Impacts of Cogongrass in South Alabama: Mapping the Extent and Understanding Perceived Threats

by

Batoul Damghani

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
August 3, 2013

Keywords: cogongrass, remote sensing, GeOBIA, economy

Approved by

Luke Marzen, Chair, Professor, Department of Geology and Geography
Toni Alexander, Associate Professor, Department of Geology and Geography
Nancy Loewenstein, Research Fellow, Department of Forestry and Wildlife Sciences
Diane Hite, Professor, Department of Agricultural Economics and Rural Sociology

Abstract

Cogongrass (imperata cylindrica) is an invasive species that was introduced to the United States in the 1900s via seed packing material in shipping containers from South Asia. It spreads by both underground rhizomes and windblown seed. Currently, it is distributed in southeastern US, particularly in the states of Alabama, Florida, Mississippi, Georgia, South Carolina, Texas, and Louisiana. Many natural resources are affected by the spread of this invasive species in Alabama. In this research project, remote sensing is utilized as well as a landowner survey instrument to map current cogongrass locations in South Alabama and assess the documented and perceived impact this invasive species has had upon the management of the land. Both a manual and automated process was as evaluated for mapping the extent on open agricultural lands and right-of-ways. The manual mapping was chosen as the more accurate method currently for mapping cogongrass with an accuracy of approximately 90.5%. Approximately 10,500 acres were mapped in Mobile and Baldwin Counties and it is estimated that it would cost between five to eight million dollars to control this much area of cogongrass. Resource managers surveyed for the study believe that there is a strong economic impact primarily in the timber industry and on livestock production.

Acknowledgments

This thesis would not have been possible without the support of many people. First of all, I would like to express my gratefulness to my advisor, Dr. Luke Marzen, who was abundantly helpful, read my numerous revisions, and gave me insightful comments. It was a great pleasure to me to work under his supervision. Thanks to him for his encouragement, great support, and patience.

Also thanks to my committee members without whose knowledge and assistance, this thesis would not have been successful. I would like to thank Dr. Toni Alexander for giving me insight towards writing thesis and great help with survey methods, the IRB process, and edits. I would like to thanks Dr. Nancy Loewenstein for helping me to fulfill the survey during the joint meeting of SE-EPPC and ALIPC, Dr. Nancy Loewenstein provided great guidance and expertise towards cogongrass. And I would like to thank Dr. Diane Hite for helping me with the survey and edits. I am particularly thankful to Dr. James Miller who inspired me about cogongrass research, my work has greatly benefited from his suggestions. Special thanks to the graduate student friends, including Tyler Jones for his assistance in my field work and help with GeOBIA, Jatinder Alucka for helping estimate costs of controlling congongrass, and Rajesh Sawant for help learning GeOBIA, all who were always offering support. And finally, thanks to the Department of Geology and Geography that were always offering support.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

GIS	Geographic Information Systems
GeOBIA	Geographic Object Based Image Analysis
NAIP	National Agricultural Imagery Program
MS	Multiresolution segmentation

CHAPTER 1

INTRODUCTION

1.1 Study background:

An invasive species is a non-native organism that has caused problems for native plants, animals, and other organisms. It spreads fast because it does not have natural enemies in its new environment to control its proliferation. The international Conservation Union (IUCN) described an invasive species as: “An alien species which becomes established in natural or semi natural ecosystems or habitats, is an agent of change and threatens native biological diversity” (McNeely, 2001; p. 242). Through both the economic impacts and effects on ecosystem services, invasive species have caused the loss of billions of dollars in United States including reductions in both quality and yield for farmers and ranchers (Livingston and Osteen, 2008).

According to Federal Noxious Weed List, cogongrass is one of the worst invasive species in the world (Randoll and Marinelli, 1996). Pine plantations, road-sides and pasture land are primary land uses infested by cogongrass (Randoll and Marinelli, 1996). Different types of natural habitat such as wetlands and forest, savannah, and sand dunes are also impacted by cogongrass (Randoll and Marinelli, 1996).

1.2 Statement of the Problem:

The increased intrusion of cogongrass into the southern states has brought a strong competitor to native vegetation in its natural surroundings. Cogongrass incursion is an excessive threat to the variety of organisms and ecological community of different species found within Alabama, especially in Mobile and Baldwin counties. Various studies have also showed the influence of cogongrass on agricultural lands and associated products which results in reduction of profits (Hubbard et al.,1944; Soerjani,1970; Eussen et al., 1976; Daneshgar et al., 2008).

In some areas when cogongrass is established, its elimination is difficult and there may be ecological impacts associated with control. Expenses associated with the eradication of cogongrass, in addition to further financial losses due to disturbances to ecosystem of those areas are some of the economic distresses.

1.3 Thesis Outline

Chapter1:

Introduction:

Study background

Statement of the problem

Thesis outline

Study area

Significance of Research

Aims and Objectives

Research Questions

1.4 Study Area:

In 1911, cogongrass unintentionally reached the state of Alabama at Grand Bay from Japan (Tabor, 1949, 1952; Dickens, 1974; MacDonald, 2004). As a result of this introduction and such subsequent invasion, an organization called The Alabama Cogongrass Task Force formed to combat this species. Through her relationship with the Task Force, the investigator of this project was able to access data collected in situ from properties across Alabama. The majority of reports were from landowners in Mobile and Baldwin counties which are characterized by a great amount of cogongrass. Therefore, this study was primarily focused on developing methods to map cogongrass in these two counties (Figure 1.1).

A survey instrument was designed to gather information from landowners and resource managers in Alabama as well as other southeastern states. Remote sensing and a survey instrument play a role in determining where to treat cogongrass in Mobile and Baldwin counties.

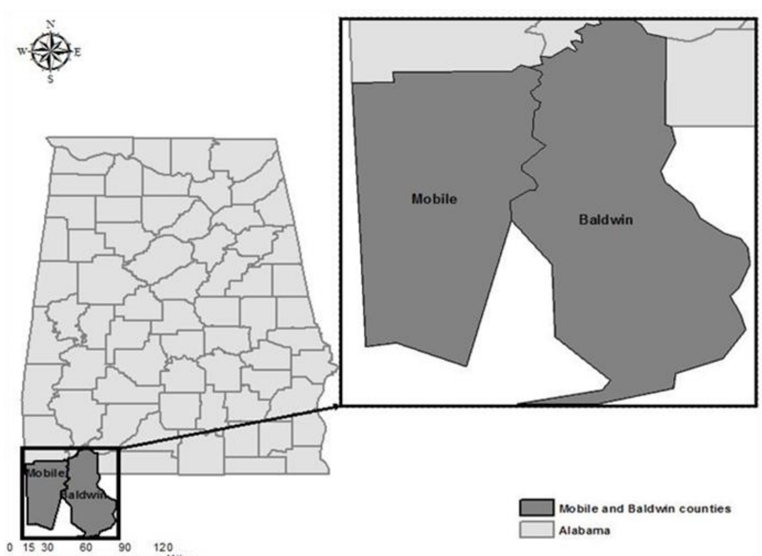


Figure 1.1 Study area for mapping part of this research

1.5 Significance of Research

It is crucial to stop the spread of cogongrass as soon as possible if it is to be contained (MacDonald, 2004). By concentrating on areas that were likely colonized as shown by the mapping methods in this thesis through a combination of remote sensing and field methods, managers may be able to save time and thus money in the fight to control cogongrass. Remote sensing may provide a cost-effective method to monitor the spread of invasive species for landowners and government agencies. For natural resource management, the latest information about the location and amount of invasive species is important for the proficient conservation of native plants as well as ameliorating management activities for agricultural purposes (Asner et al., 2008).

In this study management practices and their impacts are investigated through the survey of landowners and resource managers that participated in the joint meeting of Southeast Exotic Pest Plant Council and Alabama invasive Plant Council, 2012. The survey started with questions about the extent of lands and the kinds of activities that they do on their lands and for an estimate of the percent of lands that are used for these activities such as cropland, forest, or pasture. The questionnaire also asked if they believe they have cogongrass on their lands and if so about the method they would prefer to control cogongrass. The survey included some questions about the costs associated with the removal of cogongrass from lands. This survey is a way to assess the efforts for elimination of cogongrass and the cost that is allocated to management of it. Recognizing the significant contribution of woodland clearings on cogongrass invasion leads to a set of questions about the different usages of woodlands over an extended period of time and percent of income derived from their lands and other sources.

1.6 Aims and Objectives

It has been noted that while the impacts of Cogongrass on the economy and in particular on the productivity of forests, pasture, and orchards are evident, these impacts are yet to have been adequately documented (Loewenstein and Miller, 2007). The first objective of this study involved assessing the impact of cogongrass invasion in southern Alabama by attempting to estimate the amount and spatial extent of cogongrass in the study area of Baldwin and Mobile Counties. To address the first objective, remote sensing technology was used for mapping cogongrass in South Alabama using the National Agricultural Imagery Program (NAIP) datasets. Second, this study attempted to document the impacts and threats of cogongrass have on natural resources, based on the perception of resource managers within Alabama. Efforts to control cogongrass were also assessed with the survey instrument.

1.7 Research Questions

In this study, the following research questions were posed:

1. **Can we effectively use remote sensing to map potential habitat of cogongrass?**

a. What datasets are available to efficiently attempt to map the location of cogongrass over a large area?

b. Given that cogongrass has a unique flowering color; is it practical to find seasonal imagery to match these occurrences?

c. How efficient is it to use aerial imagery for visual examination and manual Heads-up digitizing as opposed to automated methods such as Geographic Object Based Image Analysis? What is the accuracy of the visual examination process vs. the automated process?

2. In which kinds of land use/land cover areas can we detect cogongrass with imagery?

3. What are some benefits of using Geographic Object Base Image Analysis (GeOBIA) for mapping cogongrass patches versus the visual interpretation?

a. Which variables can be used to develop rulesets in the automation process?

b. Which segmentation methods and associated parameters are best in creating objects that represent cogongrass?

c. Which rules help to separate cogongrass from other classes and especially other grasses?

4. How much area s is infested by cogongrass in Mobile and Baldwin County?

5. Can we estimate the economic loss incurred from cogongrass infestations?

6. The survey of resource managers attempts to answer the following questions for a better understanding of cogongrass impacts.

a. In which ways does cogongrass affect landowners and how are they dealing with this invasive species?

b. Is there any difference between economic impacts of cogongrass on different land covers?

c. How substantial are the economic impacts of cogongrass in Alabama?

d. What is the perceived knowledge of resource managers about different threats of cogongrass?

e. How effective are current control methods for controlling cogongrass?

f. How successful are resource managers in controlling cogongrass?

g. What are the attitudes of most resource managers towards the government agencies that help with cogongrass control?

1.8 Methodology

Two geospatial mapping techniques using the latest NAIP Imagery of the study areas were evaluated and compared to find the existing invaded areas of cogongrass in Mobile and Baldwin counties. Heads-up digitizing using a Geographical Information System (GIS) and automated remote sensing methods using Geographical Object Base Image Analysis (GeOBIA) were applied for this study. The purpose of employing these geospatial techniques was to explore the current invaded areas in these two counties and investigate the economic impacts in these counties recognizing that the impact is directly related to the amount of area of Cogongrass infestation. GeOBIA is an automated method in which both rule sets and nearest neighbor classifiers were implemented using a software platform (eCognition) recognized for its effectiveness at performing these associated techniques (Tzotsos and Argialas, 2007; Blaschke, et al. 2008). Reflectance values of the bands, the Normalized Difference Vegetation Index, shape, and compactness were used for recognition of cogongrass patches on NAIP Imagery. Heads-up digitizing and visual examination of the imagery is a more time consuming method compared to GeOBIA; however the results show that it is a more accurate method than GeOBIA for mapping cogongrass in the study areas.

The second part of this study assessed the economic impacts of cogongrass through the experiences of private landowners and resource managers and was conducted through the distribution of a survey instrument. One of the primary aims of this survey was to assess the awareness of landowners and resource managers about cogongrass, the extent to which it affects their land, and the costs associated with controlling its spread.

The survey was undertaken at the joint Meeting of the Southeast Exotic Pest Plant Council (SE-EPPC) and the Alabama Invasive Plant Council (ALIPC) on May 8-10, 2012 in Auburn, Alabama. The questionnaires were distributed to conference attendees, many of whom were landowners and/or resource managers. Survey methods were used to elicit the perceptions of conference participants on ecological impacts of cogongrass on different land cover types.

CHAPTER 2

LITERATURE REVIEW

The literature review begins with a review of the history and biogeography of cogongrass followed by a discussion of the economic impacts. The next section details control methods that are being used to limit cogongrass spread. For the efficient control of cogongrass, resource managers need to be able to find it, also major objectives in this thesis, and the literature on locational mapping and the role of remote sensing in mapping invasive species was reviewed. Next, two kinds of classification methods were presented that are used in remote sensing for extracting invasive species from imagery; a traditional method involving manual editing and a newer automated method called Geographic Object Based Image Analysis (GeOBIA). A section is included reviewing methods for assessment of the accuracy of mapping projects and lastly, this review concludes with a review of surveying methods to investigate the economic impacts of invasive species.

2.1 Historical Background and Biogeography

A number of cogongrass introduction (*Imperata cylindrical*) occurred in the Southeastern U.S. Its introduction in Alabama took place in 1912 through packing materials from Japan (Dozier et al., 1998; Tabor, 1949; Tabor, 1952). Cogongrass from the Philippines was also introduced in 1921 as a possible forage crop in Mississippi

(Dickens, and Buchanan 1971; Hubbard et al., 1944: Paterson et al., 1983; Tabor 1949, 1952; Dozier et al., 1998). Over the years some of the most common names of cogongrass have been Japgrass, bladygrass, speargrass, alang-alang, and lalang-alanag (Dozier et al., 1998, MacDonald, 2004). It is among the ten most vexatious weedy pests of the world and it has been considered as an invasive plant in over seventy countries (MacDonald, 2004). The extensive rhizomes produced by cogongrass play an important role in its spread along with seeds that are brought to their new environments by winds and on equipment (Holm et al., 1977). The rhizomes have cataphyll covers that protect them, and viability in younger rhizomes is less than older rhizomes (Ayeni and Duke, 1985; English, 1998; MacDonald, 2004). In other words, mature rhizomes produce more shoots than the younger rhizomes (Ayeni and Duke, 1985; MacDonald, 2004). The rhizomes of cogongrass are sharp which can harm the roots or bulbs of other plants (Boonitee and Ritfhit, 1984; Eussen and Soerjani, 1975; Terry et al., 1997; MacDonald, 2004).

Creation of rhizomes from seedlings is followed by two arguments. One study shows that rhizomes develop within a few weeks after germination (Holm et al., 1977; MacDonald, 2004) while another study shows that it takes about eight weeks (Shilling et al., 1977, MacDonald, 2004). Cogongrass grows both in shade and full sun and it is adaptive to many environments, especially fire-based ecosystems (MacDonald, 2007).

In terms of climate, warmer temperatures provide a favorable habitat for cogongrass settlement (Dozier, 1998). Bryson and Carter (1993) showed that cogongrass does well in areas with 75-500 cm of rainfall per year. There is disagreement about the survival of cogongrass in lower temperatures; Hubbard et al. (1944) reported that cogongrass cannot tolerate temperatures lower than -8 degrees C, while Wilcut et al. (1988) showed that cogongrass can endure -14 degrees C.

Cogongrass produces many seeds, often over 3000 per plant (MacDonald, 2004). It can form dandelion like seeds that can be dispersed by winds (Miller et al., 2010). The seed heads of cogongrass are white, cylindrical in shape and usually between 1-8 inches in length (Miller et al., 2010). The seeds produced by each plant can spread very fast and disperse as far as 50 miles (MacDonald, 2007). Establishment of seeds is possible in both areas with no disturbance such as savannas (King and Grace, 2000) and in disturbed areas with less vegetation competition (MacDonald, 2004). Another situation that helped the growth of seeds is burning (King and Grace, 2000). Young plants cannot survive flooding, and sprouting is not possible in more aquatic conditions; however older plants can tolerate wetter conditions (King and Grace, 2000).

Charismatic flowers are one of the main features of cogongrass during spring (April and May) and the first sign of infestations is often the fluffy, flashy blooms of cogongrass (Miller et al., 2010) The bright, white flowers also be useful for remote detection of the weed. However, MacDonald (2004) points out that timing of flowering can be “highly variable depending on region and environment.”

Often disturbances in the environment and vegetation can be mapped and used to estimate the potential likelihood of intrusion in a new area. Various environmental factors such as light intensity and proximity to certain geographic features like roads and forests were studied in a case study in Nepal, forecasting the prospective location of Chromolaena, an invasive species, and a statistical model was developed to all of these factors influence on its spread (Joshi et al., 2006).

Walsh et al. (2006) studied the environmental variables that were dominant in the growth of invasive plants in the Galapagos Islands. The role of climatic elements such as rainfall , temperature, soil moisture, the ability for germination, and original of several invasive plants were studied invasive species were grouped into categories based on their response to other ecological, biological, and human impacts (Thuiller et al., 2006).

Wind dispersion from infested areas along north-south highways in Alabama is one of the ways that aids the expansion of cogongrass to new territories (Dozier, 1998). Patterson and McWhorter (1983) reported that the scattering of cogongrass in Mississippi mostly occurred by rhizomes that were relocated through road building activities, with some spreading by winds (Dozier, 1998).

2.3. Economic Impacts

Many plants commonly used for forage can be superseded by cogongrass. From 1939 to 1949, more than a thousand acres in the state of Florida were planted to cogongrass to test whether cogongrass was suitable for forage. The results showed that cogongrass is indeed a poor forage for livestock (Tabor, 1952; Hall, 1983; Coile and Shilling, 1993; MacDonald, 2007). One reason for this is that the consumption and digestion of cogongrass is difficult due to its sharp bladed leaves and the great amount of silica in its leaf. In addition, the plant contains low amounts of nitrogen that makes it a non-beneficial food source for livestock (MacDonald, 2007). Many of the agricultural lands within Alabama are used for grazing livestock; and livestock farming is negatively impacted on lands infested with cogongrass due to reduced forage and livestock production.

Cogongrass can grow in modest shade, but generally does best in full sun light (Hubbard et al., 1944; MacDonald, 2007). The light compensation point of cogongrass is about two percent of full sun (Gaffney, 1996; Ramsey et al., 2003; MacDonald, 2007) and this enables cogongrass to maintain itself under forest canopies (MacDonald, 2007). Therefore, it can grow beneath the large trees in wooded areas and invade open areas when they are disturbed by natural or human causes such as clear-cutting forest plantation stands (MacDonald, 2007).

Cogongrass forms a dense thatch of leaves that makes it difficult for other plants to thrive (MacDonald, 2007; Johnson and Shilling, 2005). Cogongrass can burn very hot and damage the native ecosystem. Due to more intense and frequent fires, large infestations of cogongrass can noticeably change the normal fire routine of a fire-driven ecosystem (MacDonalad, 2007; Jose et al., 2002). As a result, biodiversity is drastically reduced, as is secondary succession (Eussen and Wirjahardja, 1973; Seavoy, 1975; Eussen, 1980; Lippencott, 2000; MacDonald, 2007).

2.4. Control of Cogongrass

There are methods of biological control but none of them are commercially available and they are still being researched. There are some insects and pathogens that are natural enemies of cogongrass. Gall midge is an insect considered to be an enemy of cogongrass. It can demolish the shoot meristems, when the rhizomes weaken (Soerjani, 1970; Mangoendiharjo, 1980; MacDonald, 2007). There are some pathogens such as

Drechslera gigantean that also can be applied for controlling cogongrass and it mainly just destroys the leaves and does not affect the rhizomes which are necessary for control (MacDonald et al., 2001; Yandoc, 2001).

Other methods of controlling cogongrass involve using herbicides. Glyphosate and imazapyr are the most widely used herbicides for this purpose (Ramsey et al., 2003; Shilling et al, 1997; Willard et al, 1997; Alvalapati et al.2007). Herbicides are used for control of cogongrass infestations. In areas where surroundings vegetation is of concern, use of glyphosate (which has soil activity) can be applied twice a year for several years or until it disappears. In areas where soil activity is not of concern, impazapyr can be applied once a year, until it disappears. Monitoring for any growth should take place as rhizomes need to be killed or else cogongrass will resprout (Dozier et al, 1998).

Other methods such as burning, mowing, or disking can work to remove cogongrass temporarily but to be successful they need to be continuously repearted for cogongrass control (Gaffney, 1996; Willard et al, 1996; Alvalapati et al.2007). Disking can be used in open flat areas and it especially effective on recently established spots. To be effective rhizomes must be disked every 1.5 months until it is eradicated (Larson and McCowin, 2009). These processes are used on new growth especially when herbicide use is not desirable or if management plans involve cultivating the site with agricultural crops. For a successful eradication of cogongrass that has been established for a long period of time in a specific area, a combination of all or some of these methods should be applied along with using herbicides (Dozier et al, 1998; Johnson, Gaffney, and Shilling, 1997; Jose et al, 2002; Alvalapati et al.2007).

There are various factors that can influence the efficacy of herbicides for cogongrass eradication, including the time of the year, the needed number of applications, and the rate of growth of cogongrass in that specific area (Shibu, et.al., 2002). There are two kinds of conditions for controlling cogongrass with herbicides. In the first situation, the kinds of herbicides that are used are soil-active herbicides which are used for invaded areas where cogongrass has been well established and existed there for a long time. And the second condition uses herbicides for recently invaded areas and these are called not-soil-active herbicides. For the patches that are well-established, both imazapyr and glyphosate are often applied but for the newly established areas just the glyphosate is more likely to be used. Glyphosate does not continue to exist in the soil after application whereas imazapyr does.

It is also important to note that Imazapyr kills hardwood trees and longleaf and slash pines. Imazapyr, which is more appropriate for well-established cogongrass is most effective when applied between August and October before the temperature drops and leaves begin to senesce. After the treatment, it may take up to 2 months for leaves to brown. Imazapyr should be applied annually until the infestation is eradicated (Larson and McGowin, 2009).

2.5. Remote sensing of Invasive Species

The spectral characteristics of healthy leaves are recorded from reflectance by remote sensors the produce images that can be analyzed (Jensen, 2007). A healthy plant will reflect highly in the near-infrared portion of the spectrum while absorbing red light. Various species will likely reflect differently, possibly allowing identification and mapping of certain species (Joshi, 2005). Remote sensing technology is a tool for detecting invasive species affecting forests, rangeland, and pasture environments (Lass et al., 2005). Discovering invasive plants locations and prediction of their new habitats is fundamental for control of their dispersal (Cord et al., 2010). Remote sensing of cogongrass could potentially help to manage and control it better by providing the ability to monitor and map its diffusion. Often it is not possible to access private lands to monitor the spread of cogongrass using solely traditional field mapping methods. However, remote sensing may provide information about these remote areas affected by cogongrass for resource managers trying to control it.

It has been shown that remote sensing can be used to map invasive species over broad areas often more effectively than with in situ methods (ITD, 2008). Aerial photography was shown by Everitt (1996) to be useful for mapping some weeds such as the leafy spurge. Multispectral and hyperspectral data were used in several studies for finding the locations of invasive species by remote sensing technology (Carson, 1995; Ustin et al., 2002; Underwood et al., 2003; Lawrence et al., 2006; Hestir et al., 2008; Ustin et al., 2008). One of the major limitations of these methods is that the species itself must have a unique spectral signature and this is one of the arguments for using multispectral and even more often the case for using hyperspectral methods. The more bands that are used will result in more detailed spectral signatures, which likely will provide better distinction amongst various species.

2.5.1. Monitoring of Aerial photos

Aerial photos have been shown to be useful in mapping invasive plants (Bradley and Mustard, 2006). There are many ways for extracting information from aerial photography including both manual interpretation and the use of computer software that is designed to extract patches of invasive species in an automated process. Manual interpretation of aerial photography by trained technicians is one way of processing aerial photos (Johnson, 1999).The technicians can find the location of a particular invasive species based on photo interpretation factors such as shape, size, site, texture, pattern and color. The detection of disease or any kind of infestation is possible by manual interpretation of aerial photos especially in the early stages of invasion (Paine and Kiser, 2012).

Müllerova, (2005) shows that aerial photographs used for observing the rate of spread and how a population of invasive plants interacts with the environment can be remotely assessed from aerial photos over time. Multi-date aerial photos of an area in the Czech Republic were used and factors such as the size and shape of infested spots of *Heracleum mantegazzianum* were extracted. Aerial photos can also be applied to identify linear features which have been shown to play a role in the spread of invasive species distribution (Thébaud and Debussche, 1991; Pysek and Prach, 1993; Planty-Tabacchi et al., 1996; Hood and Naiman, 2000; Müllerova, 2005). Rivers and roads were some of the linear shape features that were more influential in dispersal of *Heracleum* *mantegazzianum* (Müllerova, 2005).

2.5.2. Computer Mapping

Computer mapping software such as those utilized by remote sensing and geographic information system (GIS) methods may offer the ability to map invasive species for various purposes including forestry management (Johnson, 1999). Computer mapping aids the identification of distinct species and relevant to this thesis, invasive species. There are two methods to map the areas of invasion. Land surveying, often with GPS technology, can be used to collect locations of invasive species in the field. Data that are collected by GPS tools from the field can then be transferred to GIS mapping software to produce maps of the locations of invasive species. In addition, aerial photography and satellite imagery can be employed to find the location of invasive species. As with the field method, the information derived from the images can then be mapped an analyzed in GIS software (Johnson, 1999).

The GIS platform used for this thesis is ArcGIS from ESRI which is the worldwide leading supplier of GIS software. A recent development in the ArcGIS platform is the movement to relational database management systems and in particular the development of the geodatabase. One of the benefits of geodatabase is the ability to preserve the spatial integrity of data (Zeiler, 1999). There are three kinds of geodatabase: personal geodatabases, file geodatabases, and ArcSDE geodatabases. Personal geodatbases are Microsoft Access based files and is what is used in this thesis as it is a file format that is very easy to share electronically. A personal geodatabase has a smaller capacity than the file geodatabase which is about 2 GB. One of the main benefits of the geodatabase is that all the information with any feature dataset is contained in one file opposed to a shapefile which consists of many files. In addition, the personal geodatabases have topology which automatically helps to calculate area of mapped cogongrass patches.

2.5.2.1. Classification methods for Mapping

Supervised and unsupervised classifications are two methods of analyzing remotely sensed data. In a pixel based supervised classification, a user selects training sites for desired classes and then pulls them from the image using a statistical algorithm that groups pixels using the spectral information for each class. In an unsupervised classification, statistical algorithms such as ISODATA groups pixels into clusters with similar spectral curves then the user assigns the clusters to a class by referencing the imagery used for the classification (Zhu et al., 2006; Campbell, 2002). Both supervised and unsupervised classification can be accurate in classifying satellite or aerial imagery. At both single pixel and image object level, supervised classification can be utilized. Recently, Geographic Object Based Image Analysis (GeOBIA) methods for analyzing remote sensing images were developed to analyze imagery using contextual information in addition to the spectral curve (Burnett and Blaschke, 2003).

GeOBIA is a powerful technique that has been developed for image classification. It is a method for image interpretation that groups pixels of aerial or satellite imagery into vector-based objects so an analyst can go beyond spectral observation (Wang et al., 2004). With GeOBIA, the contextual and texture properties of image objects can also be used for their classification (Baatz et al., 2000). In GeOBIA, images are segmented into vector polygons (objects) and valid information can be extracted from the objects that allow them to be reshaped into meaningful objects by applying a set of rules corresponding to a desired classification scheme with their contextual properties (Schiewe et al., 2001).

Proprietary segmentation algorithms developed by a research team led by Nobel Laureate Prof. Dr. Gerd Binnig, and serving as the basis of eCognition Developer, were used in this thesis (Trimble, 2012). One of the advantages of eCognition is the use of rule sets developed for segmentation of pixels into objects and subsequent classification that can then be applied to other areas with similar land use patterns (Kampouraki et al., 2005). The segmentation and classification of cogongrass in one area can be used to map cogongrass in areas with similar physiographic properties.

2.6. Geographical Object Based Image Analysis (GeOBIA)

Remote sensing at the end of twentieth century generated a great amount of high resolution data which led to the development of new automatic methods for processing these data (Hay and Castilla, 2006). GeOBIA established a connection between Geographic Information Systems (GIS) and remote sensing by providing a link between the raster data format commonly used in traditional remote sensing to vector data more often used in GIS platforms (Hay and Castilla, 2006).

Traditional pixel based remote sensing has certain deficiencies, particularly in describing the spatial features (Hay and Castilla, 2006). These limitations include ignoring many of the photo interpretation factors that humans use to recognize features in images such as texture, shape, size, etc. In addition, high resolution imagery is very detailed and the associated variations are confusing for the pixel based methods. Contextual information associated with objects used in GeOBIA improves classification accuracies. To provide more accuracy to process remote sensing imagery, and a faster processing of a large amount of data, GeOBIA analysis is often more efficient than the traditional pixel based technique (Battz et al., 2006).

Automatic apportionment of remote sensing data into objects is known as segmentation (Hay and Castilla, 2006). After selection of the appropriate segmentation method, decision tree rulesets are established based on the spectral and spatial attributes of the objects for classification of them (Hay and Castilla, 2006). In a study that focused on a more proficient management of natural areas in Ecuador in order to have a more efficient way for controlling guava, GeOBIA was applied using commercially produced high-resolution Quickbird imagery of Galapagos Islands (Walsh et al., 2008). The results of initial segmentations were dissimilar, coarse, and resulted in mixed objects which showed different kinds of vegetation. Gradually, after several consecutive trials of segmentations with the scale parameters of 4, 1, 0.5, 0.3, and 0.2, the various scale factors were effective at pulling out small trees verses larger ones, or patches of guava trees. Therefore, all levels were applied for the classification of guava trees (Walsh, et al., 2008). It was also shown that with the rise in the numbers of classes, the differentiation of guava trees from other classes of vegetation was improved (Walsh, et al., 2008). A fuzzy membership rule was employed to classify the objects in the case that they had more than one membership in the same class.

Three kinds of segmentation in GeOBIA have been applied for the segmentations of images; region-based (Chen et al., 1991; Tian and Chen, 2007), edge based (Jain1989;

Le Moigne and Tilton, 1995; Tian and Chen, 2007) and point based segmentation (Mardia and Hainsorth, 1988; Tian and Chen, 2007). Point based segmentation is also known as pixel based segmentation (Tian and Chen, 2007; Je`hne 2005). In the pixel based segmentation, the separation of the pixels into distinct parts is done by using a threshold of pixel values (Tian and Chen, 2007). The edge-based segmentation is used to show the borders of image entities by connecting the boundaries with contours (Tian and Chen, 2007). The most widely used segmentation algorithm apparent in the literature is region-based, also known as multiresolution segmentation (Myint et al., 2011;Tian and Chen, 2007; Darwish et al., 2003; Giada et al., 2003;Shackelford and Davis, 2003; Wang et al., 2004; Al-Khudhairy et al., 2005; Kressler et al., 2005; Wei et al., 2005).

2.6.1. Multiresolution segmentation (MRS)

Several segmentation algorithms are useful in order to implement the grouping of pixels into objects in a fast and efficient manner. Multiresolution segmentation (MRS) is a recently developed segmentation procedure in which the groups of pixels are recognized as distinct objects based on the Fractal Net Evolution Approach (FNEA), and the segmentation process progresses from small and subordinate units to a larger units in the imagery (Myint, 2011). MRS starts at the pixel level but can also be applied to image objects. The combinations of pixels or image objects are grown, thus creating larger objects based on scale. The desired scale of pixels or object combinations can be specified by the user in MRS based on the purpose of study (Myint, 2011). The goal is to set a scale that allows a user to create meaningful objects in order to map features in the images.

2.6.2 NDVI Index in Classification

Since most of the study area that was analyzed for this thesis covers vegetated lands, indices that use band ratio indices are applicable. Normalized Difference Vegetation Index (NDVI) is one of the most widely utilized indices for vegetation classification, and for the discrimination of plants and non-plant land cover, NDVI is an appropriate tool (Carleer and Wolff 2006; Ning et al., 2011). Ning et al. (2011) used NDVI for classification of the vegetation classes in GeOBIA. In the study that was conducted by Myint et al. (2011), NDVI was applied for separation of grass and trees in an urban setting. Meaningful NDVI values range between 0-1 and higher NDVI values indicates higher amounts of vegetation while lower values and values close to zero indicates non-vegetated areas (Marzen et al., 2011; Weiss et al., 2004; Xie et al., 2008). Xie et al. (2008) created an NDVI Layer in eCognition by using the mean of the NDVI layer to separate the vegetation and non-vegetation polygons.

2.6.3. Manual editing in GeOBIA

To manually classify objects into certain groups, the manual editing option in eCognition can be used (Navular, 2007). Manual classification is a method that can be used to assign misclassified objects to the correct class in order to improve classification accuracy. In Myint et al. (2011), the shadows of the buildings were classified in the wrong group due to the problems such as the time of acquiring data, so shadows were reclassified manually based on the most likely class that the shadow covered.

2.6.4 Field Work for Accuracy Assessment

Assessing Accuracy of Remotely Sensed Data: Principles and Practices, provides one of the most authoritative guides to the methods of assessing classification accuracy (Congalton et al., 1999). Other studies examined for this thesis included methods for assessing mapping accuracy with in situ field work (Laliberte et al., 2004; Xie et al, 2008). In a study mapping invasive Australian pine trees using GeOBIA with digital orthoquads, accuracy was assessed through a field survey (Xie et al., 2008). The maps created of this invasive plant in the study area were checked for accuracy through a windshield survey by driving by pine trees that were next to roads and recording locations with GPS (Xie et al., 2008). Laliberte, et al. 2004 conducted a research project for mapping invasive shrubs with both Quickbird and aerial imagery using GeOBIA methods in New Mexico. Accuracy assessment of the maps was performed by doing field work in 61 sample plots within the study area. GPS was used to record each shrub larger than 50cm diameter and then the result of field work was compared with the mapping results for measuring accuracy assessment.

2.7 Assessing Invasive Species Impacts with Surveying

Several studies assess economic impacts of various invasive species by surveying a group of people (Mwebaze et al., 2010; Engeman, et al., 2010; Burt et al., 2007). The data related to the social aspects of these investigations can be collected using surveys and relating the results to other aspects of the studies (Gable, 1994). The outcomes of the survey on a small group can be useful for generalizing the results for a larger group

(Gable, 1994).

Selection of the survey method depends on the topic of study and intended application of the data (Attwell and Rule, 1991; Gable, 1994). Results of a survey can also improve interpretation of field results and other ancillary data (Gable, 1994). For this thesis, a survey of resource managers added to the mapping aspect of the study by helping to assess the impacts of cogongrass in the study areas. Surveying techniques provided a way to address the economic aspects of cogongrass in Alabama and can help examine the mapped areas in terms of the economic threats resource managers face.

In a study that was implemented for investigating the effect of horticultural business on the introduction of invasive species into new areas, a survey was utilized and analyzed applying the likert scale for rating the questions (Burt et al., 2007). The result of the survey was used to better understand the perceptions of business owners with regard to invasive plants (Burt, et al. 2007).

In Engeman, et al. (2010), the amount of economic loss in agricultural lands due to an invasive monkey species in Puerto Rico was investigated using a survey that was distributed among the landowners. Surveys were conducted over four years and were used to evaluate the economic impacts of the monkeys on farms due to loss of agricultural products.

Mwebaze et al. (2010) looked at economic loss on the Seychelles Islands due to the invasion of nonnative species. The damages suffered were from a loss of species biodiversity in various plants and animals. Several pilot surveys were done on a small group to improve the quality of the survey and make it ready for a larger group of the tourists who visit the island. Both economic and social factors were studied in analysis of the data (Mwebazeet al., 2010).

In a study that was done for exploring landowners' ideas towards species that are endangered, two kinds of survey were made for the purpose of preservation and protection of farm lands. The first part of the survey was done in an interview format with a group of thirteen farmers and afterwards a questionnaire was sent to landowners by mail to inquire about their ideas concerning the meadow jumping mouse habitat and the activities associated with economic aspect of conservation. (Brook et al.,2003).

CHAPTER 3

METHODOLOGY

3.1.Introduction

This study is conducted for the assessment of the eradication cost of cogongrass invasion in Mobile and Baldwin Counties, Alabama. It is recognized that there is direct relationship between the amount of area of cogongrass and the economic impacts, so the first aspect of this study involves testing various methods to locate and map this invasive species. Another aspect of this study involved interviewing resource managers in Alabama and surrounding Southeastern states to gain an understanding of their perceptions of cogongrass as an economic threat. In this chapter, various geospatial methodologies and the procedures for acquiring and analyzing data are introduced along with the details involved with the survey.

3.2.Data

3.2.1 NAIP Aerial Imagery

Aerial images provided by the USDA National Agriculture Imagery Program are often referred to as NAIP imagery. The imagery is usually processed either in a county mosaic or as digital orthophoto quarter quads (DOQQs) that align with the USGS 7.5" topographic quadrangles. The NAIP DOQQs are usually available in geotiff format and are projected to the Universal Transverse Mercator (UTM) grid and utilize an XY coordinate system of eastings and northings (Campbell, 2002). The NAIP imagery for Mobile and Baldwin Counties fall under Zone 16 N, North American Datum 1983. The NAIP Program began in 2003. The NAIP images were originally taken by analog film cameras and then scanned into digital format. After 2009, digital sensors were used for collecting images. The NAIP images are available as a 4-band, including the near-infrared band which allows viewing of Color Infrared (CIR) images, or a 3-band true color image which has varied by state and over time, but there is generally a preference for the 4-band imagery. In processing of the Alabama NAIP imagery, a dynamic range adjustment occurs, stretching the data to the full capability of an 8-bit sensor so digital values range between 0-255 (ITT, 2012). The NAIP imagery can be applied to agriculture and forestry mapping projects since they are taken during growing season. For this thesis, NAIP imagery that was collected during the growing season 2011 was used. The spatial resolution of NAIP imagery is 1 square meter, which is adequate for detecting potential patches of cogongrass. The NAIP data that were employed have four bands that consist of visible colors band 1(Blue), band 2 (Green), band 3 (Red) and band 4 (Near-Infrared). The NAIP imagery that covered Mobile and Baldwin Counties in 2011 consists of 285 image DOQQ tiles. The candidate cogongrass infestations were observed on all the imagery in ArcMap 10.0, and the Imagery that covered open lands including all grasslands and roadways in both counties were applied for this thesis; ultimately, the analysis was conducted on 183 images covering all open lands. These data were acquired from AlabamaView; an organization that shares geospatial datasets with the public. Much of the data AlabamaView archives are shared online (www.alabamaview.org) but at the time of data collection, the datasets were yet to be hosted online; therefore, a portable hard drive was delivered to AlabamaView and the 50GB of data were copied for use in this study.

3.2.2 American Reinvestment and Recovery Act. 2009 GIS Field Data Collection

Ancillary data provided by American Reinvestment and Recovery Act.2009 (ARRA, 2009) with Award Number 09-DG-11084419-041 "Alabama Cogongrass Control Center" awarded to Alabama Forestry Commission, 2009-2012, provided in situ GIS field data of cogongrass infestations that were reported by landowners. Locations of cogongrass were mapped by tracking their infestation with GPS, and collected data by GPS were imported to ArcGIS. The location of cogongrass infestations, both stands (partches inside of tracts) and the tracts (fields stands were located in), as well as treated patches, and all the visited stands in Mobile and Baldwin counties were provided in separate shapefile format. In total there were 516 acres of stands located in 7636 acres of tracts in both counties. Of the 516 acres of cogongrass stands approximately 265 acres were treated in total. These data were observed in the ArcMap 10.0 and were used for accuracy assessment of the manually digitized maps, as well as the maps produced with GeOBIA.

3.2.3 In Situ Field Work Data Collection

A field trip to Baldwin County was done in September 2012. The field trip took place over the course of three full days in the field in order to assess the accuracy of the digitized maps of areas of infestation for final assessment. The maps of areas believed to be possible cogongrass infestations in Baldwin County were produced as detailed below in Section 3.31. A fellow graduate research assistant (Tyler Jones) who had worked for Larson and McGowin (company awarded ARRA, 2009 project) and was familiar with cogongrass and the study area assisted with the field work. Based on the locations of candidate areas on the digitized maps, the most accessible sites were visited. A mapped polygon was drawn on the printed maps in areas that were correctly confirmed as cogongrass. A Garmin Etrex WAAS corrected DGPS was also used to record the geographic coordinates of the locations of infestations in the field. In total, 63 sites were visited (Table 3.1). Baldwin County was chosen because it was closer and the lands were more accessible than in Mobile County. Figure 3.2 is a photo of the author collecting GPS points in the field and Figure 3.1 is a close range photo of a cogongrass patch.

Collected GPS Data of Cogongrass Disturbance

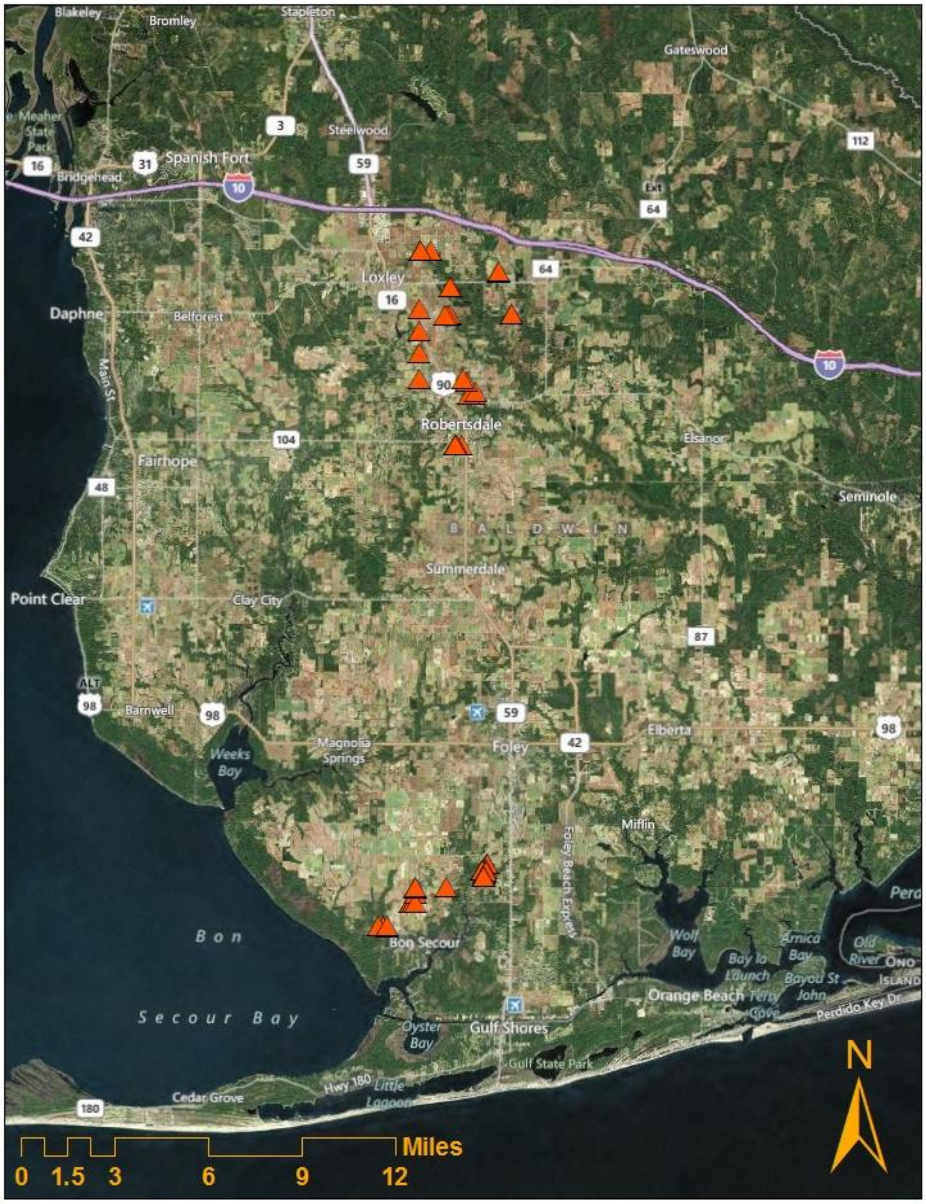


Figure 3.1 General locations of GPS data collection at candidate cogongrass sites.

Figure 3.2 The author collecting GPS points in the field.

Figure 3.3 A close-range photo of cogongrass in the field.

GPS Collected Points	Kinds of infestations	Longitude	Latitude
1	open land	-87.7141	30.5436
2	open land	-87.7106	30.5437
3	open land	-87.7134	30.5437
4	open land	-87.7134	30.5437
5	road right-of-way	-87.7140	30.5439
6	road right-of-way	-87.7041	30.5674
7	road right-of-way	-87.7064	30.5673
8	open land	-87.7033	30.5683
9	open land	-87.7083	30.5733
10	road right-of-way	-87.7100	30.5744
11	open land	-87.7337	30.5745
12	open land	-87.7337	30.5860
13	road right-of-way	-87.7338	30.5962
14	open land	-87.7337	30.6063
15	road right-of-way	-87.7169	30.6167
16	road right-of-way	-87.7171	30.6166

17	road right-of-way	-87.7173	30.6037
18	road right-of-way	-87.7176	30.6038
19	open land	-87.7189	30.6037
20	road right-of-way	-87.7199	30.6037
21	road right-of-way	-87.7277	30.6331
22	road right-of-way	-87.7337	30.6331
23	road right-of-way	-87.7334	30.6332
24	road right-of-way	-87.6914	30.6230
25	road right-of-way	-87.6914	30.6232
26	road right-of-way	-87.6916	30.6238
27	open land	-87.6845	30.6040
28	open land	87.6844	30.6040
29	open land	-87.7509	30.3225
30	open land	-87.7509	30.3225
31	road right-of-way	-87.7539	30.3228
32	open land	-87.7492	30.3223
33	open land	87.7492	30.3228
34	road right-of-way	-87.7369	30.3336

35	road right-of-way	-87.7369	30.3336
36	open land	-87.7354	30.3336
37	open land	87.7354	30.3336
38	road right-of-way	-87.7340	30.3378
39	road right-of-way	-87.7340	30.3333
40	open land	-87.7340	30.3401
41	open land	-87.7340	30.3401
42	road right-of-way	-87.7340	30.3409
43	road right-of-way	-87.7171	30.3408
44	open land	-87.6958	30.3513
45	open land	-87.6958	30.3514
46	open land	-87.6959	30.3514
47	road right-of-way	-87.6960	30.3494
48	open land	-87.6969	30.3484
49	open land	-87.6979	30.3484
50	open land	-87.6984	30.3483
51	open land	-87.6984	30.3483
52	open land	-87.6966	30.3475

53	open land	-87.6966	30.3471
54	open land	-87.6962	30.3479
55	road right-of-way(two sides of the road)	-87.6966	30.3458
56	open land	-87.777	30.429
57	open land	-87.778	30.4260
58	open land	-87.779	30.423
59	open land	-87.753	30.425
60	open land	-87.752	30.419
61	open land	-87.754	30.416
62	open land	-87.736	30.354
63	open land	-87.753	30.417

Table 3.1 provides the GPS locations of sites visited.

The XY locations of the invaded areas and whether it was in open grass land or right-of-way were documented and recorded in a field notebook while in the field. It was also determined whether the area contained cogongrass or not. The recorded GPS coordinates were entered and saved in an Excel file with the information about their locations and imported into ArcMap as a shapefile format.

3.3. Methods

Two methods of remote sensing technology were used for mapping cogongrass in south Alabama. Visual examination is one way of identifying features on aerial images (Bradley and Mustard, 2006; Johnson, 1999). Some time was spent with Alabama Cooperative Extension experts to gather their expertise in the visual interpretation of potential cogongrass infestations with the NAIP imagery in Mobile and Baldwin Counties (Miller, 2011). This informal training was utilized to aid in a Heads-up digitizing aspect of the study to manually digitize visibly evident areas that were considered to be infested with cogongrass. Secondly, an attempt was made to develop an automated method for image interpretation and cogongrass extraction using GeOBIA and eCognition Developer software. Shape, texture, color and other contextual characteristics of features were applied for finding cogongrass on NAIP imagery. Figure 3.4 shows a confirmed image of cogongrass patches with circular pattern on aerial photos taken by Alabama Forestry Commission in 2008 (Miller, 2010). Figure 3.5 shows the potential patches of cogongrass in the NAIP imagery that can be manually mapped

Figure 3.4 Oblique aerial photo showing circular patches of confirmed areas of cogongrass imagery (Miller, 2012)

Figure 3.5 Potential cogongrass patches in Baldwin County spotted with NAIP imagery

The quality of the results of the analysis with the remote sensing data was verified by accuracy assessment, involving both quantitative and qualitative evaluation (Congalton and Green, 1999). Data collected by Larson and McGorwin for Alabama Cogongrass Control Center in 2009 was used along with the imagery itself for accuracy assessment of the results of the manual classification and GeOBIA extraction of Cogongrass. In addition, field work was done to gather ground reference data during summer 2012.

3.3.1 Visual examination (Heads-up digitizing)

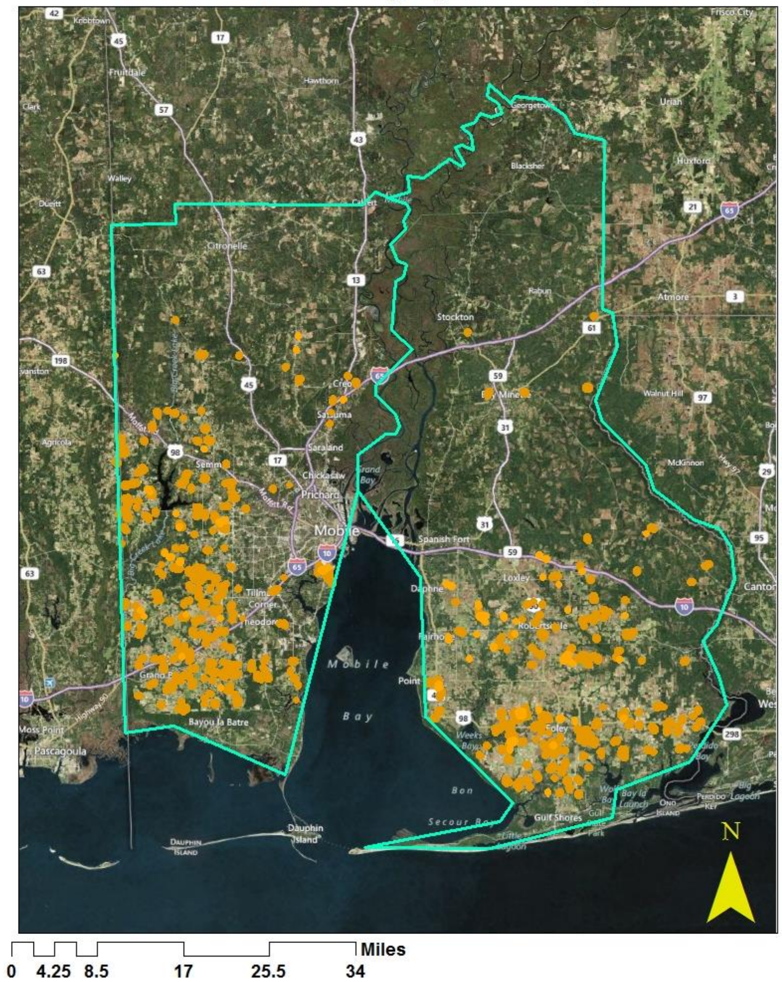
The first step was collecting the latest NAIP imagery of the study area. The latest NAIP imagery from summer of 2011 was used for this research. Heads-up digitizing was accomplished in ArcMap with these two imagery datasets. A personal geodatabase was created for the 2011 data. A geodatabase was chosen because it generally makes the accessibility, administration, and automation of data easier than shapefiles. A personal geodatabase was useful for this project because it allows all aspects of a GIS file including the vector graphics, the tabular data, as well as the projection information to all be stored in a relational database file container. In the case of a personal database, everything is stored in one Microsoft Access database file. In each geodatabase, two distinct feature datasets were built; one for the agricultural fields or pastureland that had infestations covering a majority of the area, and the second for the extent of patches within a field that visually appeared to have undergone some type of infestations possibly by invasion of cogongrass. Single feature classes were made in each of the feature datasets.

Only areas of cogongrass in open non-forested lands were evaluated because the canopy limits the ability to see the understory where cogongrass would be on forested lands. However, forested lands next to open lands infested with cogongrass are more likely to have possibly been invaded by cogongrass.

The visual interpretation of the NAIP imagery was performed by comparing the confirmed spots of the cogongrass provided by the Alabama Cogongrass Control Center from 2009. The determination of whether to consider a patch as cogongrass on some lands that were largely covered by cogongrass was a difficult task since other pasture vegetation may have similar reflectance values and color. In these cases, shape as an interpretation factor was considered as cogongrass patches often have a circular shape (Figure 3.4) which makes them more distinct from other vegetation that has a similar color. Several iterations of digitizing and editing were done over 2.5 months in summer of 2012.

Fields and patches were digitized as separate GIS layers. Figure 3.6 shows the general areas of where cogongrass fields and patches were digitized in both Mobile and Baldwin counties.

Fields and Patches of Cogongrass in Study Areas



3.6. The map of heads-up digitizing cogongrass patches in both Mobile and Baldwin Counties 2011.

3.3.2. Automated process by Geographic Object based Image Analysis

The 2011 NAIP imagery was also classified by Geographical Object Based Image Analysis (GeOBIA) using eCogonition Developer version 8. The initial step in GeOBIA using eCognition is creation of workspaces to help organize the imagery and associated rule sets. For each DOQQ, a separate workspace was made and several projects were built in each workspace by subsetting the areas of interest. Subsetting the NAIP Imagery in eCognition increases processing speed and in this analysis it also was visibly evident that working in a smaller area increases the accuracy of the classification.

In each workspace, several projects in eCognition developer were made and subsets of the DOQQs (between 400-600 x 400-600) pixels were done for each separate project. The following sections describe the steps that were followed in ruleset development. It starts with a two-step segmentation process, proceeds with two membership classification rules, followed by a nearest neighbor classification, a rule to merge all classified objects into the perspective class, and finally a rule that exports the objects to a vector format commonly used in GIS. Numerous rulesets were created and were run on a trial and error basis on these workspace projects and finally one ruleset (Figure 3.7) was selected among all of these since the results of the classifications appeared visually more accurate on the imagery than all other combination of classification rules that were tried.

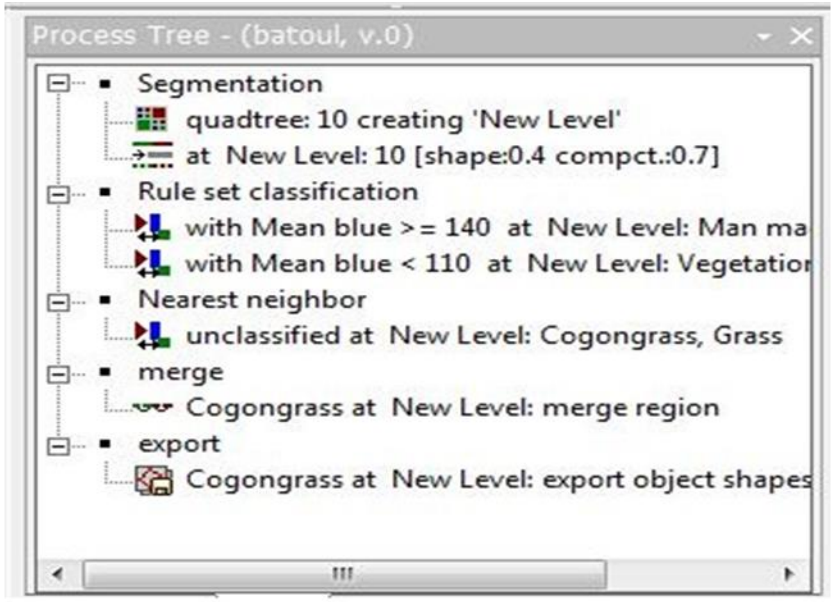


Figure 3.7 Final ruleset developed for GeOBIA classification of potential cogongrass areas.

3.3.2.1. Segmentation of the Image

Various segmentation algorithms exist in eCognition Developer and Munoz et al. 2003 point out that none of them is perfect for any application. Often a number of combinations and parameters are tested until the analyst feels they have the best segmentation for a given application (Myint et al., 2011). A good number of studies have used multiresolution segmentation as it appears to be one of the more widely used segmentation algorithms (Myint et al., 2011; Tian and Chen, 2007; Darwish et al., 2003; Giada et al., 2003; Shackelford and Davis, 2003; Wang et al., 2004; Al-Khudhairy et al., 2005; Kressler et al., 2005; Wei et al., 2005). The segmentations that were applied for this study were quadtree based segmentation and multiresolution segmentation, as described below.

One of the benefits of applying multiple segmentation algorithms in a project is the greater speed in processing the image into objects for classification. In a first trial run of processing the south Alabama imagery, multiresolution segmentation took an excessively long time to execute the process. For this reason, in subsequent trials quadtree based segmentation was first applied and based on trial and error using different scales.. Scale is one of the parameters that can be applied for specifying size of the objects that are created in quadtree based segmentation based on their spectral variation. 'Image layers' is another parameter in quadtree based segmentation that can define the amount of heterogeneity of pixels reflectance within objects. Quadtree based segmentation is a region-based segmentation that groups image pixels into objects that have a rectangular shape (Definiens, 2012). Figure 3.8 shows a part of the study area that has been segmented by the quadtree based algorithm using a scale of 10 as an initial segmentation algorithm for dividing the pixels into grid shaped objects, multiresolution segmentation was then applied on the quadtree produced objects. This 2-step process was much faster than using multiresolution segmentation alone.

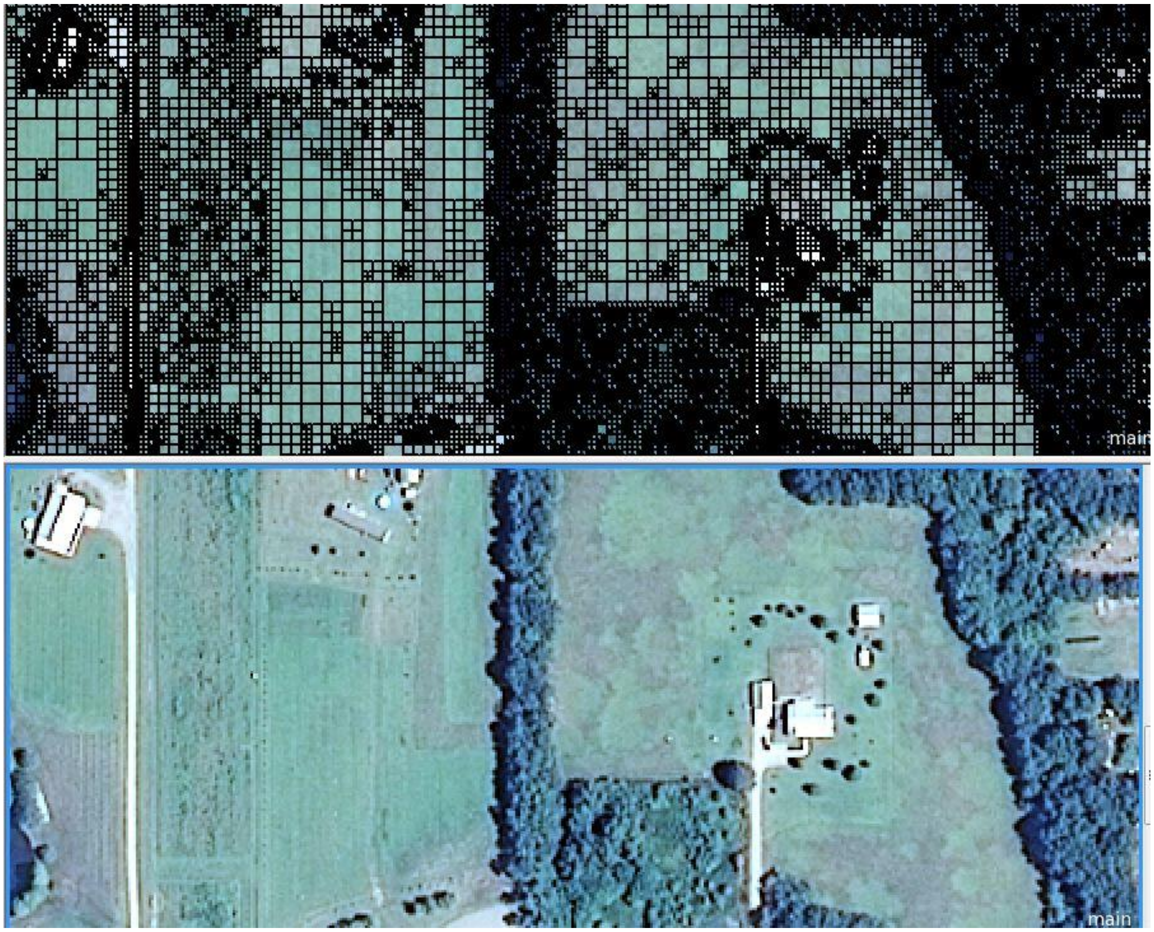


Figure 3.8 This shows the quadtree based segmentation on part of the NAIP imagery of 2011

The initial step in the multiresolution segmentation is allocation of scale, as well as compactness and shape values which was done on image objects created by the quadtree segmentation. Similarities in spectral and spatial attributes of the image objects are used and can be specified by the user (Baatz & Schape, 2000; Myint et al., 2011). The level of detail that can be used for the study is a crucial factor in choosing scale. Based on the study objectives and the level of resolution which is needed for study, scale changes (Myint et al., 2011). For this study a scale of 10 was deemed the best through trial and error and the image layers weight were assigned the value of one for the visible bands and a weight of three for the NIR band were applied for multiresolution segmentation. Figure 3.9 shows a part of the study area that has been segmented by the multiresolution segmentation.

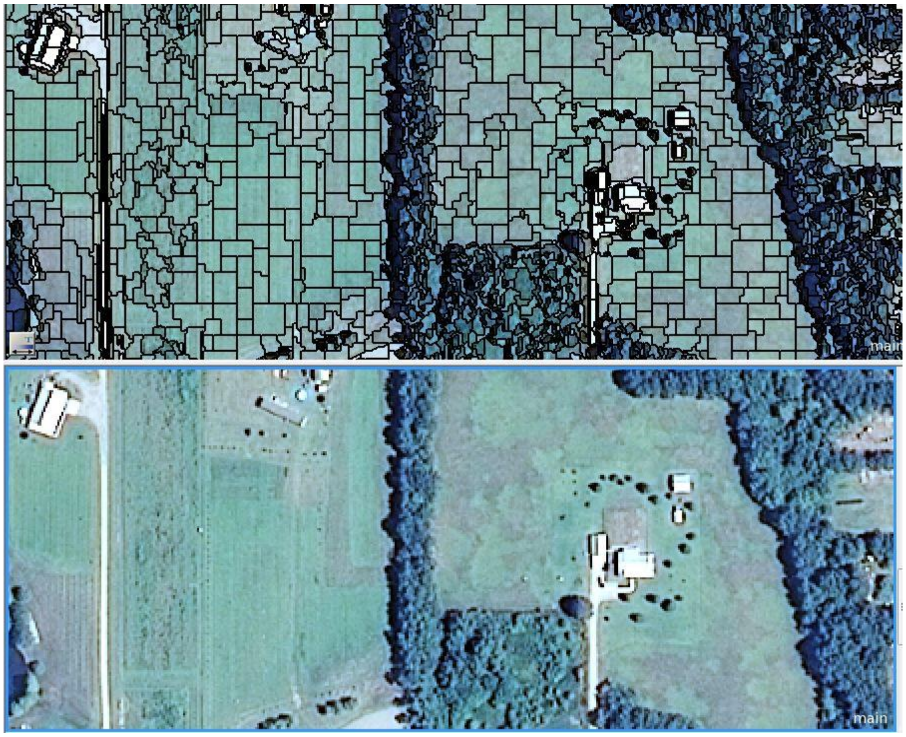


Figure 3.9 A multiresolution segmentation of part of study area using NAIP imagery

After completion of the segmentation steps, and creation of objects: those objects could be reshaped into polygons that represented potential patches of cogongrass, for this purpose the classification process was begun.

For classification, different image layer variables were tested and tried, including the various measures of the bands' mean reflectance, standard deviations of the bands, minimum or maximum number of pixels for the geometry, and the extent of the objects. Finally, mean brightness, mean max difference, and mean of the image layers were used to aid in classification of images based on the spectral characteristics of the objects. Some extent attributes such as pixel volume area, length/width, number of pixels, pixel width and one of the shape attributes that is called asymmetry were all selected to discriminate the objects based on their geometric characteristics. These all were done to help find the range of values for discrimination of numerous image objects with the goal of discerning objects that represented potential cogongrass patches.

3.3.2.2. Classification Method

For classifying the objects that were created in the segmentation step, two kinds of classification approaches were used. One of these methods is called nearest neighbor classifier (NN) that has been used in a variety of studies (Myint et al., 2011; Ivits & Koch, 2002; Laliberte et al., 2007). The other one is called the membership function classifier which is a non-parametric approach (Myint et al., 2011).

The membership function classifier was first applied to extract man-made features, and then used again to extract trees (both individual trees and stands). In order to separate man-made features and trees, some rules were developed based on examining the spectral and spatial attributes of the object features in the image. Two classes were created and a mean blue threshold of greater than 140 was used to extract man-made features and a mean NDVI of greater than 0.17 was used to separate the tree class.

In the second step, the nearest neighbor (NN) classifier was used to classify the rest of the objects in the open areas. One ruleset was developed and NN was applied to classify open areas and discriminate the cogongrass class from other vegetation. NN is part of the supervised classification where sample training sites are selected by the user

(Myint et al., 2011; Definiens, 2008). One of the benefits of NN classifiers is that it is appropriate for other regions and it can be applied for several projects, and if it is necessary for other areas more sampling of images objects can be done (Ivits & Koch, 2002, Myint et al., 2011). When executing NN in eCognition Developer with the standard nearest neighbor, the user has the choice to specify values that can be analyzed and applied for the classification (Myint et al., 2011, Definiens, 2008). For this analysis, several variables were applied in NN classifier through a trial and error process for classification of cogongrass from other classes in the open grass and crop areas. For the more efficient grouping of the image objects, some custom variables were created. For this research, since the goal of the study was defining the location of cogongrass infestations and since cogongrass areas appear less healthy than surrounding grasses a mean NDVI value was created and applied. Mean NDVI is calculated as follows:

NDVI= ((Mean NIR-Mean Red)/ (Mean NIR+ Mean Red))

Ratio green is another feature that was used for this research. For the separation of cogongrass from other kinds of vegetation in pasture and crop lands ratio green was calculated as follows:

Ratio green = **[Mean green] / (([Mean blue] + [Mean green] + [Mean red]))**

Figure 3.10 shows the variables that were used with the standard NN ruleset with the first set being the NDVI and ratio green factors. Figure 3.11 shows the mean layer values that were analyzed including brightness, maximum difference, arithmetic, blue, green, NIR, and red values. Figure 3.12 includes the geometric factors utilized by the nearest neighborhood analysis including extent factors of area, length, number of pixels, volume, and width. It also included the shape characteristic of asymmetry.

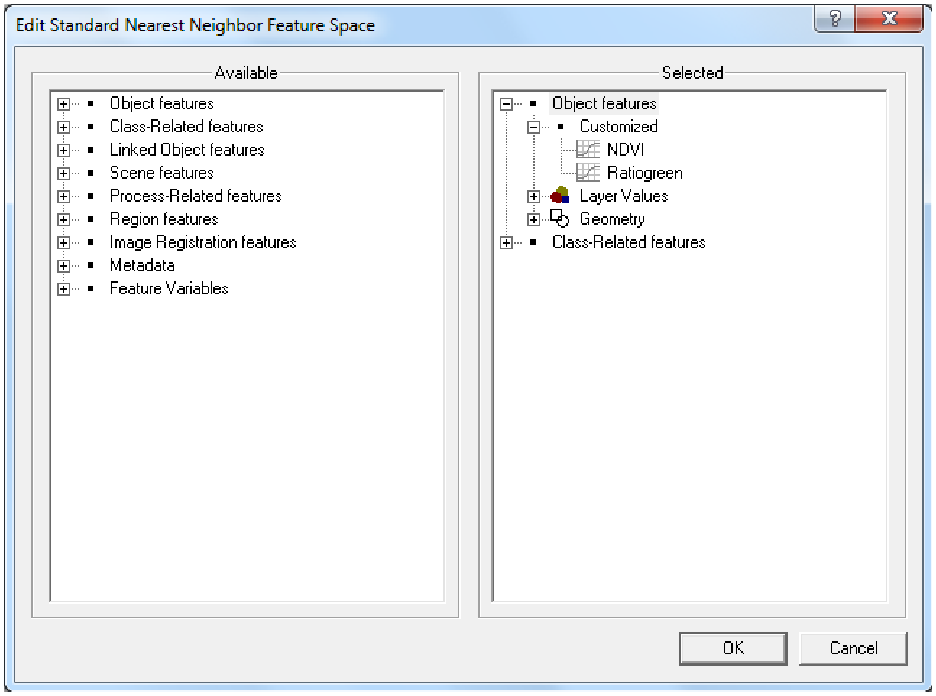


Figure 3.10 Customized factors of NDVI and Ratiogreen analyzed by NN ruleset

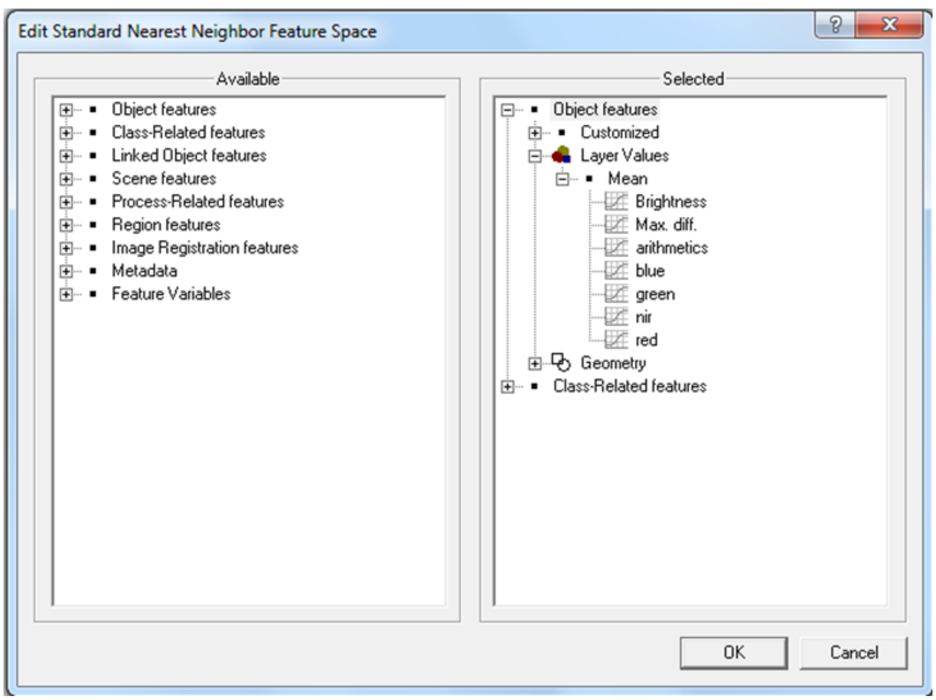


Figure 3.11 Layer values analyzed by NN ruleset.

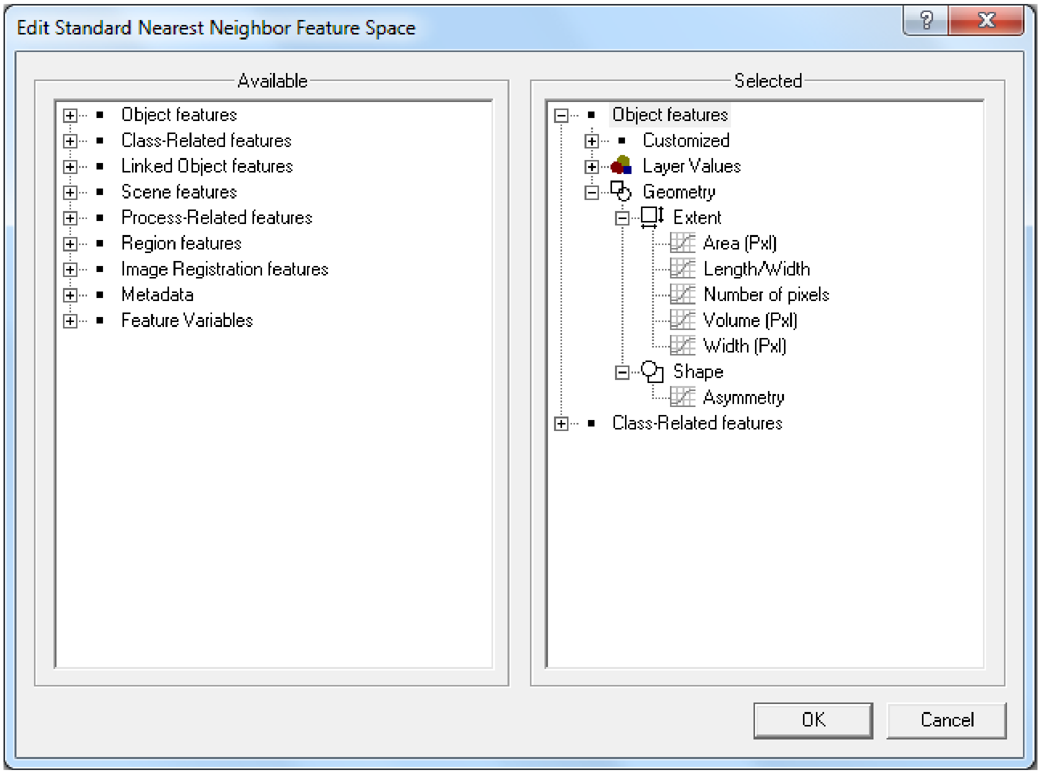


Figure 3.12 Geometric factors analyzed by NN ruleset

3.3.2.3. Export to ArcMap

After classification step, all the objects in the cogongrass class were merged by using the merge region threshold rule in eCognition Developer. The merged objects were exported in to shapefile format. The shapefiles of cogongrass were imported as a personal geodatabase and merged together by using the union function in ArcMap 10.Finally, the map of potential cogongrass patches was produced as the final map.

3.3.3. Natural Resource Manager Survey

A survey questionnaire was administered to evaluate the perceived economic impacts of cogongrass in the state of Alabama and to document methods being used to control cogongrass invasion in the Southeast. Sets of multiple choice questions, along with a few written answer questions were prepared. The survey questionnaires (Figure 3.13) were distributed among the participants in the joint meeting of Southeast Exotic Pest Plant Council and Alabama invasive Plant Council held on May, 2012. The participants were mostly resource managers in the state of Alabama. Out of one hundred fifty surveys distributed, seventy six were completed for an overall return rate just above 50%.

3.3.3.1 Descriptive Statistics

The survey questionnaire was structured in such a way to determine necessary information about attitudes towards cogongrass. Basic descriptive statistics were first implemented on survey findings. Most of the questions were organized using a likert scale. Each question was analyzed separately and was displayed in charts and graphs in Chapter 4.

1. **Please specify which states you work in?**

- Alabama _Florida _Georgia _Mississippi _South Carolina

_Louisiana _ Tennessee _Other (   )

2. **If Alabama, please specify which counties?**
3. **How would you rate your knowledge of cogongrass?**

1 (Poor)	2	3	4	5	6	7 (Excellent)
○	○	○	○	○	○	○

4. **In what capacity do you deal with cogongrass, other invasive species, and/or pest control (occupation)?**

5. **On which of the following activities do you feel cogongrass has the greatest negative economic impact?**

	1 (Low Impact)	2	3	4	5	6	7 (High Impact)
Livestock Production	○	○	○	○	○	○	○
Timber industry	○	○	○	○	○	○	○
Row crop production	○	○	○	○	○	○	○
Turf grass production	○	○	○	○	○	○	○
Others (______)	○	○	○	○	○	○	○

6. **From your experiences, which land cover has cogongrass affected the most? (Please rank the following land uses from 1 – 7, with 1=lowest impact and 7=Highest impact)**

Land cover	1 (low impact)	2	3	4	5	6	7 (High Impact)
Forest	○	○	○	○	○	○	○
Pasture	○	○	○	○	○	○	○
Cropland	○	○	○	○	○	○	○
Orchards	○	○	○	○	○	○	○
Wildlife areas	○	○	○	○	○	○	○
Roadsides	○	○	○	○	○	○	○
Powerline and other Right of Ways	○	○	○	○	○	○	○
Others	○	○	○	○	○	○	○

7. **If you have tried to control cogongrass, which of the following methods have you used?**

----- Herbicides

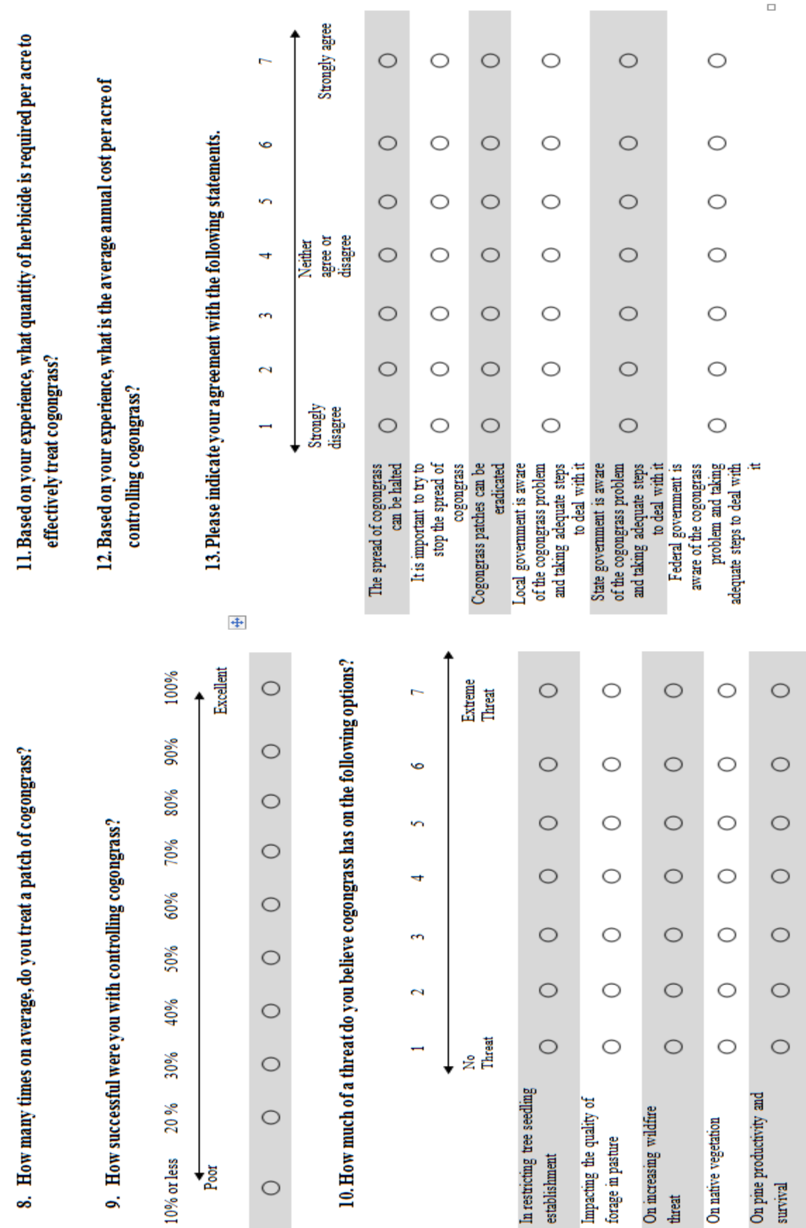
------Tillage

------Burning

------Combination of above

------Other (__________________)

Figure 3.13 The first page of survey questionnaire.



8. How many times on average, do you treat a patch of cogongrass?

9. How successful were you with controlling cogongrass?

10% or less	20 %	30%	40%	50%	60%	70%	80%	90%	100%
Poor									Excellent
○	○	○	○	○	○	○	○	○	○

10. How much of a threat do you believe cogongrass has on the following options?

	1	2	3	4	5	6	7
	No Threat						Extreme Threat
In restricting tree seedling establishment	○	○	○	○	○	○	○
Impacting the quality of forage in pasture	○	○	○	○	○	○	○
On increasing wildfire threat	○	○	○	○	○	○	○
On native vegetation	○	○	○	○	○	○	○
On pine productivity and survival	○	○	○	○	○	○	○

11. Based on your experience, what quantity of herbicide is required per acre to effectively treat cogongrass?

12. Based on your experience, what is the average annual cost per acre of controlling cogongrass?

13. Please indicate your agreement with the following statements.

	1	2	3	4	5	6	7
	Strongly disagree			Neither agree or disagree			Strongly agree
The spread of cogongrass can be halted	○	○	○	○	○	○	○
It is important to try to stop the spread of cogongrass	○	○	○	○	○	○	○
Cogongrass patches can be eradicated	○	○	○	○	○	○	○
Local government is aware of the cogongrass problem and taking adequate steps to deal with it	○	○	○	○	○	○	○
State government is aware of the cogongrass problem and taking adequate steps to deal with it	○	○	○	○	○	○	○
Federal government is aware of the cogongrass problem and taking adequate steps to deal with it	○	○	○	○	○	○	○

Figure 3.14 The second page of survey questionnaire.

CHAPTER 4

ANALYSIS

4.1 Introduction

One of the main objectives of the thesis is to estimate the amount and spatial extent of cogongrass in the study area. Both a manual method and an automated process were applied and evaluated for the mapping of the areas that potentially were affected by cogongrass in Mobile and Baldwin Counties. The manual process was done by digitizing the candidate patches and fields that appeared infested and were likely infested by cogongrass on NAIP imagery in GIS. The automated process was done by GeOBIA in eCognition Developer v.8. These two methods were developed and applied and afterwards an accuracy assessment of the mapping results was done separately. The acquired areas of candidate patches and fields help to estimate the potential cost of eradication of cogongrass from open pasture, crop lands and right-of-way areas. For the other main objective of assessing resource managers' perceptions of the threats of cogongrass as well as attempts to control cogongrass, a survey instrument was distributed during the joint Meeting between the Southeast Exotic Pest Plant Council (SE-EPPC) & the Alabama Invasive Plant Council (ALIPC) at the Auburn Hotel and Conference Center in May 2012. Anonymous questionnaires were distributed at the conference registration desk to attendees that included both public and private resource managers as well as researchers, and chemical sales representatives who deal with invasive species.

4.2. Manual Mapping

The generalized results of the digitizing of potential patches of cogongrass in Mobile and Baldwin Counties are sequentially shown in figure 4.1, and figure 4.2. Whereas figure 4.3, and figure 4.4 show a zoomed in area of a typical infested area mapped in crop land and pasture where possible patches of cogongrass were digitized. More often when a tract of land was heavily covered, the entire fields were digitized with the general areas shown in figure 4.5 for Mobile County, and figure 4.6 for Baldwin County. Figure 4.7 shows a local scale image of a typical field that was possibly covered by cogongrass and therefore digitized as a field as opposed to a smaller patch within a field.

Heads-up digitizing was done using the 2011 NAIP imagery. Both patches and fields were digitized separately in a personal geodatabase format in ArcGIS. Using a geodatabase enables area measurements since the geodatabase has topology which automatically includes the area in the attribute table (Zeiler, 1999). The fields feature class showed the lands that were heavily covered by cogongrass and the patches showed isolated areas within a field that appeared infested. NAIP imagery that was used for this thesis included 183 digital orthophoto quarter quads that covered predominantly open grass, crop lands and right-of-ways.

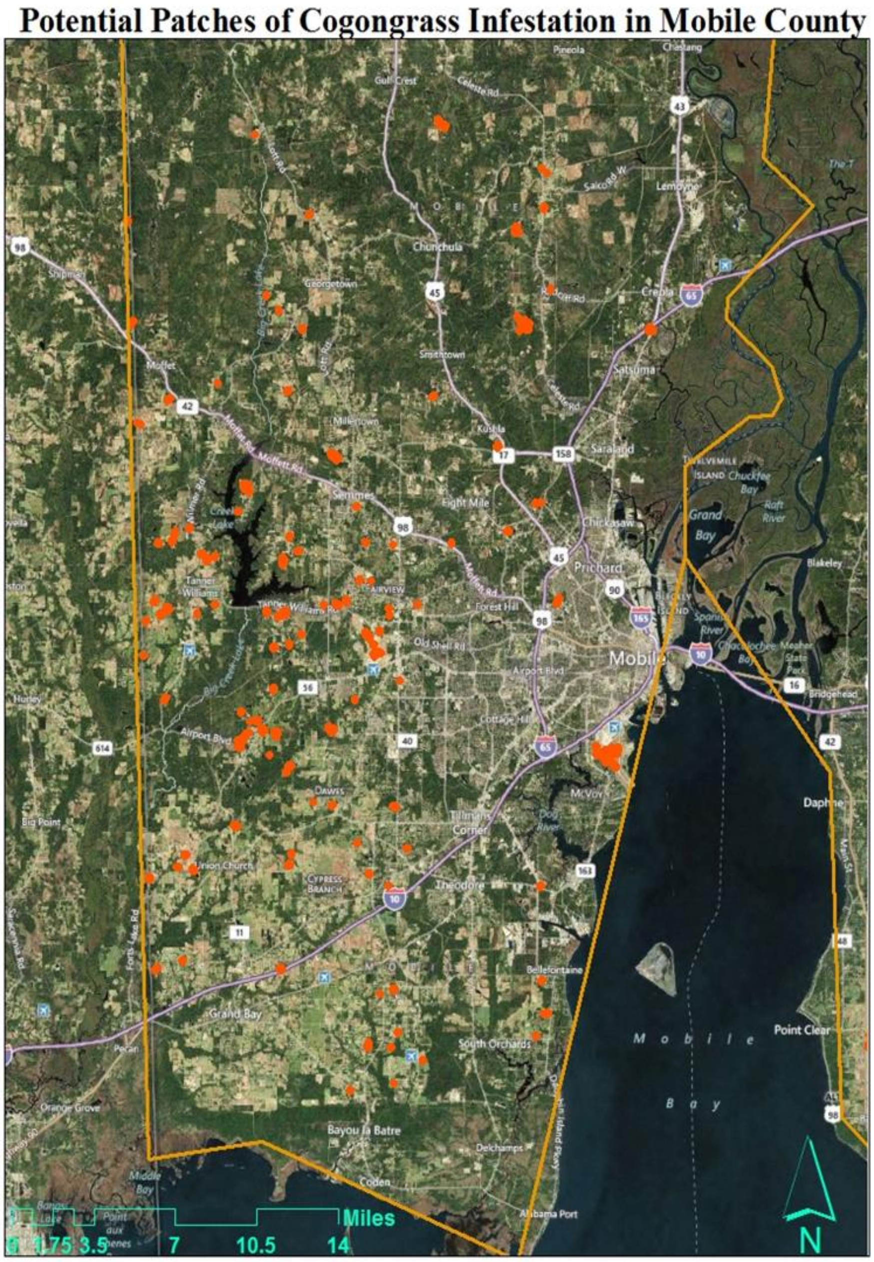


Figure 4.1 The map of candidate patches that were invaded by cogongrass in Mobile County

Potential Patches of Cogongrass Infestation in Baldwin County

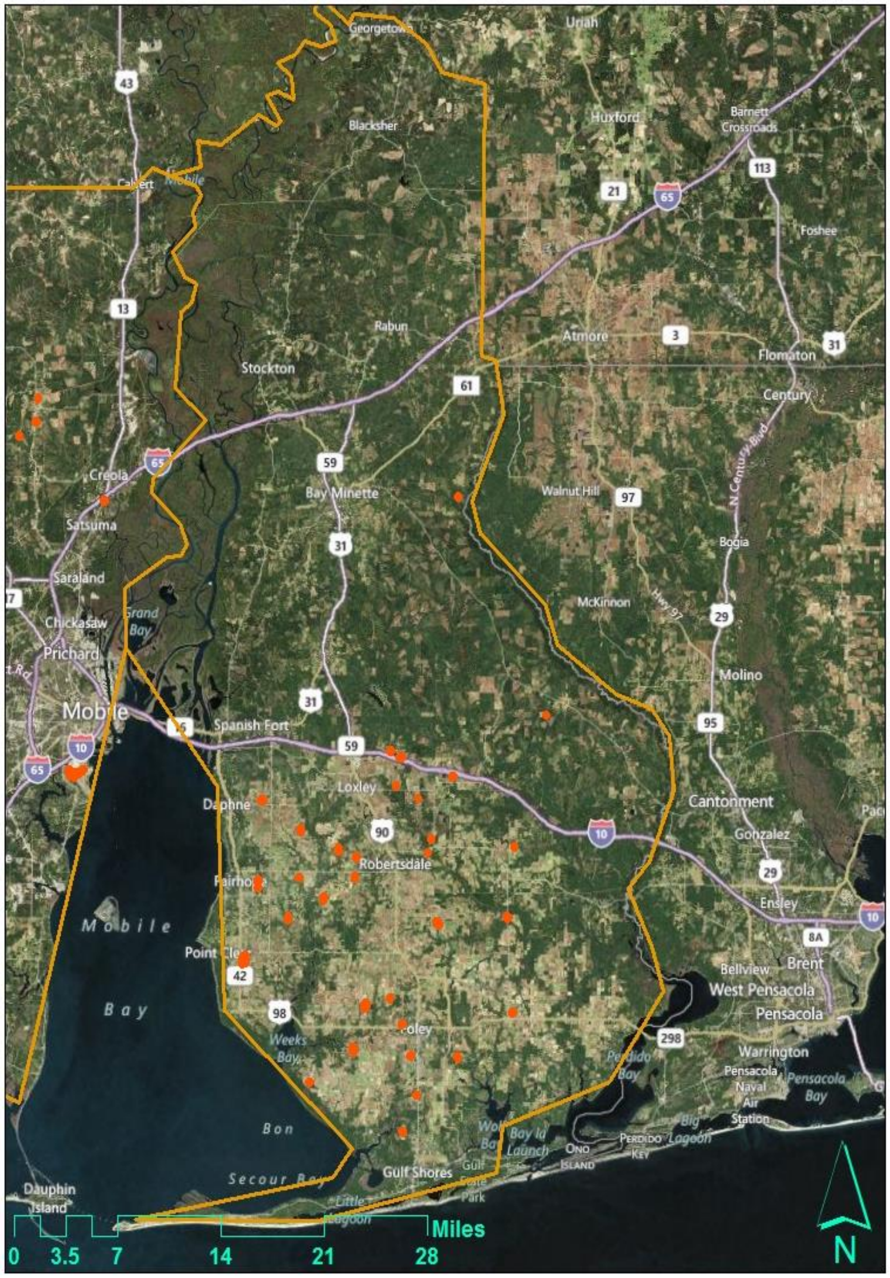
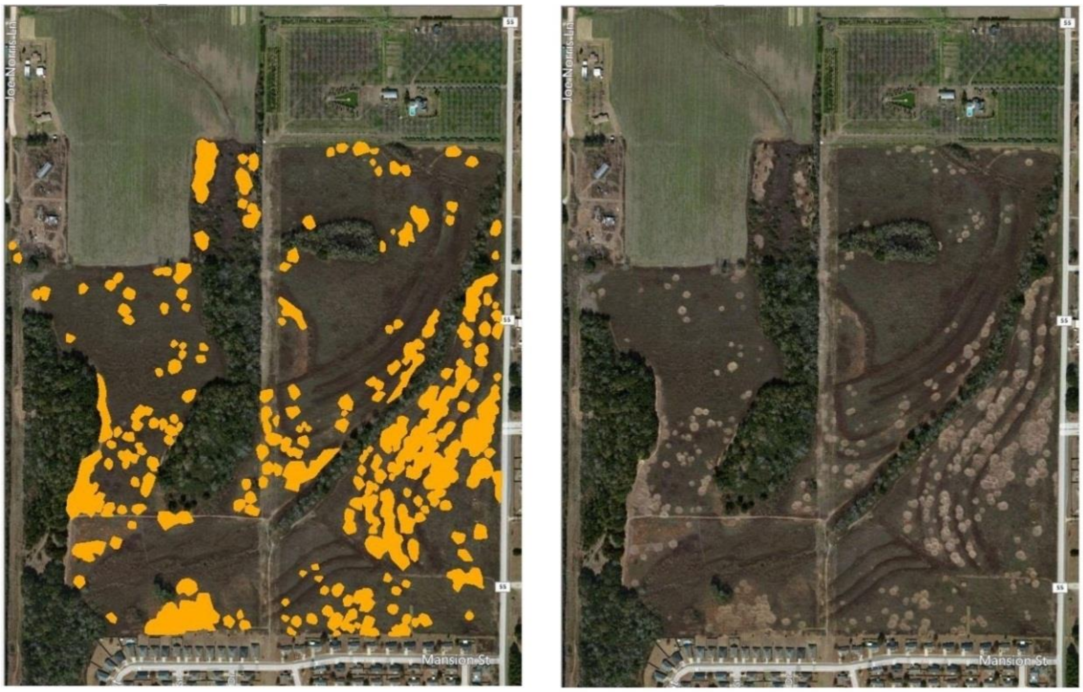


Figure 4.2 The possible patches of cogongrass infestation



Digitized image Original image

Figure 4.3 Example of the patches of cogongrass that were digitized in agricultural land

Digitized image Original image

Figure 4.4 An example of the patches of cogongrass that were digitized in pasture.

Digitized image

Original image

Figure 4.5 An example of the field that was infested by cogongrass in the study areas.

Descriptive statistics related to the area of the candidate patches were calculated by using the calculate statistics option in the attribute table of the patch and fields feature classes which gives the total polygon count, range of area values, sum, mean and standard deviation of all candidate areas. Descriptive statistics for cogongrass patches shown in Table 4.1, and Table 4.2 respectively. A total area of 10,537 acres were digitized in the open lands in Mobile and Baldwin Counties on 2011 NAIP imagery.

Potential Fields of Cogongrass Infestation in Mobile County

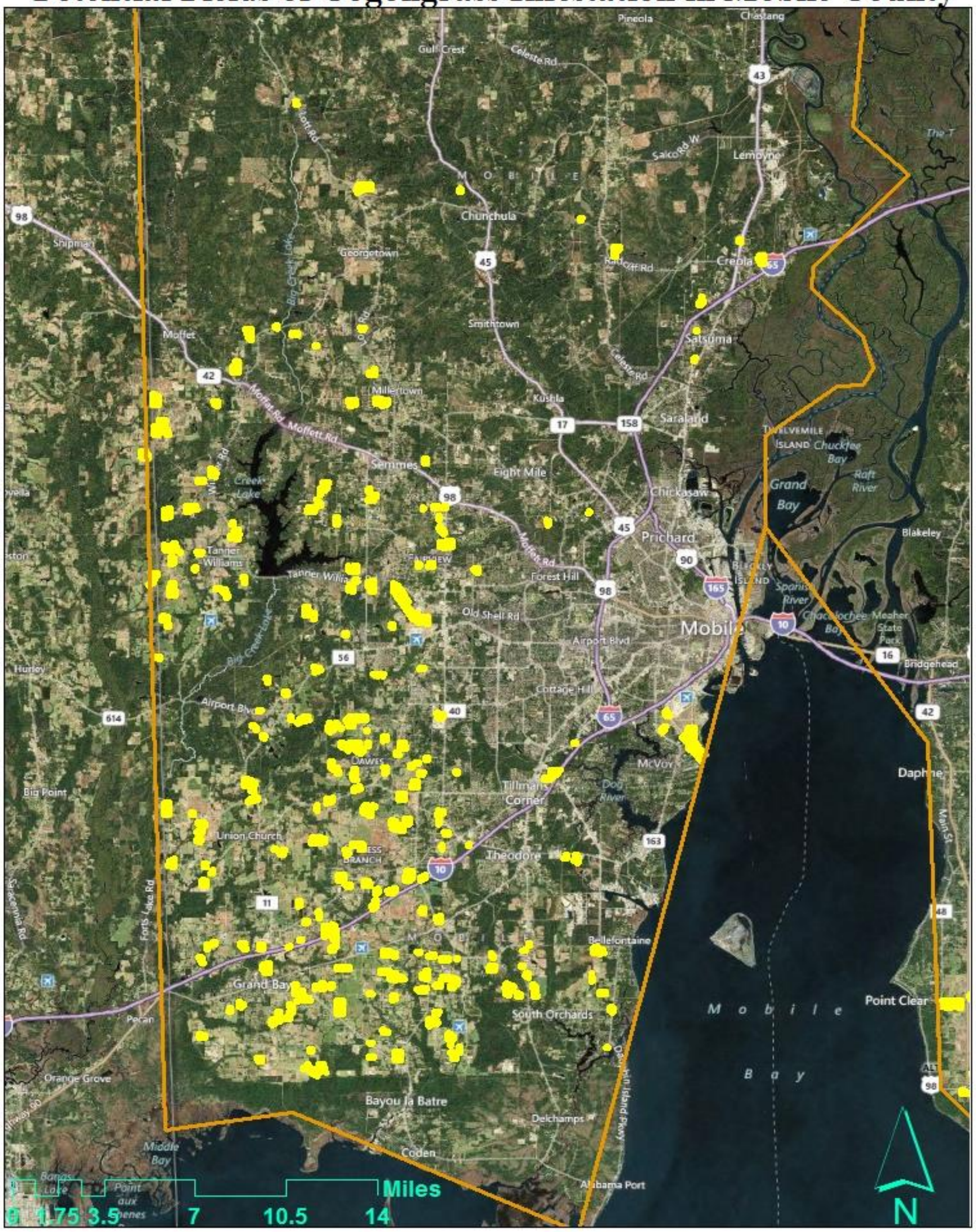


Figure 4.6 The map of possible fields of cogongrass invasion in Mobile County.

Potential Fields of Cogongrass Infestation in Baldwin County

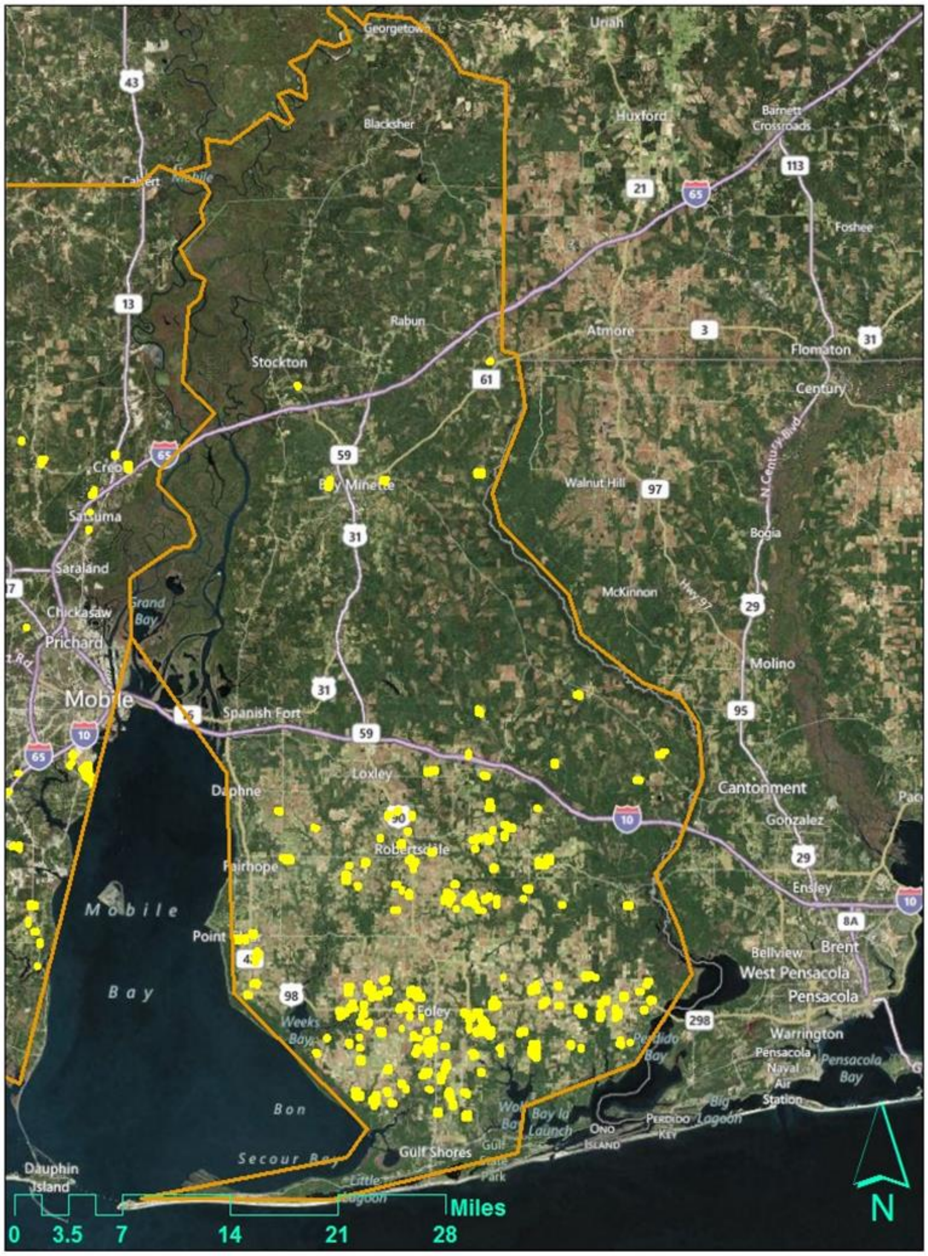


Figure 4.7 The map of the potential fields of cogongrass infestation in Baldwin County

Minimum	0.0004 acres
Maximum	14.24 acres
Sum	930.4 acres

Table 4.1 shows the size of biggest and smallest patch, sum of all polygons of cogongrass patches that were digitized.

Minimum:	0.68 acres
Maximum:	161.2 acres
Sum:	9,606.6 acres

Table 4.2 shows the size of minimum and maximum field, the total areas of all fields that were digitized.

4.2.1 Accuracy Assessment of Manual Editing

For the accuracy assessment of the digitized data, a field trip was made to Baldwin County. Analog maps of the digitized candidate areas were produced and brought along on the field trip for verification. The digitized areas were specified either as correct by drawing a circle around them on the analog maps or as incorrect areas by drawing a cross on them. GPS was used to collect location data of all the digitized areas using the geographic coordinate system. Locations visited were attempted to be spaced out using a grid pattern across the county and specific sites were chosen based on accessibility. In all, 63 sites were visited and XY location points were collected by a WAAS corrected Garmin DGPS. A percentage was then calculated to determine the percent correct. Table 4.3 shows the GPS collected points of the sites visited and whether or not they were invaded by cogongrass.

GPS Collected points	Kinds of infestations	Longitude	Latitude	Accuracy Assessment
1	open land	-87.7141	30.5436	Correct
2	open land	-87.7106	30.5437	Correct
3	open land	-87.7134	30.5437	Correct
4	open land	-87.7134	30.5437	Correct
5	road right-of-way	-87.7140	30.5439	Correct
6	road right-of-way	-87.7041	30.5674	Correct
7	road right-of-way	-87.7064	30.5673	Correct
8	open land	-87.7033	30.5683	Correct
9	open land	-87.7083	30.5733	Correct
10	road right-of-way	-87.7100	30.5744	Correct
11	open land	-87.7337	30.5745	Correct
12	open land	-87.7337	30.5860	Correct
13	road right-of-way	-87.7338	30.5962	Correct
14	open land	-87.7337	30.6063	Correct
15	road right-of-way	-87.7169	30.6167	Correct
16	road right-of-way	-87.7171	30.6166	Correct

17	road right-of-way	-87.7173	30.6037	Correct
18	road right-of-way	-87.7176	30.6038	Correct
19	open land	-87.7189	30.6037	Correct
20	road right-of-way	-87.7199	30.6037	Correct
21	road right-of-way	-87.7277	30.6331	Correct
22	road right-of-way	-87.7337	30.6331	Correct
23	road right-of-way	-87.7334	30.6332	Correct
24	road right-of-way	-87.6914	30.6230	Correct
25	road right-of-way	-87.6914	30.6232	Correct
26	road right-of-way	-87.6916	30.6238	Correct
27	open land	-87.6845	30.6040	Correct
28	open land	-87.6844	30.6040	Correct
29	open land	-87.7509	30.3225	Correct
30	open land	-87.7509	30.3225	Correct
31	road right-of-way	-87.7539	30.3228	Correct
32	open land	-87.7492	30.3223	Correct
33	open land	-87.7492	30.3228	Correct
34	road right-of-way	-87.7369	30.3336	Correct

35	road right-of-way	-87.7369	30.3336	Correct
36	open land	87.7354	30.3336	Correct
37	open land	-87.7354	30.3336	Correct
38	road right-of-way	-87.7340	30.3378	Correct
39	road right-of-way	-87.7340	30.3333	Correct
40	open land	-87.7340	30.3401	Correct
41	open land	-87.7340	30.3401	Correct
42	road right-of-way	-87.7340	30.3409	Correct
43	road right-of-way	-87.7171	30.3408	Correct
44	open land	-87.6958	30.3513	Correct
45	open land	-87.6958	30.3514	Correct
46	open land	-87.6959	30.3514	Correct
47	road right-of-way	-87.6960	30.3494	Correct
48	open land	-87.6969	30.3484	Correct
49	open land	-87.6979	30.3484	Correct
50	open land	-87.6984	30.3483	Correct
51	open land	-87.6984	30.3483	Correct
52	open land	-87.6966	30.3475	Correct

53	open land	-87.6966	30.3471	Correct
54	open land	-87.6962	30.3479	Correct
55	road right-of-way(two sides of the road)	-87.6966	30.3458	Correct
56	open land	-87.777	30.429	Correct
57	open land	-87.778	30.4260	Correct
58	open land	-87.779	30.423	Incorrect
59	open land	-87.753	30.425	Incorrect
60	open land	-87.752	30.419	Incorrect
61	open land	-87.754	30.416	Incorrect
62	open land	-87.736	30.354	Incorrect
63	open land	-87.753	30.417	Incorrect

Table 4.3 GPS coordinates of the potential areas of cogongrass infestations that were digitized on NAIP imagery in part of study area.

Out of the 63 sites visited, 57 were confirmed as cogongrass, yielding an overall accuracy of 90.5 percent. It is noted that the error here would be considered to be errors of commission where patches or fields were mapped as possibly being cogongrass, but fieldwork revealed they were incorrect. While in the field, 6cogongrass sites were also observed cogongrass, but they were not in the digitized maps; these would be considered errors of omission. The field trip was conducted in summer 2012, whereas the imagery was collected in winter 2011, so the omitted sites possibly could have emerged since

2011. Table 4.4 shows the GPS coordinates of the omission errors of cogongrass infestation that were collected during the field trip to Baldwin County.

Longitude	Latitude
-87.88384	30.46136
-87.87841	30.47143
-87.87810	30.47145
-87.78523	30.41445
-87.78508	30.41773
-87.78497	30.41758

Table 4.4 The coordinates of the cogongrass that were errors of omission.

4.3 Geographic Object Based Image Analysis (GeOBIA)

For comparison to the manual method of heads-up digitizing, an automated GeOBIA process was applied and evaluated on the NAIP imagery of 2011. This was done in the eCognition Developer v.8.Workspaces were created for each orthoquad, and creation of several projects within each workspace was done by sub-setting the imagery into less than 600*600 pixels. Sub-setting the imagery increased the speed of the analysis in the eCognition Developer and the process was more efficient. A ruleset was developed as described in more detail in Chapter 3 and this ruleset was used in each project for separation of the areas of candidate cogongrass infestations. Included first in the ruleset were segmentation algorithms which involved a combination of quadtree-based and multiresolution segmentations that were applied consequently to create objects (vector polygons) from the pixels. Afterwards, classification of the objects was done and in the first steps of classification the tree canopy and man-made features were extracted. Last, a nearest neighbor classifier method was used to separate the areas appearing to be infested by cogongrass and was extracted in agricultural areas and right-of-ways. Figure 4.8 shows the areas of possible cogongrass that were classified by GeOBIA in Mobile County, and Figure 4.9 shows the areas of the cogongrass that were identified by GeOBIA in Baldwin County. In addition to those maps, a zoomed in image of potential cogongrass patches is provided in figure 4.10.

The exported shapefiles of cogongrass infestation areas that were defined by GeOBIA were imported to ArcMap 10, and converted to a personal geodatabase in order to calculate the area automatically. All tiles were then merged into one dataset for the entire study area. To calculate area, an attribute table of the geodatabase was opened and a new field was added for area column and geometry calculated to measure the areas in acres. The total area of cogongrass measured by GeOBIA was 5,382 acres. Table 4.5.shows the size of maximum, minimum, sum in acres, and the number of polygons of all the patches of cogongrass that were defined by GeOBIA.

Map of Cogongrass Infestations in Mobile County by GeOBIA

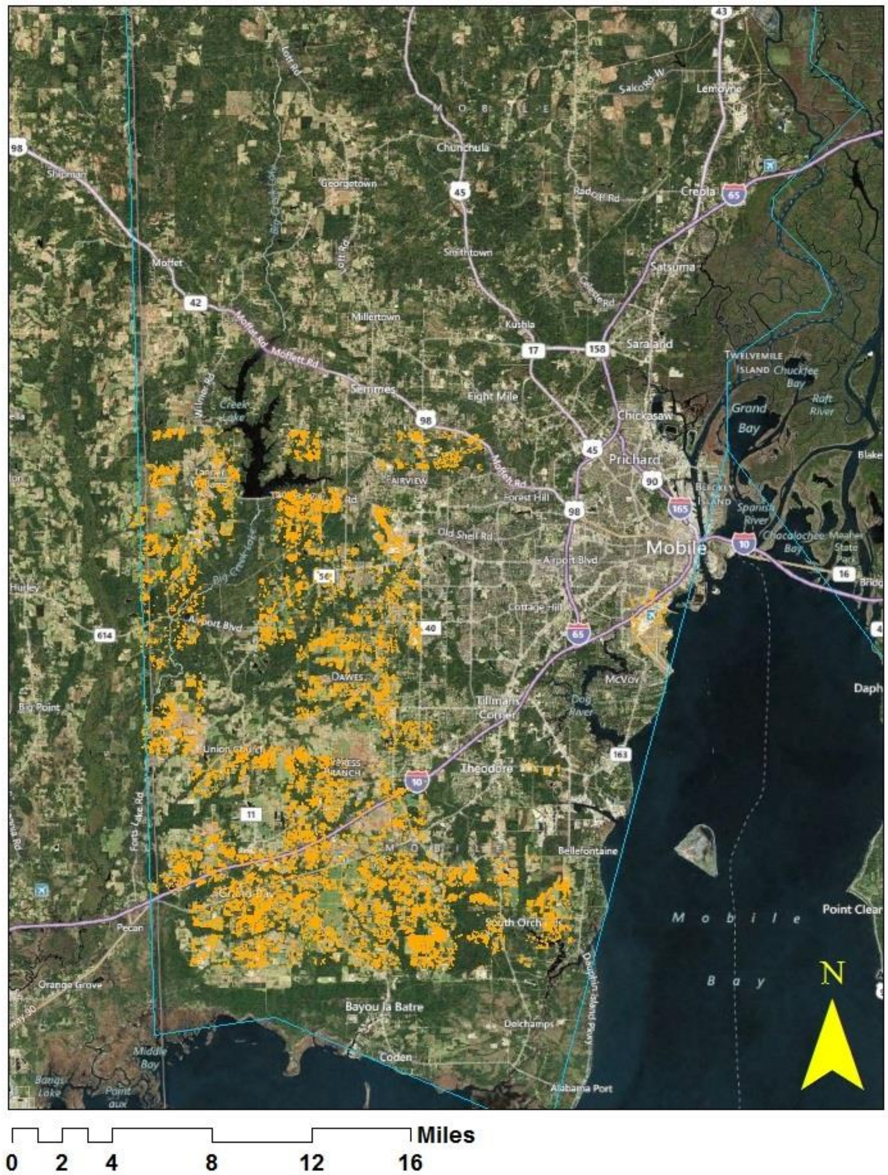


Figure 4.8 Areas of cogongrass infestations in Mobile County by GeOBIA

Map of Cogongrass Infestations in Baldwin County by GeOBIA

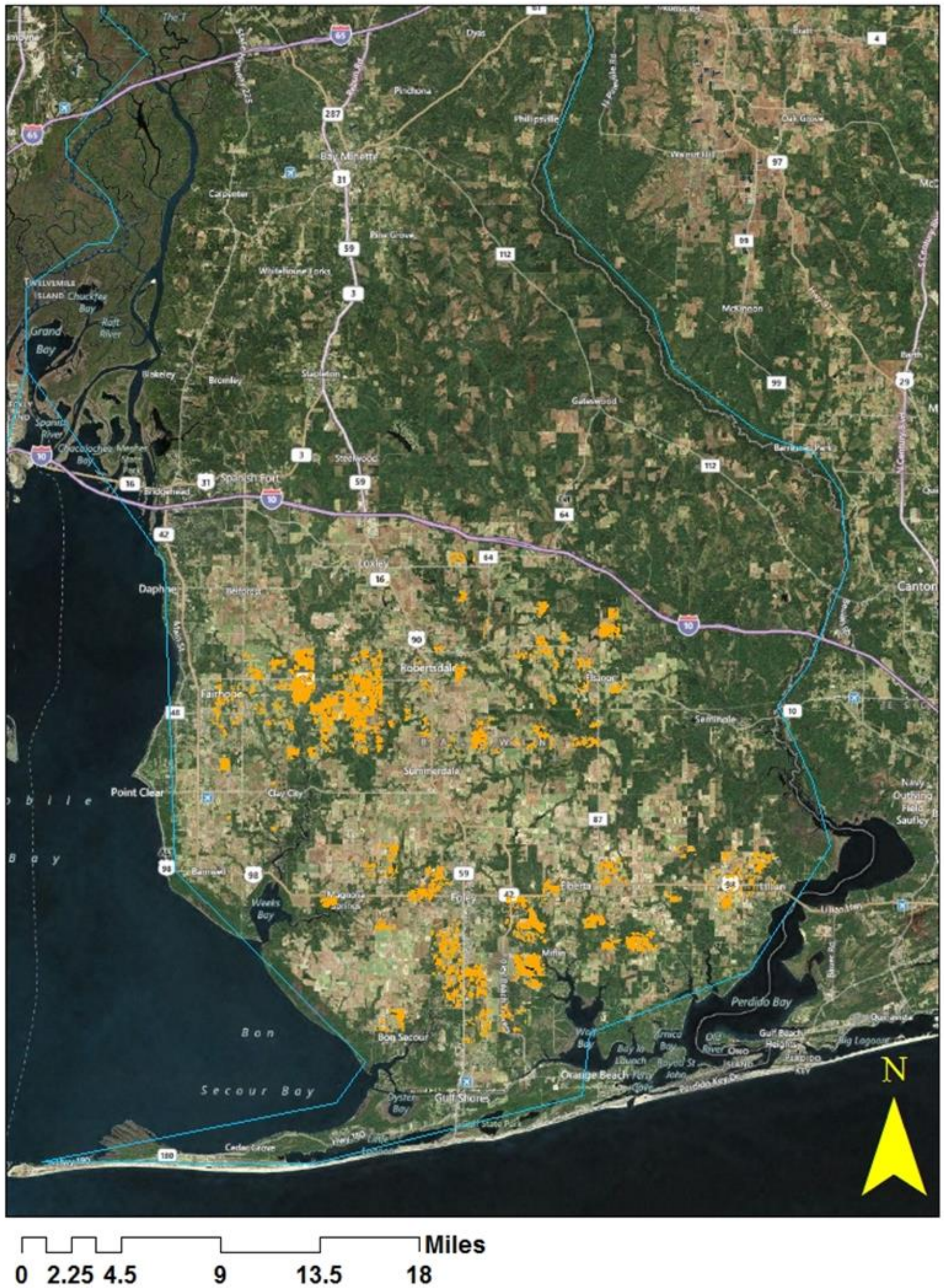


Figure 4.9 Areas of cogongrass infestations in Baldwin County by GeOBIA

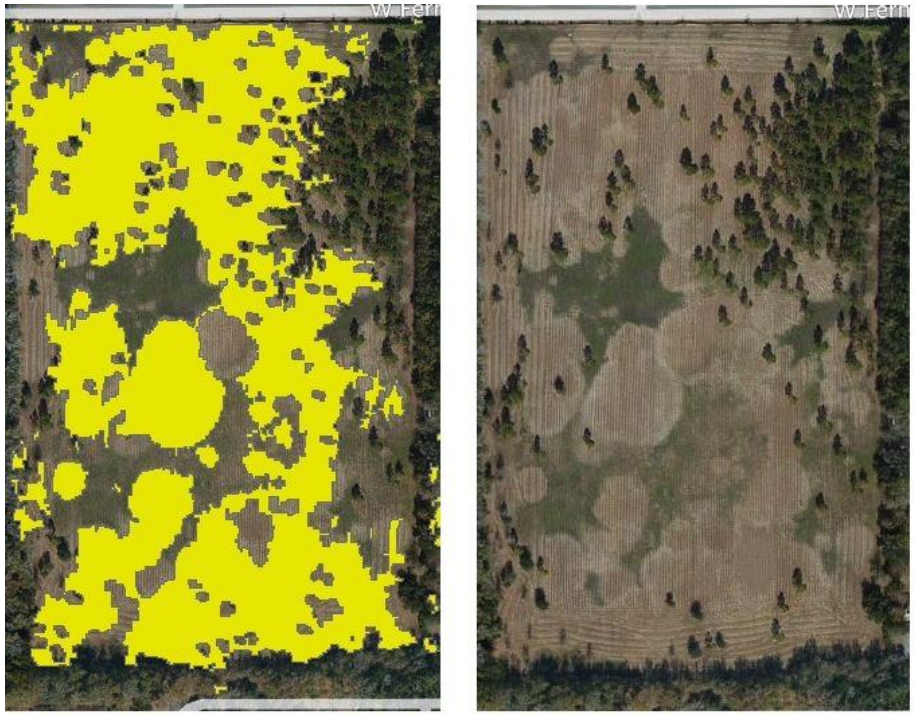


Figure 4.10 Cogongrass patches that were classified by GeOBIA

Minimum:	0.002 acres
Maximum:	2.5 acres
Sum:	5,382.2 acres

Table 4.5 The range of area values and sum of the cogongrass areas with GeOBIA

4.2.1 Accuracy Assessment of GEOBIA

Accuracy assessment of the possible cogongrass infestations defined through the GeOBIA method was done through several steps. In the first step, 283 polygons (approximately 10%) were randomly selected using the National Park Service AlaskaPak extension (NPS, 2012) in ArcMap. The locations of those polygons were then compared with the imagery and in situ data provided by the Alabama Cogongrass Center (ARRA, 2009). Out of 283 polygons that were selected, 149 points were deemed to be cogongrass patches, indicating 52.7 percent accuracy for classification of cogongrass in the GeOBIA method.

4.3. A Survey of Resource Managers' Perception of Dealing with Cogongrass

The survey was organized in such a way to collect information about the perception of people who help manage cogongrass regarding control methods, economic impacts, and other threats. About 150 questionnaires were distributed among the participants and 76 of the questionnaires were collected during the joint meeting between the Southeast Exotic Pest Plant Council (SE-EPPC) and the Alabama Invasive Plant Council (ALIPC) in May 2012. The results of the survey by each question are summarized below:

1. **Specify which states you work in?**

Figure 4.11 shows the distribution of people in terms of which states they work in regard to cogongrass. A majority of the participants were working solely in Alabama, but about a third of the respondents were working in other states.

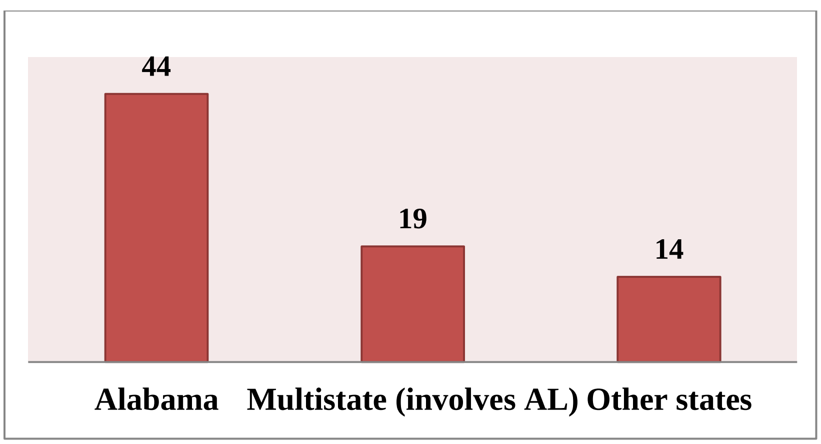


Figure 4.11 The percent of respondents from Alabama and other states

2. **If Alabama, please specify which counties?**

Among all the participants of the conference that work in Alabama, the respondents were grouped into four categories: statewide, multi-county, countywide, and other. Figure 4.12 shows that out of sixty three respondents, the majority of the participants worked in multiple counties, followed by a group that work statewide, and several work just one county.

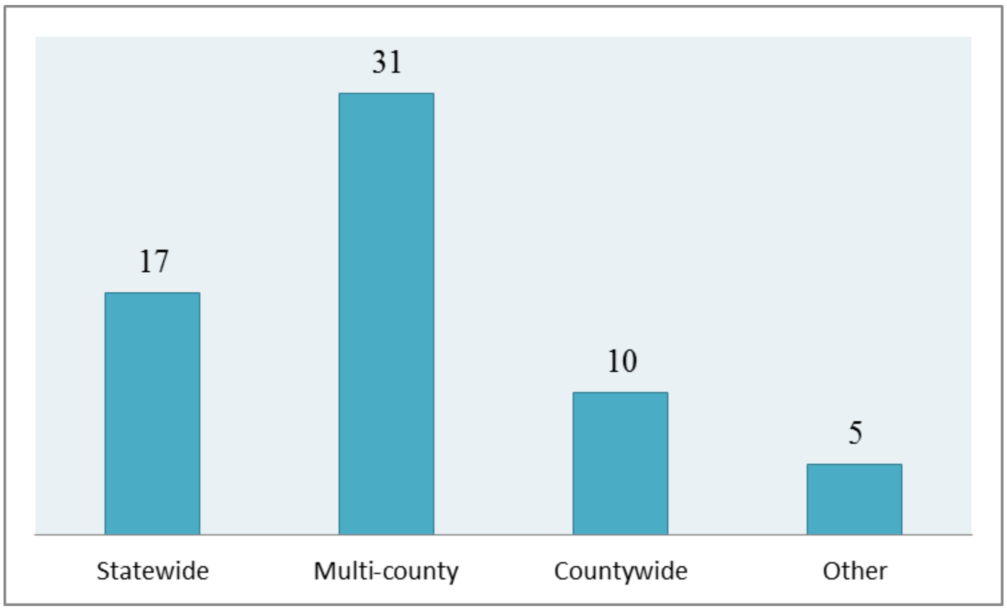


Figure 4.12 The number of participants in base on statewide, Multicounty, county and other

3. **How would you rate your knowledge of cogongrass?**

The knowledge of participants about cogongrass was asked using a likert scale of one to seven where one represents poor and seven represents excellent. The overall average rate of the knowledge of people surveyed was 4.99, indicating an above average knowledge of cogongrass.

4. In what capacity do you deal with cogongrass?

Participants were grouped into several classes based on their occupations related to cogongrass. According to Figure 4.13, many of the participants at the conference were involved in invasive plant management and herbicide applications. The second largest group involved people who were identified to be tied to some aspect of forestry. The third group involved people who were working on education and outreach related to invasive species, and the smallest group involved people who worked in government agencies.

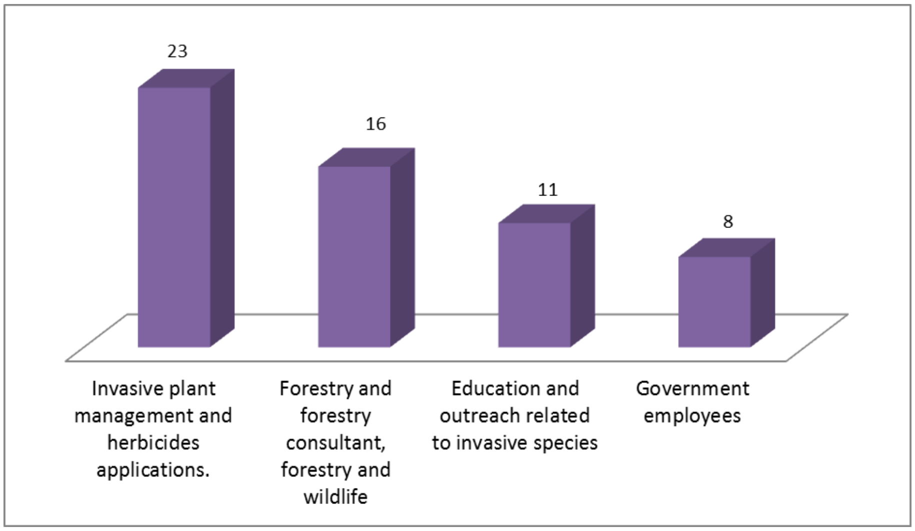


Figure 4.13 Participant occupation regarding to cogongrass

5. On which of the following activities do you feel cogongrass has the greatest negative economic impact?

In this question, the respondents were asked to rate the negative economic impacts of cogongrass on livestock production, the timber industry, row crop production, turf grass production, and other activities. The results show that cogongrass is perceived to have the most negative impact on timber industry at 5.62, followed by livestock production at 4.33, turf grass industry at 4, at 3.08 for row crop production, and 2.22 on other activities such as recreational areas and roadsides(Figure 4.14).

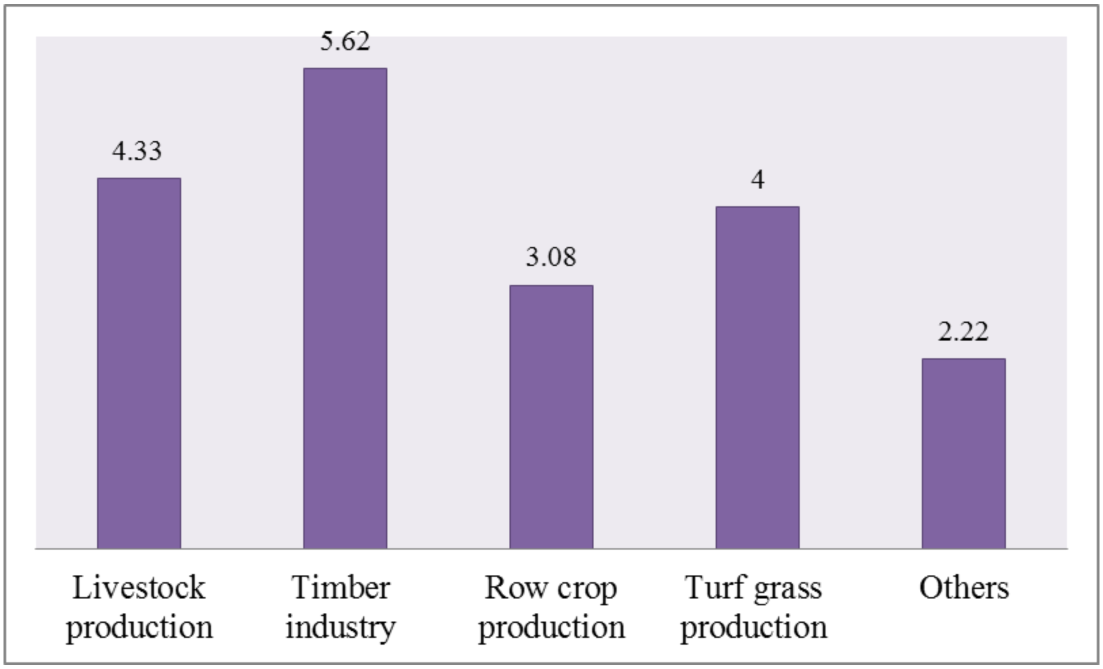


Figure 4.14. The average negative economic impacts of cogongrass on livestock production, turf grass production, timber industry, row crop production and others. (1-7 scale).

6. From your experiences, which land cover has cogongrass affected the most?

The respondents were asked to rate the impacts of cogongrass on different land covers**.** Figure 4.15 shows that cogongrass is perceived to have the highest impact on roadsides with the average of 5.47 followed by forest with 4.95, power line and other right-of-way with the average of 4.82, wildlife areas at 4.7, pasture at 4.17, orchards at 3.21, cropland at 2.54, and other at 1.08.

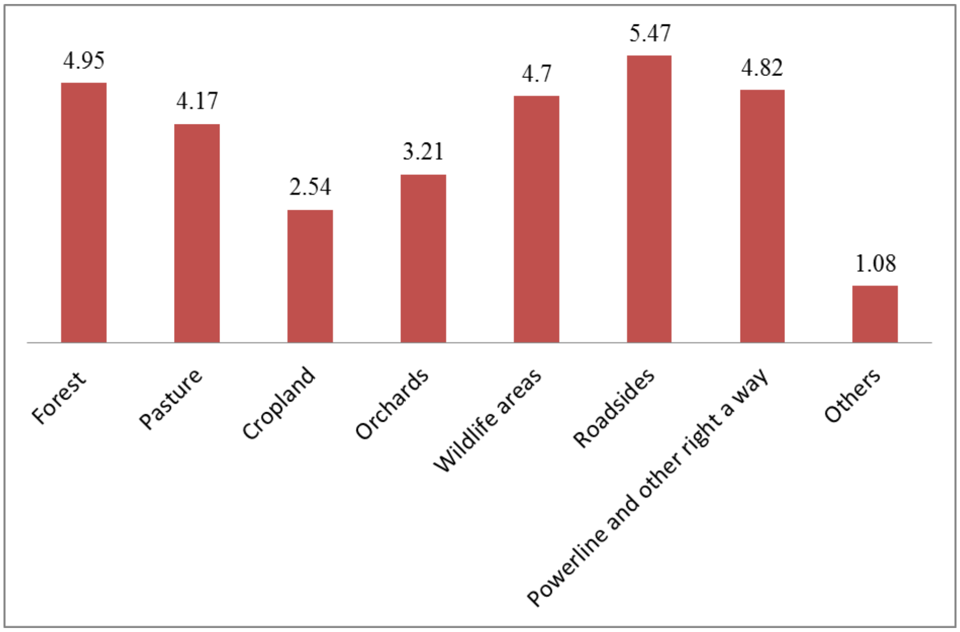


Figure 4.15.The average impacts of cogongrass on different land covers base on the participants' ideas (1-7 scale).

.

7. **If you have tried to control cogongrass, which of the following methods have you used?**

As shown in figure 4.16, herbicides are the most widely used for controlling cogongrass by far while tillage is the lowest.

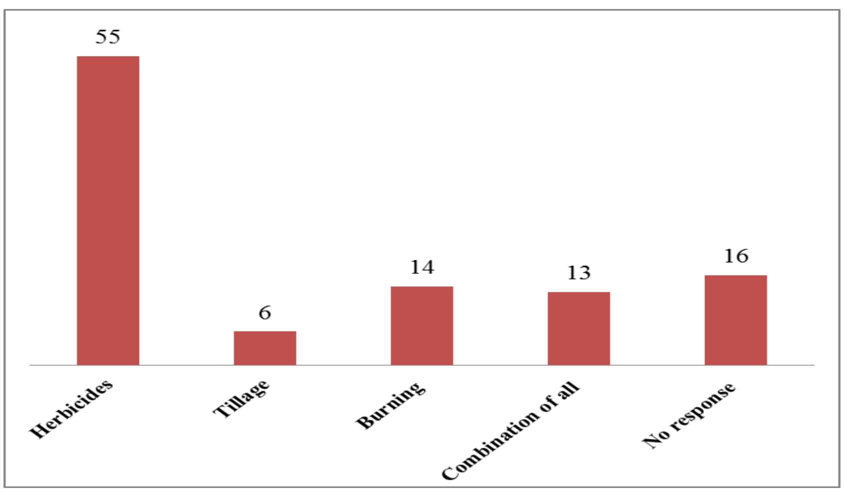


Figure 4.16.The number of tried control methods that have used

8. How many times on average, do you treat a patch of cogongrass?

Out of 76 responses, 50 people answered this question. Figure 4.17 shows the number of times during the year that cogongrass is treated based on the participants responses. Nineteen people marked that they treated patches of cogongrass twice per year, 17 treated a patch of cogongrass three times per year, seven participants treated a patch once per year, and seven people said that they treated a patch of cogongrass more than three times per year. This diagram shows that participants, based on their situations used one of these methods or applied all of them, but this information does not mean that they think their method best works to eradicate cogongrass.

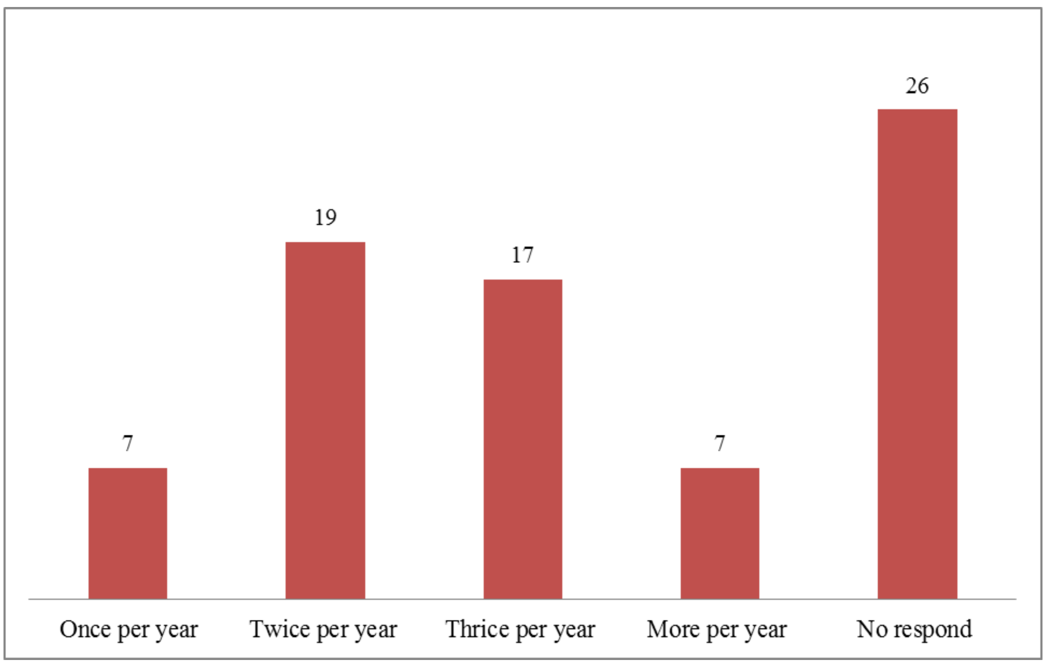


Figure 4.17 The number of people and their ideas towards the times during a year that a patch of cogongrass should be treated.

9. How successful were you with controlling cogongrass?

Figure 4.18 shows that out of 76 responses, 32 respondents felt that they were 80% or more successful in controlling cogongrass, while 27 people felt that they had 30 % or less success in controlling cogongrass.

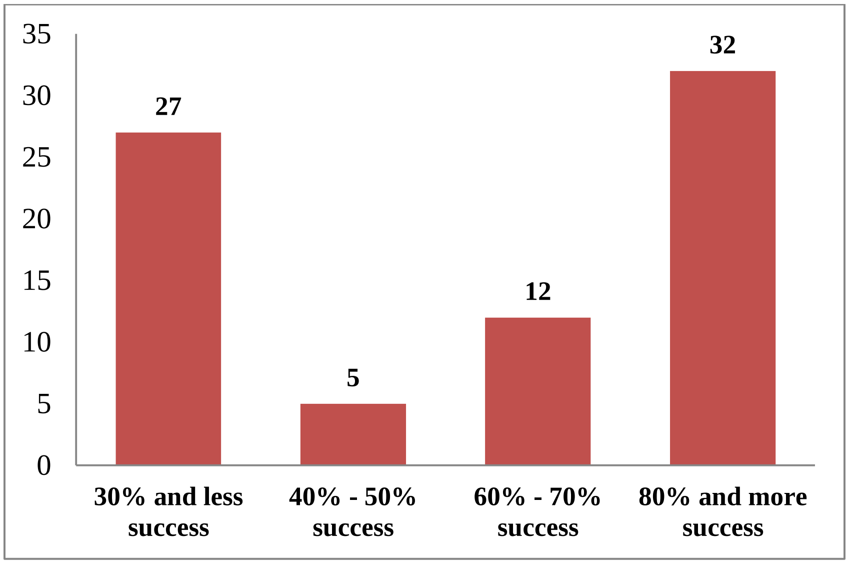


Figure 4.18 Respondent successes in controlling cogongrass.

10. How much of a threat do you believe cogongrass has on the following options?

Most of the participants believed that cogongrass has the highest impact on native vegetation, followed by restricting tree seedling establishment, pine productivity and survival, increasing wildfire threat, and impacting the quality of forage in pasture (Figure 4.19).

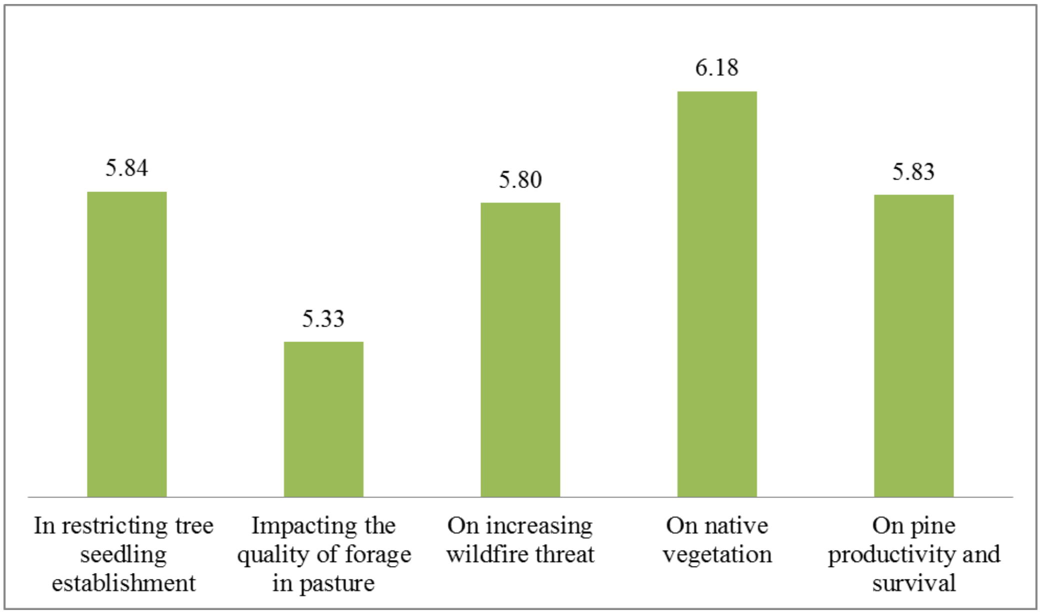


Figure 4.19 The average rate of cogongrass impact on restricting tree seedling establishment, impacting the quality of forage in pasture, increasing wildfire threat, on native vegetation, and pine productivity and survival (1-7 scale).

11. Based on your experience, what quantity of herbicide is required per acre to effectively treat cogongrass?

Based on the participants' responses, the average quantity of herbicides that they used for a patch of cogongrass is 9.51 gallons. They did not clarify whether this amount is herbicides mixed with water or herbicides alone.

12. Based on your experience, what is the average annual cost per acre of controlling cogongrass?

Twenty-two people responded to this question, and the average of those responses showed that the average cost of cogongrass patch eradication based on participants' knowledge is $207 per acre. However, they did not specify if this is just the cost of herbicides or if it involves the cost of labor, and other costs needed for controlling cogongrass.

13. Please indicate your agreement with the following statements.

This question asked the participants about their ideas towards the following comments:

- The spread of cogongrass can be halted
- It is important to try to stop the spread of cogongrass
- Cogongrass patches can be eradicated
- Local government is aware of the cogongrass problem and taking adequate steps to deal with it
- State government is aware of the cogongrass problem and taking adequate steps to deal with it
- Federal government is aware of the cogongrass problem and taking adequate steps to deal with it

The question has the scale of one to seven, where one represents strongly disagree and seven means strongly agree. Figure 4.20 shows that average responses of participants and that "it is important to try to stop the spread of cogongrass" has the highest average of 6.43 and "Local government is aware of the cogongrass problem and taking adequate steps to deal with it" has the lowest average score of 3.03.

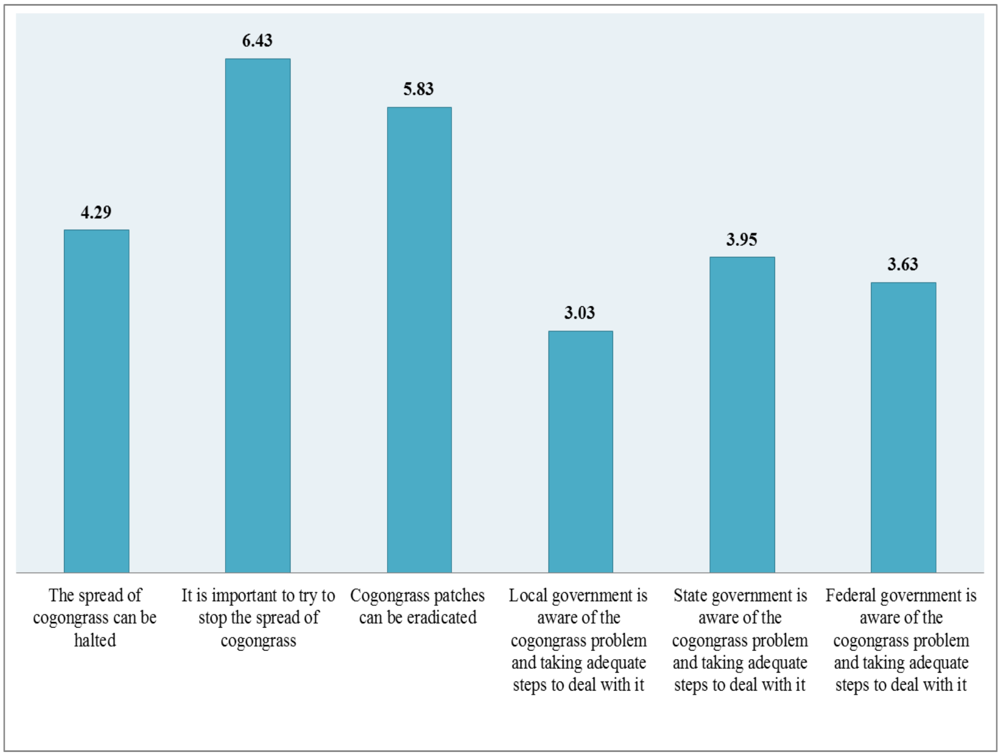


Figure 4.20 The diagram of average rate of participants' ideas towards different suggestive ways for controlling cogongrass in the United States (1-7 scale).

Estimated Cost of Control

Cogongrass can be controlled with two herbicides, glyphosate and imazapyr or a combination of the two. Glyphosate, which does not have soil activity, is typically used in areas where there are hardwood trees or other desirable vegetation. Imazapyr, which is soil active, is typically used to control cogongrass in loblolly pine plantations or other areas where soil activity is not a concern.

With glyphosate the recommended application rate is 4 lb active ingredient (a.i) per acre at two times per year, spring and fall (Miller and Enloe, 2009). The length of time required to control an infestation can vary, but it will typically take at least two to three years to eradicate cogongrass on a site. Using this scenario, a total of 16-24 lbs active ingredient per acre would be used to eradicate an infestation. The price of glyphosate varies, but currently averages around $30, resulting in a cost of $480 to $720 per acre for the glyphosate needed to eradicate cogongrass. The cost of surfactant, which is required for most formulations of glyphosate, is about 30 dollars, so the final cost for chemicals would be $501 to $ 737.

With imazapyr 0.75 lb a.i per acre is a typically recommended rate for treatment, with one treatment per year for 2 to 3 years. More treatments may be required for some infestations. For a 2 to 3 year treatment regime, the amount of imazapyr applied would be 1.5 to 2.25 lb, a.i, per acre which would cost $168 to $ 252. Including the cost of a surfactant would bring the total chemical cost to $198 to $282.

In some cases both glyphosate (4lb a.i) and imazapyr (0.75 a.i) are applied together, using one application per year for 2 to 3 years. Chemical costs (herbicide plus surfactant) for this scenario would be $433 to $635.

In situations, where a soil-active herbicide cannot be used or is not desired (e.g., pastures, croplands and right of ways) glyphosate alone is the preferred control option. Given that the majority of area mapped in this study occurred in pasture, crop land and right of ways, the cost of herbicides for cogongrass treatment is based on using glyphosate alone.

Of the two mapping methods tested, the digitized method was much more accurate, and therefore this is what is used for estimating the cost of cogongrass control. The cogongrass infestations were specified by heads-up digitizing which did not capture infestations under trees, therefore the majority of infestations were considered to be in open lands.

The total area of cogongrass infestations that were digitized in Mobile and Baldwin counties was approximately 10,537 acres. The estimated cost for glyphosate and surfactant to eradicate this acreage is $ 5,279,037 and $7,765,769 over a 2 to 3 year period. This estimate is extremely conservative as it does not include labor or travel costs.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary

Cogongrass became highly invasive in Alabama following its introduction for forage in the early 20th century. Forests, pasture and croplands, and road sides or utility right-of-ways are impacted by cogongrass infestations. According to previous studies, cogongrass has resulted in a substantial amount of economic loss on agricultural products (Hubbard et al. 1944; Soerjani 1970; Eussen et al. 1976; Daneshgar et al.2008). Cogongrass incursion is a major problem because it affects a variety of organisms and ecological communities of different species found within Alabama, especially Mobile and Baldwin Counties.

To assess the impact of cogongrass invasion in Mobile and Baldwin Counties, one of the main study objectives was to estimate the amount and spatial extent of cogongrass. Mapping the extent of the cogongrass invasion was done utilizing remote sensing techniques. From a birds-eye view cogongrass can only be seen in open areas such as pasture, crop lands, and right-of-way areas making it difficult to map in forested areas. Aerial imagery prepared by the National Agricultural Imagery Program (NAIP) and collected during the summer of 2011 was used in this study. One of the benefits of NAIP imagery is that it is a product provided by a number of government agencies at little or no cost to the general public. The NAIP imagery that was used for this study has four spectral bands (blue, green, red, and near-infrared), with the spatial resolution of one meter.

The mapping part of the thesis consisted of two parts including a manual method by using heads-up digitizing and an automated process by using Geographic Object based Image Analysis (GeOBIA) to map the spatial extent of cogongrass in the study areas. For applying the manual editing ArcGIS 10 software was used and the automated method was conducted with eCognition Developer v.8. The accuracy assessment of two mapping methods was done towards the end of the study during the summer of 2012. Accuracy assessment of heads-up method was performed by visiting the study areas through a trip to the field using analog maps produced and a GPS tool to ascertain the geographic coordinates of the cogongrass of the field sites visited. The GeOBIA method in eCognition was assessed by selecting random polygons for the maps produced and these were assessed against the imagery and the in situ data collected by the Alabama Cogongrass Center (ARRA, 2009). The overall accuracy assessments of these two methods were performed separately with the analysis showing that the manual method was substantially more accurate.

In this study management practices and their impacts were investigated through a survey of resource managers involved with this invasive species. The survey questionnaires were distributed among the attendees at the joint meeting between the Southeast Exotic Pest Plant Council (SE-EPPC) and the Alabama Invasive Plant Council (ALIPC) on May 8-10, 2012 in Auburn, Alabama. The results of the survey indicated which land covers are perceived to be most impacted by cogongrass, as well as the kind of activities that are affected by cogongrass based on perception of the participants. Additionally, the cost of cogongrass eradication, the control methods, the amount of success in controlling cogongrass, and use of various management techniques were evaluated in the survey. Personal interviews with scientists with expertise on cogongrass aided with estimating costs for control and locating ancillary data to aid in analysis and field verification.

Results of the mapping provided the areas of cogongrass infestation in the pasture and crop lands as well as right-of-ways of Mobile and Baldwin Counties. The outcomes of the survey and interviews provided an estimated cost of controlling cogongrass per acre. Therefore, by obtaining the areas of infestation and the estimate of the cost of controlling cogongrass per acre, the overall cost for eradication of cogongrass in these two counties was estimated. In this final section of the thesis, the research questions of the thesis from Chapter 1 of the thesis are revisited and discussed.

Controlling cogongrass on the open lands for Mobile and Baldwin Counties based on this analysis requires up to two to three herbicide treatments per year at an approximate cost of $ 500 to $737 per acre over two to three years.

5.2 Research Question Conclusions

1. Can we effectively use remote sensing to map potential locations of cogongrass?

a) What datasets are available to efficiently attempt to map the location of cogongrass over a large area?

The likelihood of discriminating invasive plants from the surrounding vegetation generally increases with remote sensing data as the number of spectral bands increases and as a consequence, the accuracy of the mapping results will usually be better (Hunt et al., 2012). Remote sensing data that have a higher spectral resolution are primarily produced in the private sector. Hyperspectral data are an example of data that have many spectral bands (often greater than 100) and that have been used and promoted for mapping invasive species (Ustin et al., 2002; Underwood et al., 2003; Lawrence et al., 2006; Hestir et al., 2008; Ustin et al., 2008). However, hyperspectral data are expensive, difficult to process, and require large amounts of storage (Hunt et al., 2012). If applied regionally across the Southeast, or even for a study such as this one covering two relatively large counties, the use of current hyperspectral technology would be cost-prohibitive.

Multispectral datasets also have been shown to have some success in mapping invasive species (Walsh et al., 2008). Multispectral datasets are collected by both satellites and aircraft. In either case, they are more expensive for high resolution datasets purchased from a commercial vendors (Hunt et al., 2012). There are multispectral datasets that are available for free in the public domain. Two such datasets that were investigated for the capability of mapping Cogongrass were the Landsat Thematic Mapper (TM) satellite imagery and the National Agriculture Imagery Program (NAIP) dataset, both of which were available for free for the state of Alabama. Although Landsat TM covered a large footprint and had clear images several times per year, the relatively course resolution of 30m x 30m did not detect potential areas of cogongrass well. Therefore, NAIP imagery of 2011 was chosen as the ideal dataset for mapping cogongrass over a large area in this regional scale study.

b) Given cogongrass has a unique flowering color; is it practical to try to find seasonal imagery to match this occurrence?

Fluffy, flashy blooms of the cogongrass during spring from April and May are often the first signs of an infestation (Miller et al., 2010). Environmental factors affect the time of flowering of the cogongrass and therefore where and when it flowers varies substantially within the study area. Several Landsat TM images from April through June of the year 2010 and 2011, were observed and it was determined that flowering was not detectable with the coarse datasets. NAIP imagery is flown in the prime of the growing season generally after cogongrass flowers. Utilizing high resolution multispectral or hyperspectral data may be possible to detect cogongrass while flowering, but once again is cost-prohibitive.

c) How efficient is it to use aerial imagery for visual examination and Heads-up digitizing as opposed to automated methods such as Geographic Object Based Image Analysis? What is the accuracy of the visual examination process vs. the automated process?

The accuracy assessment of the GeOBIA method in this analysis was 52% while the accuracy assessment of heads-up digitizing was 90.5% when considering errors of commission. From the experiences of conducting this research, it was determined that there is a trade-off in terms of producing results, the heads-up digitizing was more accurate, but it takes weeks and months to manually digitize every image, whereas once a ruleset is developed in eCognition it can then be applied relatively quickly to other imagery.

2. In which kinds of land use/land cover can we detect cogongrass with imagery?

The birds-eye perspective of NAIP imagery limited this analysis to open land covers where grass can be seen including pasture and crop lands areas as well as roadside and utility right-of-ways. In the right-of-ways it was more difficult to detect cogongrass because a circular pattern of cogongrass spread was not as common. For right-of-ways it may be more efficient to do in situ field detection as opposed to remote sensing. Much of the ground data received from the Alabama Cogongrass Center includes right-of-way locations many of which are shared with the public on an Alabama Forestry Commission website (AFC, 2012). In addition, there is a useful citizenry portal for mapping cogongrass that focuses largely on public spaces including right-of-ways that was launched by the Center for Invasive Species and Ecosystem Health at the University of Georgia that is called the Early Detection and Distribution Mapping System (EDDMapS) www.eddmaps.org.

3. What are some benefits of using Geographic Object Base Image Analysis (GeOBIA) for mapping cogongrass patches versus the visual interpretation?

With visual interpretation of imagery, that is often very diverse, humans deal with this heterogeneity according to gestalt principles (Lang 2008) encompassing the idea that the brain is holistic and self-organizing allowing interpretation of an image as a whole rather than from its parts. Humans perceive the imagery and extract features to give meaning to them. GeOBIA is an attempt to mimic this process by grouping pixels into objects and applying rules to make them more meaningful. With time, as GeOBIA methods develop they will likely improve and come closer to interpreting images as well as the human brain.

Although the heads-up digitizing produced a higher accuracy map, the main benefit of the automated process developed in eCognition is that the rulesets can be applied to other areas relatively quickly. While 52% is not as accurate as the results produced with manual methods, it still could provide locations for people looking to locate infested areas that are possibly cogongrass over half of the time which is better than randomly going out into the field looking for cogongrass. Again, given GeOBIA methods continue to develop, the accuracy for mapping cogongrass and other invasive species will likely improve.

a) Which variables can be used to develop rulesets in the automation process?

The variables used in the development of this ruleset were determined through a trial and error process and it is noted that other rules could possibly produce more accurate results. The variables that were used in the development of the rulesets focused primarily on the four bands of the imagery as well as shape and texture of objects that were segmented in eCognition Developer. Ratios of the bands were used to pull out differences in vegetation with the average Normalized Difference Vegetation Index ((Mean NIR-Mean Red)/ (Mean NIR+ Mean Red)) and a Ratio green index [Mean green] / (([Mean blue] + [Mean green] + [Mean red])).

The spectral properties of the image objects like the mean of layer values which consist of mean blue, green, red, near-infrared, and brightness, and max difference of image objects were used. The extent property that was applied consists of area, length/width, number of pixels, volume of pixels, and width of pixels. Shape consists of asymmetry of the image objects. These variables were applied by nearest neighbor (NN) classifier to separate cogongrass polygons from the surrounding vegetation.

b) Which segmentation methods and associated parameters are best in creating objects that represent cogongrass?

It was determined through a trial and error process that a two-step segmentation including a quadtree based algorithm with the scale of 10 on the pixels in the first step and a second algorithm using multiresolution segmentation with the scale of 10 on the objects created in step one worked efficiently. The sequential segmentations helps to increase the speed of data processing in eCognition Developer and provided objects that best match the areas for discrimination of cogongrass from other kinds of vegetation.

c) Which rules help to separate cogongrass from other classes and especially other grasses?

Two methods were used to classify the images: NN and membership function. Membership function is a single parametric method for classification of image and nearest neighbor is a multi-parametric method. In the first step, the membership function was applied to classify manmade features and tree canopy. In the second step, for the classification of the cogongrass from other kinds of plants, several parameters of cogongrass polygons were specified through trial and error and these parameters were applied in the classification of cogongrass through the nearest neighbor method.

4. What is the area of lands is affected by cogongrass in Mobile and Baldwin County?

The total area of land affected by cogongrass as specified through heads-up digitizing of both patches and fields in open areas of Mobile and Baldwin Counties was estimated to be 10,537 acres in pasture, crop lands, and right-of-ways.

5. Can we estimate the economic loss of cogongrass infestations?

The heads-up digitized patches and fields show that the amount of lands that was infested by cogongrass is 10,537 acres in open areas. Considering patches and fields in the open lands, according to experts focused on estimating the cost of herbicides usage, for treatment of cogongrass glyphosate 4lb active ingredients per acre should be used during 2 to 3 years so the total amount of glyphosate which is needed per acre is 16 to 24 lbs during 4 to 6 times treatment. The current cost of glyphosate is $30 dollars per gallon. Therefore, the cost of cogongrass eradication by herbicides is $ 5,279,037 and $7,765,769 for the two counties. Other costs which involve surfactants and dye added to herbicides, equipment, labor, travels, and mapping costs, and calculating these cost are complicated and many estimates are involved in that.

6. The survey of resource managers attempts to answer the following questions for a better understanding of cogongrass impacts.

a) In which ways does cogongrass affect landowners and how are they dealing with the invasive species?

The results of the survey showed that the timber industry is perceived to be the most affected by cogongrass invasion. After that, livestock production and turf grass production also were scored highly in as being affected by cogongrass. The survey participants felt that cogongrass had the least influence on row crop production. These results could be somewhat skewed as many of the participants identified themselves as being associated with forestry. Overwhelmingly, participants said they are using herbicides to control cogongrass.

b) Is there any difference between economic impacts of cogongrass on different land covers?

While much of the literature reviewed discusses the negative impact of cogongrass on livestock and pasture lands, results of the survey show that cogongrass has the most negative impact on roadsides and forests. After that, power line, other right-of-way, and wildlife areas were perceived to be mostly influenced by cogongrass. Perception was that the lowest impact was on pasture and orchards based on the results of the survey. While the mapping displayed a great amount of infestations in pasture and crop areas, the potential economic impacts in forested areas, were not possible using remote sensing methods. Roadsides and utility right-of-ways likely received a high score for impact because they play a role in the spread of the invasive species.

c) How substantial are the economic impacts of cogongrass in Alabama?

A review of the literature shows that cogongrass has an influence on the economy in the agricultural and silvicultural sectors of the economy and the survey indicates many agree, ast all these industries were thought to be substantially influenced by cogongrass invasions, especially the timber industry and livestock production. A major cost associated with cogongrass is its control, which is most effectively accomplished. For the open areas in just two counties in Alabama, it is estimated that control could cost between five to seven million dollars. When it is considered that cogongrass has spread to over half of Alabama's counties, this is a substantial economic impact. It is interesting that given these substantial costs there was a strong sentiment (5.83 out of 7) in the survey that cogongrass can be eradicated and doing so is very important.

d) What is the perceived knowledge of resource managers about different threats of cogongrass?

According to the findings of the survey, the majority of the respondents were aware of the threat of cogongrass on native vegetation. After that they were aware of the restricting tree seedling establishment and pine productivity and survival. Fewer people were aware of the effect of cogongrass on increasing wildfire threat, and impacting the quality of forage in pasture lands. Few stated that they knew the impacts of cogongrass on the quality of forage in pasture lands.

e) How useful are current control methods for controlling cogongrass?

The majority of participants preferred on using herbicides more than other control methods. Fifteen percent of the participants use burning, and a few used the tillage as a control method. Approximately 13 percent of the respondents stated that they used all control methods which involves herbicides, tillage, and burning for controlling of cogongrass.

f) How successful were resource managers in controlling cogongrass?

The views are diverse about this question. Out of 76 participants, 32 stated that they were less than 80% successful in controlling cogongrass. However, 27 participants said that they had 30% or less success in controlling cogongrass. Current research indicates that to be successful in controlling well-established areas of cogongrass that treatments must be administered three-to four times per year, yet of the 50 respondents who responded to the question about how many times they treated it, 26 did so less than three times per year.

g) What are most of resource managers' attitudes towards the government agencies help with controlling cogongrass?

Based on the survey, resource managers indicated that awareness of the state and federal government of the cogongrass problem is important, and that they will take adequate steps to deal with it more than local government. In all the questions regarding the government involvement scores were low.

References

Alabama Forestry Commission (AFC). 2012. Cogongrass viewer. Last accessed 1 November, 2012. http://www.forestry.alabama.gov/viewers/afc_cogongrass_viewer.aspx

AL-Khudhairy, D.H.A., Caravaggi, I. and Giada, S., 2005, Structural damage assessments from Ikonos data using change detection, object-oriented segmentation, and classification techniques. Photogrammetric Engineering and Remote Sensing, 71,pp. 825–838.

Alvalapati, J.R.R., S.,Jose, G.A., Stainback, J.R.Matta, and D.R., Carter.2007. Economics of Cogongrass Control in Slash Pine Forests. Journal of Agricultural and Applied Economics, 7,00(Month 2007): 59-66.

American Reinvestment and Recovery Act. 2009. Award Number 09-DG-11084419-041 "Alabama Cogongrass Control Center" awarded to Alabama Forestry Commission, 2009-2012.

Asner, G.P., M.O. Jones, R.E. Martin, D.E. Knapp, R.F. Hughes. 2008. Remote sensing of native species in Hawaiian forests. Remote Sensing of Environment 112. 1912-1926.

Ayeni, A. O. and Duke,W. B. 1985. The influence of rhizome features on subsequent regenerative capacity in speargrass (Imperata cylindrica (L.) Beauv.). Agr. Ecosyst. Environ. 13: 309–317.Baatz, M. and A.Schape.2000.Multiresolution Segmentation-An optimization Approach for High Quality Multi-scale Image Segmentation. Angewandte Geographische Inofrmationverabeitubng Xll, ED. J. Stroble et al. AGIT Symposium, Salzburg, Germany.2000.pp.12-23.

Bradley, B. A. and Mustard, J. F. 2006. Characterizing the landscape dynamics of an invasive plant and risk of invasion using remote sensing. Ecol. Appl. 16: 11321147. Bryson, C. T. and Carter, R. 1993. Cogongrass, Imperata cylindrica, in the United States. Weed Technol. 7: 1005–1009.

Brook, A., M. Zint, and R. De Young. 2003. Landowners' Responses to an Endangered Species Act Listing and Implications for Encouraging Conservation. Conservation Biology, Pages 1638-1649. Volume 17, No.6, December 2003.

Bryson, C. T. and R. Carter. 1993. Cogongrass, Imperata cylindrica, in the United States. Weed Technol. 7:1005–1009.

Burt, J.W. A. A, Muir, J. Piovia-Scott, K.E. Veblen, A.L. Chang, J.D. Grosssman, H.W. Weiskel. 2007. Preventing horticultural introductions of invasive plants: potential efficacy of voluntary initiatives. Biol Invasions 9:909–923.

Burnett, C. and T. Blaschke.2003. A multi-scale segmentation/object relationship modeling Methodology for landscape analysis. Ecological Modeling 168 (2003) 233–249.

Carleer, A.P. and Wolff, E., 2006, Urban land cover multi-level region-based classification of VHR data by selecting relevant features. International Journal of Remote Sensing, 27, pp. 1035–1051.

Campbell, J.B., 2002. Introduction to Remote Sensing. Guildford Press, New York.pp.66-99.

Chen, S., Lin, W. and Chen, C., 1991, Split-and-merge image segmentation based on localized feature analysis and statistical tests. Graphical Models and Image Processing,53, pp. 457–475.

Coile, N.C. and D.G. Shilling. 1993. Cogongrass, Imperata cylindrica (L.) Beauv.: A Good Grass Gone Bad! Fla. Dept.of Agric. and Consumer Services. Bot. Cir. No. 28, 4 pp.

Cord, A., D. Klein, S. Dech. 2010. Remote Sening Time Series for Modeling Invasive Species Distribution: A case Studey of Tamarix spp.in the US and Mexico. International Environmental Modelling and Software Society (iEMSs)2010 International Congress on Environmental Modelling and Software.Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada.David A. Swayne, Wanhong Yang, A. A. Voinov, A. Rizzoli, T. Filatova. (Eds.)http://www.iemss.org/iemss2010/index.php?n=Main.Proceedings.

Darwish, A., Leukert, K. and Reinhardt, W., 2003, Urban land-cover classification: an object based perspective. In 2nd GRSS/ISPRS Joint Workshop: Remote Sensing andData Fusion over Urban Areas, 22–23 May, Berlin, pp. 278–282.

Definiens (2008). Definiens Developer 7.0, USERGUIDE. (Part of eCognition software)

Definiens (2012). Definiens Developer 8.64, USER GUIDE. (Part of eCognition software).

Dickens, R. 1974. Cogongrass in Alabama after sixty years. Weed Sci. 22: 177–179.

Dickens, R. and G. A. Buchanan. 1971. Old weed in a new home—that's cogongrass. Highlights Agric. Res. 18:2.

Dozier, H., J.F. Gaffney, S.K. McDonald, E.R.R.L. Johnson, and D.G. Shilling. 1998. "Cogongrass in the United States: History, Ecology, Impacts, and Management." *Weed Technology* 12:737-43.

Early Detection & Distribution Mapping System (EDD MapS). 2012. The University of Georgia - Center for Invasive Species and Ecosystem Health. Last accessed 30 November, 2012. http://www.eddmaps.org.

Engeman, R.M., J.E. Laborde, B.U. Constantin, S.A. Shwiff, P. Hall, A.Fuffiney, F.Luciano. 2010. The economic impacts to commercial farms from invasive monkeys in Puerto Rico. Crop Protection 29 (2010) 401–405.

English, R. 1998. The Regulation of Axillary Bud Development in the Rhizomes of Cogongrass (Imperata cylindrica (L.) Beauv.). Ph.D. dissertation, University of Florida, Gainesville, FL.

Eussen, J. H. H. 1980. Biological and ecological aspects of alang-alang [Imperata cylindrica (L.) Beauv.]. In: Proceedings of BIOTROP workshop on alang-alang in Bogor, 27–29 July 1976. pp. 15–22, Biotropica Special Pub.No. 5 Bogor, Indonesia.

Eussen, J. H. H. and Soerjani, M. 1975. Problems and control of ‘alang-alang’ [Imperata cylindrica (L.) Beauv.] in Indonesia. In: Proc. of 5th Ann. Conf. of Asian-Pacific Weed Sci. Soc. Vol. 5, pp. 58–64.

Eussen, J. H. H., Slamet, S., and Soeroto, D. 1976. Competition between alangalang [Imperata cylindrica (L.) Beauv.] and some crop plants. SEAMEO Regional Center for Tropical Biol., Bogor, Indonesia. Biotropica Bull.No. 10.

Eussen, J. H. H. and Wirjahardja, S. 1973. Studies of an alang-alang, *Imperata cylindrica* (L.) Beauv. vegetation. Biotropica Bull. No. 6.

Gable, G. G. 1994. “Integrating Case Study and Survey Research Methods: An Example in Information Systems,"European Journal of Information Systems, Vol 3, No 2, 1994, pp.112-126.

Gaffney, J.F. 1996. “Ecophysiological and Technological Factors Influencing the Management of Cogongrass (*Imperata cylindrical*).”Ph.D. dissertation. University of Florida: Gainsville.

Giada, S., De Groeve, T. and Ehrlich, D., 2003, Information extraction from very high resolution satellite imagery over Lukole refugee camp, Tanzania. International Journal of Remote Sensing, 24, pp. 4251–4266.
Hall, D.W. 1983. Weed watch...Cogongrass. Florida Weed Sci. Soc. Newsletter 5:1-3.

Hay, G.J., Castilla, G. 2006. Geographic object-based Image Analysis(GEOBIA): A new name for a new discipline.

Hestir, E.L., S. Khanna, M.E. Andrew, M.J. Santos, J.H.Viers, J.A.Greenberg, S.S.Rajapakse, S.L.Ustin. 2008. Identification of invasive vegetation using hyperspectral remote sensing in the California Delta ecosystem. Remote Sensing of Environment 112 (2008) 4034–4047.

Holm, L. G., Pucknett, D. L., Pancho, J. B., and Herberger, J. P. 1977. TheWorld's Worst Weeds. Distribution and Biology. Univ. Press of Hawaii, Honolulu,HI.

Hood, W.G. & Naiman, R.J. (2000) Vulnerability of riparian zones to invasion by exotic vascular plants. Plant Ecology,148, 105–114.

Hubbard, C. E. 1944. Imperata cylindrica. Taxonomy, Distribution, Economic significance, and Control. Imp. Agric. Bur. Joint Publ. No. 7, Imperial Bureau Pastures and Forage Crops,Aberystwyth, Wales. Great Britton.

Hunt, R., R. Hamilton, and J. Everitt. Mapping Weed Infestations Using Remote Sensing. Weed Manager's Guide to Remote Sensing and GIS — Mapping & Monitoring.. http://www.fs.fed.us. Last access 30 November, 2012.

Identification of Invasive Species in the Daniel Boone National Forest Using Hyperspectral Imagery (ITD).Final report. April 2008.

ITT. 2012. Aerial Photography Field Office—National Agriculture Imagery Program (NAIP) Suggested Best Practices –Final Report. CDRL A006 SUBMITTED UNDER GSA Contract Number GS-23F-0284M, SIN 871_2. http://www.fsa.usda.gov. Last access 16, November,2012.

Ivits, E., & Koch, B. 2002. Object-oriented remote sensing tools for biodiversity assessment: A European approach. Proceedings of the 22nd EARSeL symposium, Prague, Czech Republic, 4–6 June 2002. Rotterdam, Netherlands: Millpress Science Publishers.

Jain, A., 1989, Fundamentals of Digital Image Processing (Englewood Cliffs, NJ: Prentice-Hall).

Jensen, J.R. 2007.Remote sensing of the environment. Pearson Prentice Hall.
Je` hne, B. 2005. Digital Image Processing (Berlin: Springer).

Johnson,D.E. 1999. "Surveying, Mapping, and Monitoring Noxious Weeds on Rangeland "in "Biology and Management of Noxious Rangeland Weeds" by Sheley, R.L., J.K Petroff, J.K.,J.clark. Biology Corvallis,Oregan :Oregon State University Press.30-31pp.

Joshi, C., J. D. Leeuw, J.V.Andel, A.K.Skidmore, H.D. Lekhak, I.C. van Duren, N. Norbu. 2006. Indirect remote sensing of a cryptic forest understory invasive species. Forest Ecology and Managemnet 225(2006) 245-256.

Johnson, E.R.R.L ,and D.G. Shilling. 2005. FACT SHEET:COGON GRASS. Plant Conservation Alliance's Alien Plant Working Group. Weeds Gone Wild: Alien Plant Invaders of Natural Areas. http://www.nps.gov/plants/alien. Last access 28 March, 2012.

Johnson, E.R.R.L. , J.F. Gaffney, and D.G. Shilling. 1997. "Revegetation as Part of an Integrated Management Approach for the Control of Cogongrass." *Proceedings of the Southern Weed Science Society* :50-141.

Jose, S., J. Cox, D.L. Miller, D.G. Shilling, and S. Merritt. 2002. "Alien Plant Invasions in Southeastern Forest: The Story of Cogongrass." *Journal of Forestry* 100:41-4.

Kampouraki, M., G.A. Wood, T.R. Brewer, 2003."Opportunities and limitations of object based image analysis for detecting urban impervious and vegetated surfaces using true-colour aerial photography by urban impervious and vegetated surfaces using true-color aerial photography in "Object Based Image Analysis." Springer Berlin Heidelberg, Pages. ObjectBased Image Analysis. 2008: 555-569.

King, S. E. and Grace, J. B. 2000. The effects of soil flooding on the establishment of cogongrass (Imperata cylindrica), a nonindigenous invader of the southeastern United States. Wetlands 20: 300–306.

King, S. E. and Grace, J. B. 2000. The effect of gap size and disturbance type on invasion of wet pine savanna by cogongrass, Imperata cylindrical (Poaceae).Am.J.Bot.87:1279-1287.

Kressler, F.P., Steinnocher, K. and FRANZEN, M., 2005, Object-oriented classification of orthophotos to support update of spatial databases. In IGARSS '05 Proceedings, 1, pp. 253–256.

Laliberte, A.S., A.Rango, K.M. Havstad, J.F. Paris, R.F. Beck, R. McNeely, A.L.Gonzalez. 2004. Object-oriented image analysis for mapping shrub encroachment from 1937 to 2003 in southern New Mexico. Remote Sensing of Environment 93: 198– 210.

Lang, S. 2008. Object-based image analysis for remote sensing applications: modeling reality-dealing with complexity. In *Object-Based Image Analysis* book. Th. Blaschke, S. Lang, and G.J., Hay (Eds). Berlin Heidelberg. Springer-Verlag:1-27.

Larson, L.K., and McGowin,J..2009. report; Cogongrass, One of the Most Devastating Weeds in the World, Finally Meets Its Match in Alabama.

Lass, L.W., T.S. Prather, N.F. Glenn, K.T. Weber, J.T. Mundt, and J. Pettingill. 2005. A review of remote sensing of invasive weeds and example of the early detection of spotted knapweed (Centaurea maculosa) and babysbreath (Gypsophila paniculata) with a hyperspectral sensor. Weed Science 53(2):242-251.

Lawrence, R.L., S.D. Wood, R.L. Sheley. 2006. Mapping invasive plants using hyperspectral imagery and Breiman Cutler classifications (RandomForest). Remote Sensing of Environment 100 (2006) 356 – 362.

Le Moigne, J. and Tilton, J., 1995, Refining image segmentation by integration of edge and region data. IEEE Transactions on Geoscience and Remote Sensing, 33, pp. 605–615.

Livingston, M.J.,and C. Osteen. 2008. Integrating Invasive Species Prevention and Control Policies. Economic Brief No. 11. USDA, Economic Research Service, September 2008.

MacDonald, G.E. 2004. Cogongrass (Imperata cylindrica)- Biology, Ecology, and Management. Critical Reviews in Plant Sciences. 23(5):367-380.

MacDonald, G.E. November,2007. “Cogongrass (Imperata cylindrica): Biology, Distribution And Impacts in the Southeastern U.S”. Arthur R. Outlaw Convention Center Mobile, Alabama. Cogongrass Management Guide: 10-23.

Mangoendiharjo, S. 1980. Some notes on the natural enemies of alang-alang (Imperata cylindrica) in Java. In: Proceedings of BIOTROP workshop on alang-alang in Bogor, 27–29 July 1976. pp. 47–55, Biotropica Special Pub. No. 5 Bogor, Indonesia.

Mardia, K. and Hainsorth, T., 1988, A spatial thresholding method for image segmentation. IEEE Transactions on Pattern Analysis and Machine Intelligence, 10,pp. 910–927.

Marzen, L.J., Z. Szantoi , L.M.B. Harrington, and J.A. Harrington, 2011, Implications of Management Strategies and Vegetation Change in the Mount St. Helens Blast Zone. Geocarto International, v. 26, n. 5, p. 359-376.

McNeely, et al. 2001.Human dimensions of invasive alien species. Gland, Switzerland and Cambridge, UK, IUCN, 242pp.

Miller, J.H. 2007. The context of the South’s Cogongrass Crisis. Cogongrass Management Guide: 6-9.

Miller, J.H. 2011. Personal Interview with Dr.James Miller, Research Ecologist. USDA Forest Service Southern Research Station.February, 2011.

Miller, J.H. 2012.”About establishedd patches of cogongrass”.Email to Batoul Damghani.15 November, 2012.

Miller, J.H., E. B., Chambliss, N. J., Loewenstein. 2010. A Field Guide for the Identification of Invasive Plants in Southern Forests. United States Department of Agriculture Forest Service, Southern Research Station,General Technical Report SRS–119: 84-85.

Miller, J.H., S.T. Manning , S.F. Enloe. 2010. A Management Guide for Invasive Plants in Southern Forests. United States Department of Agriculture, Forest Service, Southern Research Station. Asheville, NC 28804. General Technical Report SRS_131.pp84-92.

Miller, J.H and Enloe, S. F. 2009. Alabama Forestry Commission’s Cogongrass Control Recommendations.http://www.forestry.state.al.us/PDFs/Cogongrass_Control_Recommendations_022709.pdf.

Mullerova,J., Pysek, P., Jarosik, V., Pergl, J.Aerial photographs as a tool for assessing the regional dynamics of the invasive plant species *Heracleum mantegazzianum.* Journal of Applied Ecology 2005(42). 1042-1053.

Mwebaze, P., A., MacLeod, D., Tomlinson, H., Barois, J., Rijpma. 2010. Economic valuation of the influence of invasive alien species on the economy of the Seychelles islands. Ecological Economics 69(2010) 2614-2623.

Myint, S.W. P.Gober, A. Brazel, S.G.Clark, Q.Weng. 2011. Per-pixel vs. object-based classification of urban land cover extraction using high spatial resolution imagery. Remote Sensing of Environment 115:1145-1161.

National Park Service AlaskaPak Extension for ArcGIS (NPS).2012.National Park Service U.S. Department of the Interior.

Paine, D.P., J.D. Kiser. 2012. Aerial Photography and Image Interpretation. Third Edition. John Wiley & Sons, Inc., Hoboken, New Jersey.

Patterson, D. T. and C. G. McWhorter. 1983. Distribution and control of cogongrass (Imperata cylindrica) in Mississippi. U.S. Department of Agriculture, Agricultural Research Service, Southern Weed Science Laboratory, Stoneville, Mississippi, USA.

Planty-Tabacchi, A.M., Tabacchi, E., Naiman, R.J.,Deferrari, C. & Decamps, H. .1996. Invasibility of species rich communities in riparian zones. Conservation Biology, 10, 598–607.

Pysek, P. & Prach, K. 1993. Plant invasions and the role of riparian habitats: a comparison of four species alien to central Europe. Journal of Biogeography, 20, 413–420.

Ramsey, C.L., S. Jose, J. Cox, D.L. Miller, D.G. Shilling, K. Portier, and S. Merritt. 2003. “Cogongrass[*Imperata cylindrical(L.)Beauv.]* Response to Herbicides and Disking on a Cutover Site and in a Mid-Rotation Pine Plantation in Southern USA.” *Forest Ecology and Management* 179(2003):195-207.

Schiewe J, Tufte L, Ehlers M.2001.Potential and problems of multi –scale segmentation methods in remote sensing .In :GIS_Zeitchrift fur Geoinformationssysteme 6/2001.pp. 34-39.

Seavoy, R. E. 1975. The origin of tropical grasslands in Kalimantan, Indonesia.J. Trop. Geo. 40: 48–52.

Shackelford, A.K. and Davis, C.H., 2003, A combined fuzzy pixel-based and object-based approach for classification of high-resolution multispectral data over urban areas.IEEE Transactions on Geoscience and Remote Sensing, 41, pp. 2354–2363.

Shilling, D.G., T.A. Bewick, J.F. Gaffney, S.K. McDonald, C.A. Chase, and E.R.R.L. Johnson. 1997. "Ecology, Physiology, and Management of Cogongrass (Imperata cylindrical)." Final Report. Florida Institute of Phosphate Research.

Soerjani, M. 1970. Alang-alang *Imperata cylindrica* (L.) Beav., pattern of growth as related to its problem of control. *Biol. Trop. Bull.* **1**: 88–96.

Tabor, P. 1949. Cogongrass, Imperata cylindrica (L.) Beauv., in the southeastern United States. Agron. J. 41: 270.

Tabor, P. 1952. Comments on cogon and torpedograsses: A challenge to weed workers. Weeds. 1:374-375.

Terry, P. J., Adjers, G., Akobundu, I. O., Anoka, A. U., Drilling, M. E.,Tjitrosemito, S., and Utomo, M. 1997. Herbicides and mechanical control of Imperata cylindrica as a first step in grassland rehabilitation. Agroforest.Syst. 36: 151–179.

Thébaud, C. & Debussche, M. (1991) Rapid invasion of Fraxinus ornus L. along the Herault River system in southern France: the importance of seed dispersal by water. Journal of Biogeography, 18, 7–12.

Thuiller, W., D.M. Richardson, M. Rouget, S. Proches, J.R. Wilson. 2006. Interactions between environment, species traits, and human uses describe patterns of plant invasions. Ecological Society of America 87(7). 1755-1769pp.

Tian, J., D.M.,Chen. 2007. Optimization in multi-scale segmentation of high-resolution satellite images for artificial feature recognition. International Journal of Remote Sensing Vol. 28, No. 20, 20 October 2007, 4625–4644.

Trimble.2012."About Gerd Binnig, 1986 Nobel Laureate for Physics".http://www.ecognition.com/document/about-gerd-binnig-1986-nobel-laureate-physics. Last access 1 Novemeber, 2012.

Tzostsos, A. and Argialas D. 2007. Support Vector Machine Classification for object-Based Image Analysis. In : Object-Based Image Analysis – Spatial Concepts For Knowledeg – Driven Remote Sensing Applications. Springer 2007.

Underwood, E., Ustin, S., & DiPietro, D. (2003). Mapping nonnative plants using hyperspectral imagery. Remote Sensing of Environment, 86, 150−161.

Ustin, S.L., D. DiPietro, K. Olmstead, E. Underwood, and G.J. Scheer. 2002. "Hyper spectral Remote Sensing for Invasive Species Detection and Mapping ".IEEE: University of California, Davis.1658-1660pp.

Ustin, S.L., Andrews, M., Andrew M.E., Cheng, Y.B., DiPietro, D., Kefauver, J., Noujdina, N., Olmstead, K.S., Ramirez, C.M., Tom, E.T., Underwood, E.2008. Application of Hyperspectral Techniques to monitoring and management of invasive plant species. SERDP Project SI-1143. Strategic Environmental Research and Development Porgram. Arlington, VA 22203_1821.

Walsh, S.J., A. L., McClearly, C.F., Mena, Y., Shao, J.P, Tuttle, A., Gonzalez, R., Atkinson. 2008. QuickBird and Hyperion data analysis of an invasive plant species in the Galapagos Islands of Ecuador: Implications for control and land use management. Remote Sensing of Environment 112 (2008). 1927–1941.

Wang Z., Wei W., Zhao S, Chen X. 2004. Object-orientated Classification and Application in Land Use Classification Using SPOT-5 PAN imgery. IEEE, 3158-3160.

Wei, W., Chen, X. and Ma, A., 2005, Object-oriented information extraction and application in high-resolution remote sensing image. In IGARSS '05. Proceedings, 6, pp.3803–3806.

Weiss, J.L., Gutzler, D.S., Coonrod, J.E.A., Dahm, C.N., 2004. Longterm vegetation monitoring with NDVI in a diverse semi-arid setting, Central New Mexico, USA. Journal of Arid Environment 58 (2), 249–272.

Wilcut, J. W., R. R. Dute, B. Truelove, D. E. Davis, and J. C. Williams. 1988. Temperature factors limiting the spread of cogongrass (Imperata cylindrica) and torpedograss (Panicum repens). Weed Sci. 36:49–55.

Willard. T.R., J.F. Gaffney, and D.G. Shilling. 1997. "Influence of Herbicide Combinations and Application Technology on Cogongrass (*Imperata cylindrical*) Control. "*Weed Technology* 11:76-80.

Willard, T.R., D.G. Shilling, J.F. Gaffney, and W.L. Currey. 1996."Mechanical and Chemical Control of Cogongrass(*Imperata cylindrical*). "*Weed Technology* 10:722-6.

Xie, Z., C. Roberts, B. Johnson. 2008. Object-based target search using remotely sensed data: A case study in detecting invasive exotic Australian Pine in south Florida. ISPRS Journal of Photogrammetry & Remote Sensing 63 (2008) 647–660.

Yandoc, C. 2001. Biological Control of Cogongrass, Imperata cylindrical (L.) Beauv. Ph.D. dissertation, University of Florida, Gainesville, FL.

Zeiler, M. 1999. Modeling Our World: The Esri Guide to Geodatabase Design. Environmental Systems Research Institute, Inc. ISBN i-879102-62-5.

Zhu, G.B., X.L. Liu, Z.G. Jia. 2006. A multi-resolution hierarchy classification study compared with conservative methods. ISPRS WG II/3, II/6 Workshop "Multiple representation and interoperability of spatial data", Hanover, Germany, February 22-24.