.56 to 0.95. Correlations from March to June range from 0.58 to 0.95. The correlation values after June range from 0.56 to 0.87.

The pumped drained wetlands have three correlation values where the $H_0$ could be rejected: the Bradley Unit in June and August and the Houston Unit in June and October (Figure 6). There is a direct correlation between NDVI and NDWI for the pump drained wetlands. Values where $H_0$ was rejected ranged from 0.60 to 0.79. For the correlation values where $H_0$ was not rejected, the correlation is not statistically significant based on the comparison of the t-distribution and the degrees of freedom in the critical values table.

The naturally occurring wetland present at Eufaula NWR had a single correlation value in June where $H_0$ could not be rejected (Figure 6). The natural wetland in the month of June had a medium correlation between NDVI and NDWI with a value of 0.57. Based on the comparison of the t-distribution and the degrees of freedom in the critical values table, $H_0$ was rejected in all other months.

**Dendrogram**

From the dendrogram it was determined that gravity and pumped wetlands are dissimilar from each other (Figure 9). The values on the left side of the chart show similarity, the bottom of the chart is one (which represents a high level of similarity), and
the values decrease further away from the x-axis. For the pumped wetlands the Bradly Unit and Houston Unit have a strong similarity with a value of 0.62. The Kennedy Unit (pumped) has a weaker similarity to the other pumped wetlands; the Kennedy Unit's similarity is 0.23. In the gravity drained wetland group the Molnar Unit and Davis-Clark Unit has a strong similarity of 0.68; which is the highest level of similarity of all wetlands. The Upland Unit (gravity) has a medium similarity to the Molnar Unit and Davis-Clark Unit with a value of 0.4. The natural wetland is more similar to the gravity drained wetlands than to the pump drained wetlands. However, the similarity (0.02) to the gravity drained wetlands is low.

**Analysis of Variance**

The ANOVA had a confidence level of 0.95 that H₀ (samples are drawn from the same population) was rejected if the p-value was less than 0.05. For NDVI values at pumped wetlands, the months of March, April, May, and October had p-values that were less than 0.05. For those months H₀ was rejected in favor of Hᴬ. For those months the mean weight of NDVI values from the three pumped wetlands are not the same. The summer months of June, July, August, and September had p-values higher than 0.05. For those months, H₀ was not rejected because, the mean weight of the NDVI values from the three pumped wetlands were similar.

NDVI values at gravity drained wetlands showed similar results to the NDVI values at pump drained wetlands. The months of March, April, May, June, and October had p-values that were less than 0.05. For those months H₀ was again rejected in favor of Hᴬ. Rejection of H₀ means that the weighted mean of NDVI values at gravity wetlands for those months were not drawn from the same population. The summer months of July,
August, and September all had p-values that were higher than 0.05, so $H_0$ could not be rejected.

NDWI values at pumped wetlands had similar results for every month except May. The p-value for the month of May was less than 0.05. The results of the ANOVA for the month of May suggest that the weighted mean of NDWI values from the three pumped wetlands was not similar, because $H_0$ was rejected. March, April, June, July, August, September, and October all had p-values above 0.05. For those months $H_0$ could not be rejected.

While the results of the ANOVA were similar for the NDVI values at the two types (pumped, gravity) of wetlands, the NDWI values for the two types of wetlands was not. Only the months of March, and September had p-values that were higher than 0.05, which meant that $H_0$ could not be rejected. This means that the NDWI values at the gravity drained wetlands for the months of March and September were similar. April, May, June, July, August, and October all had p-values that were less than 0.05, so $H_0$ was rejected in favor of $H_A$. 
CONCLUSION

Based on the results both the primary hypothesis and secondary hypothesis were confirmed. From the results of the time series is a significant change in NDVI and NDWI over time at all wetland units at Eufaula NWR. Based on the averages and standard deviations of all NDVI values, there are changing amounts of vegetation present at all of the wetland units from 1984 to 2011. Wetland units at the refuge have lower levels of vegetation during March than any other months. Vegetation at the refuge wetlands begins to become more apparent during the month of April. Vegetation is more abundant starting in May and lasting through September. There is less vegetation during the month of October than there is during the summer months. These trends show a phenological change in vegetation from the last frost of the year (March) to the first frost of the year (October). This trend suggests that vegetation starts to grow after the last frost of the year in mid-March through April.

Results from NDWI time series analysis show similar results to that of the NDVI time series analysis. In the month of March there is little wetness present at any of the pumped or gravity wetlands. Wetness is slightly present at the naturally occurring wetland during the month of March. Wetness then becomes present at all wetlands during the month of April. During the summer months (starting in May) wetness is consistently shown to be at all of the refuge wetlands. In the month of September from 1985 to 1987 there was little wetness present at any of the natural or managed wetland units. Unlike the NDVI results, October has the highest wetness values.

The results of the correlation analysis demonstrated that there are statistically significant correlations between vegetation (NDVI) and wetness (NDWI) depending on
the type of wetland. Gravity pumped wetlands have a strong correlation between vegetation and wetness. The gravity drained wetlands showed a higher correlation during the months of March and April. The naturally occurring and pump drained wetlands do not show a correlation between vegetation and wetness suggesting that there is little to no dependency between the two. The results of the correlation partially confirm the hypothesis that there exists a direct association between NDVI and NDWI.

One explanation for the strong correlation between NDVI and NDWI for the gravity drained wetlands is that those wetland areas are much smaller in size than the naturally occurring wetland and the pump drained wetlands. The similarity in vegetation at pumped and gravity drained wetlands during the summer months may have occurred because those months have a similar climate than the months of March, April, and October. Statistically significant correlations seen from March through June may exist because vegetation is just starting to grow and is more sensitive to the climate. The lower similarity in the dendrogram between the natural wetland areas and the gravity drained wetlands may be due to the fact that there is no human interference in the way that water is removed.

From the dendrogram it is inferred that natural wetland areas and gravity drained wetland areas have a statistically insignificant amount of similarity. The dendrogram also suggests that the gravity draining management practices are more similar to that of naturally occurring wetlands than the practice of draining wetlands using a pumping system. The results of the agglomerative hierarchical clustering show that wetlands with similar management practices do have similarities based on the Pearson correlation coefficient, since the dendrogram indicates that all of the gravity drained wetlands are
similar to each other but dissimilar to the pump drained wetlands. The results of the
dendrogram confirm the hypothesis that the three wetlands that are pump drained are
similar to each other and that the three wetlands that are gravity drained are similar to
each other but different from the pump drained wetlands.

The results from the ANOVA indicate that vegetation at pumped and gravity
drained wetlands are similar. For both types of wetlands $H_0$ was not rejected in the
summer and $H_0$ was rejected in the early months of March and April, and in the last
month (October) for both pumped and gravity wetlands. The results suggest that
vegetation at gravity drained wetlands are similar to each other in summer months. It also
suggests that vegetation at pump drained wetlands are similar to each other in summer
months, based on NDVI values.

Unlike the NDVI, NDWI values at the managed wetlands did not have similar
ANOVA results. The ANOVA suggests that wetness at pump drained wetlands is similar,
and that the time of year does not influence the similarity of the pumped wetland areas at
Eufaula NWR. ANOVA $p$-values for NDWI at gravity drained wetlands indicate that the
wetlands are not similar to each other and that the time of year does not influence the
similarity of the gravity drained wetlands.
DISCUSSION

Future research and other similar studies could be done at Eufaula NWR to determine why the wetland areas at this refuge are behaving the way they do. An ecological study of the type of vegetation present would be helpful in understanding the phenological changes, and why vegetation is responding in a similar way at both gravity and pump drained wetlands. A vegetation study was done on 25 wetlands in Alberta Canada to determine the types of vegetation present at those wetlands and also to determine what environmental factors are influencing the vegetation (Trites and Bayley, 2009).

A study on water quality at the refuge could give insights and also possibly indicate wetland health. A water quality study may also determine if vegetation is decreasing because of polluted water instead of a decrease in precipitation. A study done on wetlands located in Spreewald, Germany; tested water quality and looked for pollutants; to determine how pollutants were affecting the wetland system (Maassen et al., 2012). A study of the types of birds and the frequency of their visits to each of the three types of wetlands (natural, pumped, gravity) at Eufaula NWR could indicate if birds visit artificial wetlands as often as they do natural ones.

An in-depth climate study would be appropriate and may suggest reasons for vegetation and wetness fluctuations and similarity. A study of precipitation was done on wetlands located in the UK and Ireland to determine how a change in climate (particularly precipitation) could impact wetlands in that region (Dawson et al., 2003). Another study of climate change at wetlands locations was done in the prairie pothole region of western Canada to determine what effect a change in climate (temperature,
precipitation, and standardized precipitation index) would have on wetlands in that region of Canada (Withey and Kooten, 2011).
LITERATURE CITED


Figure 1. Map of Eufaula National Wildlife Refuge outlined in yellow. The refuge is located in both Alabama and Georgia. The Chattahoochee River is the boundary between the states of Alabama and Georgia. South of the Refuge is the city of Eufaula, AL. Note the large size of the Chattahoochee River in comparison with the Eufaula NWR.
Figure 2. Top: A photograph of wintering waterfowl at Eufaula National Wildlife Refuge. Bottom: Wetland area at Eufaula National Wildlife Refuge. Taken by the author December 27th 2012
Figure 3. Map of wetlands included in Eufaula National Wildlife Refuge. Eufaula National Wildlife Refuge is outlined in yellow, gravity drained wetlands have red boundaries, pump drained wetlands have purple boundaries, and natural wetland sections have blue boundaries.
Figure 4. NDVI time-series graphs by month. Each graph covers a time series of 1984-2011 and includes all seven wetland areas.
Figure 5. NDWI time-series graphs by month. Each graph covers a time-series of 1984-2011 and includes all seven wetland areas.
<table>
<thead>
<tr>
<th>YEAR</th>
<th>MARCH</th>
<th>APRIL</th>
<th>MAY</th>
<th>JUNE</th>
<th>JULY</th>
<th>AUG</th>
<th>SEPT</th>
<th>OCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1992</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6. Months of each year for which cloud free Landsat images were available.
Figure 7. Correlation coefficient between NDVI and NDWI values by wetland and month. Row colors indicate management practices; boldface values indicate a significant correlation.

<table>
<thead>
<tr>
<th>Wetland Type</th>
<th>Wetland Name</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRAVITY</td>
<td>Molnar</td>
<td>0.59</td>
<td>0.95</td>
<td>0.87</td>
<td>0.83</td>
<td>0.68</td>
<td>0.47</td>
<td>0.60</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>Upland</td>
<td><strong>0.90</strong></td>
<td>0.86</td>
<td>0.70</td>
<td>0.85</td>
<td>0.68</td>
<td>0.63</td>
<td><strong>0.67</strong></td>
<td><strong>0.88</strong></td>
</tr>
<tr>
<td></td>
<td>D-C</td>
<td>0.91</td>
<td>0.89</td>
<td>0.68</td>
<td>0.72</td>
<td>0.48</td>
<td>0.06</td>
<td><strong>0.57</strong></td>
<td>0.18</td>
</tr>
<tr>
<td>Natural</td>
<td>Natural</td>
<td>-0.02</td>
<td>0.57</td>
<td>0.19</td>
<td>-0.02</td>
<td>-0.07</td>
<td>0.08</td>
<td>0.48</td>
<td>0.01</td>
</tr>
<tr>
<td>Pumped</td>
<td>Bradly</td>
<td>0.29</td>
<td>-0.27</td>
<td>0.48</td>
<td><strong>0.80</strong></td>
<td>0.00</td>
<td><strong>0.61</strong></td>
<td>0.53</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>Houston</td>
<td>0.41</td>
<td>0.38</td>
<td>0.50</td>
<td><strong>0.71</strong></td>
<td>0.33</td>
<td>0.35</td>
<td>0.36</td>
<td><strong>0.62</strong></td>
</tr>
<tr>
<td></td>
<td>Kennedy</td>
<td>-0.43</td>
<td>0.18</td>
<td>-0.26</td>
<td>0.43</td>
<td>0.12</td>
<td>0.35</td>
<td>0.33</td>
<td>0.22</td>
</tr>
</tbody>
</table>

N= 13 17 15 10 9 15 13 21
Figure 8. Graph of average correlation coefficient between NDVI and NDWI values over each month by wetland unit.
Figure 9. Dendrogram chart. The shorter the connecting line the more similar the wetlands are in their biomass and wetness relationship.