Mapping Loblolly Pine Decline Hazard and Risk across the Southeastern United States

by

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Abstract

Loblolly Pine Decline was first noted in 1959 in the Oakmulgee and Tuscaloosa Ranger Districts in the Talladega National Forest, located in the southeastern United States. This slow mortality is not new to the area, but is just beginning to be understood and proper management assessed. Loblolly Pine Decline has been detected primarily throughout Alabama and Georgia, but there have been reports from eastern Texas to North Carolina. This study was conducted in the 9 states of Alabama, Arkansas, Florida, Georgia, Mississippi, Louisiana, North Carolina, South Carolina, and eastern Texas. The study was made up of 678 counties covering approximately 102,836,000 hectares.

A comprehensive view of predisposing site factors needed to be developed as a tool to use in managing forests and investments. Previous research has identified the symptomology, fungi, insect vectors, and predisposing factors involved. This project utilized slope and aspect data to further understand how site conditions predispose stands to this decline, and created a comprehensive map for the southeastern United States, from Texas to North Carolina. The map was created using ArcGIS® Arc Map™ 10, Forest Inventory and Analysis Data (United States Forest Service), and ERDAS IMAGINE® 9.3 spatial analyst models. It will serve as a valuable tool to understand loblolly pine sites that are already at risk for Loblolly Pine Decline and thus the proper allocation of resources for management practices. It will also serve as a guide for proper

tree species placement on Loblolly Pine Decline Hazard sites to reduce future Loblolly Pine Decline.

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Chapter 1

Literature Review

> "*Forests are complex dynamic communities of living and dead trees interacting among themselves and with an array of microbes, pests, environmental, human and other factors to continuously shape and reshape the community over time. Death of trees is as inevitable as birth and growth to the vitality of the forest, but when death interferes with our financial or emotional expectations, we consider it abnormal and look for a simple explanation*" (Manion and Lachance, 1992).

1.1 Early Southeastern Agriculture

Land usage and management have changed considerably since the mid-1860s when cotton (*Gossypium* sp.) was king. In 1896 in Alabama alone, 1.3 million ha (3.2 million acres) were planted to cotton, and 1 million of its then 2 million residents were directly involved in the cotton industry (Hawk, 1934). Cotton was said to have influenced religion, law, politics, and art in the south (Smith, 2007). Land that was not cultivated for cotton was planted to corn, oats (*Avena sativa* L.), and cowpea (*Vigna unguiculata* (L.) Walp.) forage (Mitchell *et al*., 2008).

With much of the early agriculture lacking proper land management, the soil became depleted of nutrients and highly eroded. These conditions were caused by excess tillage, repeated crop cultivation and the nutritional toll that cotton took on the soil (Trimble, 1974). Despite the poor soil conditions, the cotton industry eventually let go of its stronghold on southern agriculture, due in large part to the introduced boll weevil (*Anthonomous grandis* Boheman). The boll weevil was so devastating that some historians say its impact extended well beyond agriculture and economics. This invasive pest, coupled with a rural economy that had not fully recovered from the Civil War, brought poverty and changed southern rural agriculture (Strickland, 1994) to an industry based on forest products.

After the cotton crash, large-scale loblolly pine (*Pinus taeda* L.) plantings were initiated to convert these abandoned agricultural lands into productive forests that would mitigate the extensive soil erosion. Natural regeneration of cut over forests also assisted in making loblolly pine the predominant conifer species of the southeastern United States (Shultz, 1999).

1.2 Loblolly Pine (*Pinus taeda* L.)

Loblolly pine was first described in 1753 (Coder, 2006) and was a minor component of the southeastern forest landscape. Prior to European settlement, the original southern forests were dominated by longleaf pine (*P. palustris* Mill.), mixed hardwood uplands, mixed hardwood bottomlands, and swamps. Loblolly pine was an important component of moist sites that were protected from frequent wildfire (Shultz, 1999).

Loblolly pine naturally ranges from east Texas to Florida and the eastern seaboard to southern New Jersey. The species is also known as Bull Pine, North Carolina pine, and Old-field pine (Moore *et al*., 2008). Most of the loblolly pine range is contiguous, with the exception of the Mississippi River flood plain and a separate population in Texas called the “lost pines.” Within its range, loblolly pine overlaps with the native ranges of other southern pines that include longleaf pine, shortleaf pine (*P. echinata* Mill.), slash pine (*P. elliottii* Engelm.), pitch pine (*P. rigida* Mill.), Virginia pine (*P. virginiana* Mill.) and pond pine (*P. serotina* Mill.).

Loblolly pine has a number of favorable characteristics that have attributed to its widespread planting in the southeast. The species is ideal for site restoration as it easily regenerates and is the hardiest of the southern pines in terms of its reproductive ability and rapid growth rate on diverse sites. This prolific seeder also provides large yields per hectare at a relatively early age, and can create beneficial wildlife habitat when stands of varying ages grow in close proximity (Shultz, 1997). This adaptability has led to it being planted extensively across the southeast, both on and off sites preferred by the species. It also has a shallower system of lateral roots instead of a larger tap root like that of longleaf pine. These characteristics made loblolly pine ideal for the heavily eroded soils of the early 20th century, and the diverse sites that the forest industry manages today. With genetically improved loblolly pine available, the opportunity for expansive plantings on a full range of site conditions, with genetically similar trees has become the new norm within the forest industry (Byram *et al*., 2005).

1.3 Forest Declines

“Decline” is a general term applied by forest pathologists to a reduction in tree vigor that begins slowly, later increasing in severity in symptomology over time. The decline usually being expressed by a sequence of symptoms beginning with leaf discolorations and chlorosis, leaf and twig size reductions, branch die-back, thinning crowns, total leaf loss, and reduction in annual stem radial growth (Manion, 1991; Manion and Lachance, 1992). The reduction in vigor increasingly weakens the tree, making it more susceptible to insects and biotic organisms such as fungi. Decline mortality differs in that single tree selection is not the norm, but rather selection of a single species at the landscape level (Skelly, 1993).

The concept of forest declines as put forth by Manion (1981) is not a new phenomenon, as forest declines can be traced as far back as 1739 with oak decline in Germany (Edmond *et al*., 2000). Other examples of forest decline include red oak (*Quercus rubra* L.) decline and mortality, which occurred in the Nantahala National Forest in the late 1970's on dry, shale soils (Tainter *et al*., 1984). Cork oak (*Quercus* suber L.) in the Mediterranean basin of Tunisia have been in decline for the last several decades. Studies have suggested that Cork oak's decline is associated with changes in tree physiology (Ja *et al*., 2011). In the Tanzawa Mountains of Japan, decline of natural beech forests have been recorded since the 1980's; attributed to air pollution, water stress and insect infestation (Ishimura *et al*., 2011).

Declines are characterized by a series of abiotic and biotic factors that together reduce the vigor of a certain species and eventually lead to tree mortality at the stand level. These factors are referred to as "stressors" and come in three distinct types: predisposing, inciting, or contributing. Predisposing factors, most commonly abiotic stressors, are in place prior to the tree or stand inhabiting a site. Topographic features such as slope and aspect (Eckhardt and Menard, 2008) or highly eroded soils (Manion, 1991) are some examples. Inciting factors occur on trees once they are weakened by the predisposing factors. Moisture stress can act as an inciting factor or a contributing factor (Jurskis, 2005), as well as logging damage (Edger *et al*., 1976) or highway deicing salts (Horsley *et al*., 2000). Abiotic stressors can be any of the three factors, but have high incidence as a predisposing factor. Contributing factors eventually lead the tree to mortality. Thus, the decline complex involves a number of factors that work in concert and results in tree mortality, unlike diseases such as Annosum Root Rot (*Heterobasidion irregulare* Otrosina & Garbelotto, formerly *Heterobasidion annosum* (Fr.) Bref. syn. *Fomes annosum* (Fr.) Cooke) or Pitch Canker caused by *Fusarium circinatum* Nirenburg & O'Donnell.

1.4 Loblolly Pine Decline

Loblolly Pine Decline (LPD) was first noted in 1959 in the Oakmulgee and Talladege Ranger Districts in the Talladega National Forest (TNF), located in the southeastern United States (Brown and McDowell, 1968). Tree mortality was initially referred to as Loblolly Pine Die-Off. Historically, the dominate species in the TNF was longleaf pine, but like most of the southern United States, after harvesting and agriculture abandonment, much of the area was replanted to loblolly pine (Johnson, 1947). Forest Service personnel had reported poor tree health and tree mortality that could not be easily explained. Based on reports of this unexplained condition in loblolly pine, this "die-off" and mortality usually occurred in sawtimber sized trees that were in recently cutover areas. The symptoms associated with this die-back were short chlorotic needles with short retention times on live branches. It was noted that the trees next to severely affected trees were healthy. Many agencies, such as the Southeastern Forest Experiment Station, Alabama National Forests and Insect and Disease Control Offices examined these affected areas. Initial causes of tree mortality included soil conditions due to deviations of normal temperature, and precipitation. Precipitation and temperature did not indicate anything that could be correlated to the trees' poor condition. Studies revealed that loblolly pine in the affected areas were growing on soil that was better suited for hardwood species. Further examination of the root systems revealed that many feeder roots were either dead or dying. It was unknown whether the fine feeder root mortality occurred prior to, or after the above grown symptomology (Roth and Peacher 1971).

The mortality of loblolly pine in these areas was believed to be due to *Phytophthora cinnamomi* (Rands), the fungus responsible for Littleleaf disease (LLD) (Roth *et* al., 1948; Campbell and Copeland, 1954; Roth, 1954; Oak and Tainter, 1988). However, Roth and Peacher (1971) concluded that the tree mortality was not due to either *H. irregulare* (formerly *Heterobasidion annomsum*; formerly *Fomes annosus*) or *P. cinnamomi*. While *H. irregulare* was recovered from recently cut stumps, and admittedly caused some tree mortality, this pathogen was not responsible for the large areas of mortality. In addition, *Phytophthora cinnamomi* was isolated from some plots, but not enough for the pathogen to be the causal agent of the wide-spread mortality either. Littleleaf disease has been found more predominantly in shortleaf pine in areas of high moisture retention, and where shortleaf pine was present in the areas; this tree species was not affected. Roth and Peacher (1971) also concluded that the symptoms were not due to insects, foliage diseases, or heartrots. The final conclusion was the affected loblolly pine were growing off site, and therefore would be expected to have shorter life rotation and reduced vigor at an earlier age than other stands.

With loblolly pine the tree of choice on both industrial and private lands in the southeastern United States, the species is now used on 80% of all plantations. The large area of loblolly pine planted increased the incidence of premature mortality throughout central Alabama. These areas included Bibb and Tuscaloosa counties as well as Anniston and Heflin National Forest lands (Allen, 1994; Hess, 1997). From 1999-2003, further work was conducted to examine the unexplained loblolly pine mortality in those areas. Research by Eckhardt *et al.* (2007) reported the mortality was a decline that included both mutualistic root-feeding bark beetles and native and introduced fungi in the genus *Leptographium*. The main root-feeding bark beetles recovered were *Hylastes salebrosus* (Eichhoff), *H. tenuis* (Eichh.), *H. porculus* (Erickson), as well as *Hylobius pales* (Herbst), *Pachylobius picivorus* (Germar) and the lower bole and root collar feeding beetle *Dendroctonus terebrans* (Olivier). These bark beetles vector the sticky spores of *Leptographium* spp. as they infest and colonize stressed pine trees (Klepzig *et al*., 1991; Jacobs and Wingfield, 2001; Eckhardt *et al*., 2007). The beetles would not cause tree mortality alone, but coupled with the fungi that eventually block root transportation of water and nutrients, the tree is further compromised and eventually dies. *Leptographium* spp. are anamorphs of the genus *Grosmannia* (Zipfel *et al*., 2006), formerly *Ophiostoma* (Harrington, 1987). *Leptographium terabrantis* Barras and Perry (Barras and Perry, 1971), *L. procerum* (W.B. Kendr.) M.J. Wingf (Horner and Alexander, 1983), *L. serpens* (Goid) Siemaszko, and *Grossmania huntii* (R.C. Rob. Jeffr.) Zipfel, Z.W. de Beer & M.J. Wingf are the four main fungi in the decline complex (Matusick, 2010). These mutualistic fungi inhabit the root tissue of stressed trees, making the root tissues more inhabitable to the root-feeding bark beetles by lowering the trees' defenses. Some of the beetles even feed on the fungi itself (Eckhardt *et al*., 2007).

In addition to the insect and fungi association, topographical features have also been linked with the decline. Loblolly pine planted on extremely diverse sites across the southern United States, a number of stands are located on historically unfavorable sites. Loblolly pine stands on sites of increased slope and south/southwest aspects have been found to be more prone to develop LPD symptoms as well as other southern yellow pines (Eckhardt and Menard, 2008). The complex interaction of abiotic and biotic factors responsible for tree mortality are now described as Loblolly Pine Decline, in which loblolly pine from 20-60 years become stressed and begin to decline, leading to eventual premature tree and stand mortality.

1.5 Hazard and Risk Mapping

To properly create and use hazard and risk maps, it is vital to understand the terminology that goes with them, they are well stated in Noson (2002).

"*Hazard Mapping: …the process of identifying and displaying the spatial variation of hazard events or physical conditions (e.g. potential ground shaking, steep slopes, flood plains, hazardous material sites, climate zones, etc.).*"

"*Hazard Assessment: The probability or chance of an event occurring in a particular area based on geological evidence, historical data, and projections derived from theoretical analysis.*"

"*Risk: Risk may be defined as the likely consequences (damage, loss, etc.) that may result from the impact of an event on exposures (values at risk) with specific event related vulnerabilities. Risk may be considered the combination of hazard, vulnerability, and exposure. An event resulting in unacceptable consequences may be considered high-risk even if the frequency might be low.*"

"*Mitigation: Actions taken to eliminate, prevent, or strengthen community exposures to achieve target risk levels. Occurrence of a hazard tests the effectiveness of mitigation measures to improve performance and lower damage, injuries, and/or financial losses.*"

Hazard and risk maps are constructed to accomplish a wide range of outcomes. They can range in use as a tool to study socio-economic purpose of a community to proving vital in areas of the world with high incidences of seismic activity (Noson, 2002). Tsunami hazard maps are also valuable throughout the world, not only to rate areas of high hazard and risk, but to establish evacuation routes to minimize risks in high hazard areas (Venturato *et al*., 2007). In addition, flooding is a concern in developed and non-developed areas. Flooding risks could be due to the proximity to a river for transportation and food, or urban sprawl creating large run-off events and over-loading small watershed systems. In both scenarios, and other similar examples, hazard mapping can assist in taking precautions to minimize risks (van Westen *et al*., 2002; Adeaga, 2005; Büchele *et al*., 2006).

Hazard and risk maps can also be useful when looking at frozen water. In higher altitudes, avalanche hazard and risk maps serve as tools to minimize losses of lives and property. In the late 19^{th} and early 20^{th} centuries avalanches increased in Iceland. Icelanders had always lived with natural disasters, but avalanches claimed the most lives. Therefore, a need arose for the citizens to become more educated regarding where to live and how to plan evacuation routes in the case of an avalanche (Grímsdóttir, 2008).

Similar to natural disasters, the impact of land use has taken a toll. Risk mapping has been used in combination with remote sensing to achieve a broad area look at land use and degradation (Haboudane *et al*., 2002). Increased urbanization can lead to more impervious surfaces for water, and improper farming techniques can quickly deplete soil nutrients and make it vulnerable to erosion. Remote sensing can create a large view of areas to better understand cumulative effects.

Hazard maps can serve the natural resource as well as those that depend on it. Areas in developing countries that rely on groundwater to drink and irrigate crops have concerns of contamination with either pesticides or fertilizers. Parameters that include depth to groundwater, recharge capability, aquifer media, soil media, and topography can be put into a Geographical Information System (GIS). With the use of a GIS, a groundwater vulnerability map can be created to help the community understand their effect on the vital resource and assist in mitigation of over usage (Al-Adamat *et al*., 2003).

When working with invasive pests, risk mapping could be useful for the allocation of resources for mitigation efforts. For an exotic pest to successfully establish itself many factors must properly align. A risk map can give a potential range an invasive pest could inhabit and the threat level/possibility of becoming established. For example, a geographic region not only needs to be favorable for the invasive pest but pathways have to be in place from its point of entry. For this reason many invasive pests never become established. A risk map for a new invasive pest can predict movement based on available pathways to suitable geographic regions. Such a risk map could be effective in the slowing and possible eradication of the pest with the proper allocation of phytosanitary efforts (Yemshanov et al., 2010).

A current look at *Sirex noctilio* (Fabricius) in North America is an example of an invasive forest pest being mapped using geographic hot spots and pathways in order to implement mitigation efforts (Yemshanov *et al*., 2009). Native to Europe, western Asia, and northern Africa, *S. noctilio* is currently established in southeastern Ontario (de Groot *et al*., 2006), as well as New York and Pennsylvania in the United States (ISSG, 2012).

Due to broad bioclimatic tolerance of the woodwasp (Carnegie *et al*., 2006) survival is possible in the entire range of the eastern United State temperate forests. Although little is known on the population ecology in North America, some behavioral knowledge can be explored from studies in Australia (Haugen *et al*., 1990) and Argentina (Corley *et al*., 2007). Based on the insects' behavior in other countries, *S. noctilio* is considered to be a serious threat to pines in the United States and Canada (Borchert *et al*., 2007). Therefore, steps to limit this insect's movement are warranted until entomologists can determine the insect's ability to become established in North America. Invasive pests like the Sirex woodwasp will continue to be an issue in the expanding global marketplace.

Despite attempts to limit the movement of non-native pests, invasive species are widely seen as a serious economic problem in North America. Estimates in 2009 for economic impacts on United States agricultural, forestry, and public health due to invasive exotic pest species exceeded US$120 billion annually, costs for Canada were near CDN$7.5 billion. These estimates were considered low because they do not include all the indirect and market costs associated with these losses. Attempts to mitigate these losses in the United States the National Invasive Species Council was established by Executive order 13112 (Clinton, 1999). This order served to coordinate the efforts of federal agencies, in particular the United States Forest Service and the United States Department of Agriculture's Animal and Plant Health Inspection Service (APHIS). These agencies conduct research, management and regulatory activities to manage invasive species (Yemshanov *et al*., 2009).

1.6 Loblolly Pine Decline Hazard Mapping

In 2003 a number of sites were identified in central Alabama that were associated with aspects and slopes with LPD symptomology; i.e. sparse crowns with tufted, chlorotic needles (Eckhardt and Menard, 2008). The correlation of aspect and slope were of interest due to studies where topography played a role in decline complexes involving other tree species. In Pennsylvania declining sugar maple (*Acer sacharrum* Marsh.) stands were noted at higher elevation and S, SW, W, and NW aspects (Drohan *et al*., 2002). Horsley *et al.* (2000) also linked sugar maple decline to topographic position on the Allegheny Plateau. In 2001 it was reported that altitude, slope and aspect were correlated with fir decline in the Vosges Mountains of France (Thomas *et al.*, 2002). Menard (2007) further mapped LPD risk sites in central Georgia, looking at areas for risk within Red Cockaded Woodpecker (*Picoides borealis* Vieillot) habitat. Because of these trials (Eckhardt, 2003: Menard, 2007) the parameters for hazard sites for loblolly pine stands at risk are better understood. For example, aspect risk ratings range from 337.5° to 67.5° for low risk, 67.6° to 112.5° and 292.6° to 337.4° for medium risk, 247.6° to 292.5° for high risk, and 112.6° to 247.5° for severe risk. Percent slope risk ratings range from 0 to 5% for low, 5.1 to 10% for medium, 10.1 to 15% for high, and >15% for severe risk (Eckhardt and Menard, 2008). Combining these two risk factors allows for the creation of hazard rating system based on the slope and aspect parameters.

1.7 Southeast United States LPD Hazard Map

The areas previously mapped by Eckhardt (2003) and Menard (2007) cover parts of central Alabama and Georgia. Loblolly Pine Decline has been detected primarily throughout Alabama and Georgia, but there have been reports from eastern Texas to

North Carolina that have been confirmed through positive identifications at the Forest Health Dynamics Laboratory at Auburn University. The long rotation of timber does not lend itself to rapid changes in stand objectives. Because of the uncertainty that surrounds the extent of LPD, land managers need an accurate tool to determine the potential risk of future outbreaks of LPD. This project intends to develop a map across the wide range on which loblolly pine is found. The Four Class Hazard map created can be used as a management tool in the attempts to mitigate current and future LPD in the southeastern United States.

Chapter 2

Hazard and Risk Mapping of Loblolly Pine (*Pinus taeda* L.) Decline in the southeastern United States

2.1 Abstract

Loblolly Pine Decline is a disease complex that poses a threat to the forests and economy of the southeastern United States. This tree mortality is not new to the area, but scientists have just begun to understand the issue and proper management techniques are being assessed. Once the symptoms of Loblolly Pine Decline are visible, the forest stand is at risk of continued mortality. A comprehensive view of predisposing site factors needed to be developed as a tool to use in managing forests and investments. Previous research identified the symptomology, fungi, insect vectors, and predisposing factors involved. This project utilized slope and aspect data to further identify sites that may predispose stands to this decline, and created a comprehensive map for the southeastern United States, from Texas to North Carolina. The map can serve as a tool to understand loblolly pine sites that are already at risk for Loblolly Pine Decline and thus the proper allocation of resources for management practices. It can also serve as a guide for proper tree species placement on Loblolly Pine Decline Hazard sites to reduce future Loblolly Pine Decline.

2.2 Introduction

Loblolly Pine Decline is a disease complex that poses a threat to the forests and economy of the southern United States. Maps of Loblolly Pine Decline (LPD) Sites have been produced on small areas but not on the range on which the decline complex occurs. From 1999-2003 sites were mapped in central Alabama study areas that were associated with aspects and slopes with LPD symptomology of thin, sparse crowns with tufted, chlorotic needles (Eckhardt, 2003). The correlation of aspect and slope were of interest due to other examples where topography played a role in tree declines. Menard (2007) further mapped LPD risk sites in central Georgia, looking at areas within Red Cockaded Woodpecker (*Picoides borealis* Vieillot) habitat. Because of these trials (Eckhardt, 2003; Menard, 2007) the parameters for hazard sites of loblolly pine stands at risk were better understood. For example, aspect range from 337.5° to 67.5° for low risk, 67.6° to 112.5° and 292.6° to 337.4° for medium risk, 247.6° to 292.5° for high risk, and 112.6° to 247.5° for severe risk. Percent slope risk ratings range from 0 to 5% for low, 5.1 to 10% for medium, 10.1 to 15% for high, and >15% for severe risk (Eckhardt and Menard, 2008). Combining these two risk factors allows for the creation of a hazard rating system based on the slope and aspect parameters.

The areas that have been previously mapped cover parts of central Alabama and Georgia, where LPD has been reported (Eckhardt, 2003; Menard, 2007). Eckhardt (2003) mapped the Oakmulgee, Talladega, and Shoal Creek Ranger Districts. The Oakmulgee Ranger District is located in west-central Alabama and covers portions of Bibb, Hales, Perry, Dallas, Chilton, and Tuscaloosa counties, approximately 63,130 hectares. The Talladega Ranger District and Shoal Creek Ranger District are located in northeast Alabama. These two districts cover parts of Calhoun, Cherokee, Clay, Cleburne, and Talladega counties.

Loblolly Pine Decline has been detected throughout Alabama and Georgia, but there have been reports from eastern Texas to North Carolina through positive identifications at the Forest Health Dynamics Laboratory at Auburn University. The long rotation of timber does not lend itself to rapid changes in stand objectives. Due to the uncertainty that surrounds the extent of LPD, land managers need an accurate map to determine the potential risk of future outbreaks of LPD. Developing such a map will create a useful management tool that can be utilized by land managers attempting to mitigate current and future LPD in the southeastern United States.

2.3 Objectives

The objective of this research was to create a Loblolly Pine Decline hazard map based on predisposing slope and aspect stress parameters from previous research and field observations where decline has been reported. Once the hazard map was created a risk map was to be created using the most updated loblolly pine coverage layer available. The hazard and risk maps were then to be ground truthed using relevant parameters. These objectives were created in order to understand the amount of hazard across the southeast United States landscape. Furthermore, they were intended to quantify the amount of loblolly pine currently at varying levels of risk across the study area.

2.4 Materials and Methods

2.4.1. Four Class Hazard Map Creation

2.4.1.1. Mosaic

The study was set up to span from eastern Texas, also known as the 'Piney Woods', to North Carolina. This 9 state expanse included 678 counties covering approximately 102,836,000 hectares. Such an increase in area led to larger computations and data acquisition. A Four Class Hazard Map was created for each of the 9 southern states to create a final Four Class Hazard Map for the southeastern States of interest. States were processed individually due to the large size of the 10m Digital Elevation Model (DEM) files. The 10m DEMs used for this project were part of the National Elevation Dataset (NED) created by the United States Geological Service (USGS) Earth Resources Observation and Science (EROS) data center. The NED is a collection of the best-available elevation data in a seamless mosaic. The DEMs were acquired from the USGS Geospatial Data Gateway (GDG) located online at http://datagateway.nrcs.usda.gov/. Ten-meter DEMs were acquired for Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina and eastern Texas.

Digital Elevation Models were created by the USGS GDG using 7.5-minute elevation data at one-third arc-second resolution (approximately 10m). For some areas the 10m DEMs were created from resampled LIDAR (Light Detection and Ranging) or aerial photography. Photogrammetrical techniques used on aerial photography scanned the aerial photographs with mapping software to collect x, y, and z coordinates over large areas. This was done in combination with known (x, y, and z) coordinates used as control points. The elevation points from the derived Digital Terrain Model (DTM) were then stored as raster DEMs (Geospatial Data Gateway, 2012).

The DEMs were received either by DVD or FTP online; they were delivered in small parcels as they are stored with the Geospatial Data Gateway. For example the State of Alabama consisted of 2,813 files, 936 of those being TIFF image files that needed a mosaic process to form a contiguous 10m DEM for that state. The other files were data reference files for each TIFF file.

ERDAS IMAGINE® v. 9.3 was used for the mosaic processing of the individual TIFF files into a single state 10m DEM. The mosaic process used was Mosaic Direct located under the Data Preparation/'Data Prep' option, Mosaic Images\Mosaic Direct (Fig. 2.1). In the Mosaic Direct window the TIFF files for the desired state were selected as a group from their saved location. The TIFF files were then added with 'Add Images', an output location and name were specified and saved as an IMG image file. Once completed, this process created a mosaic image of the parceled 10m digital elevation models for each state (Fig. 2.2).

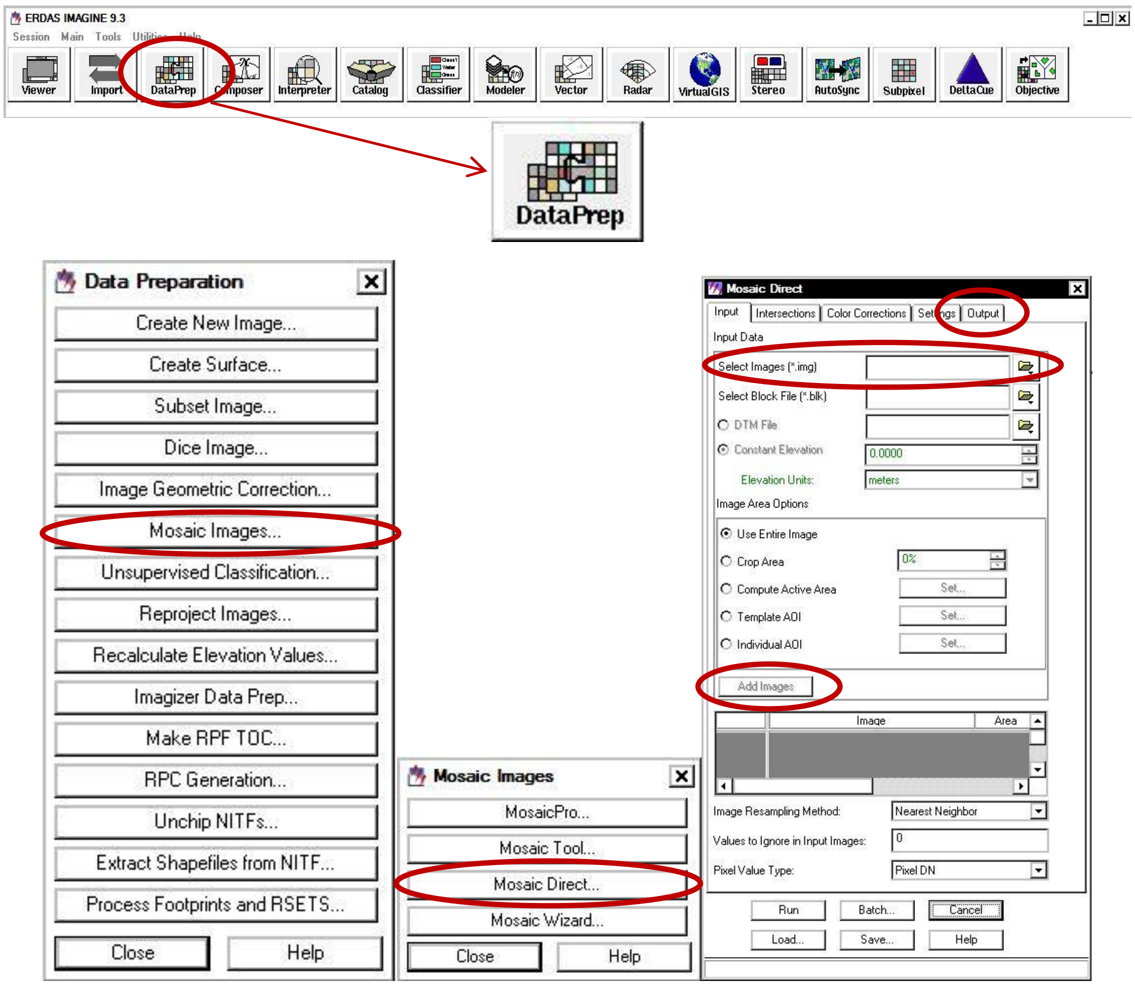

Fig. 2.1. ERDAS IMAGINE® 9.3 Data Preparation Mosaic Images steps using Mosaic Direct.

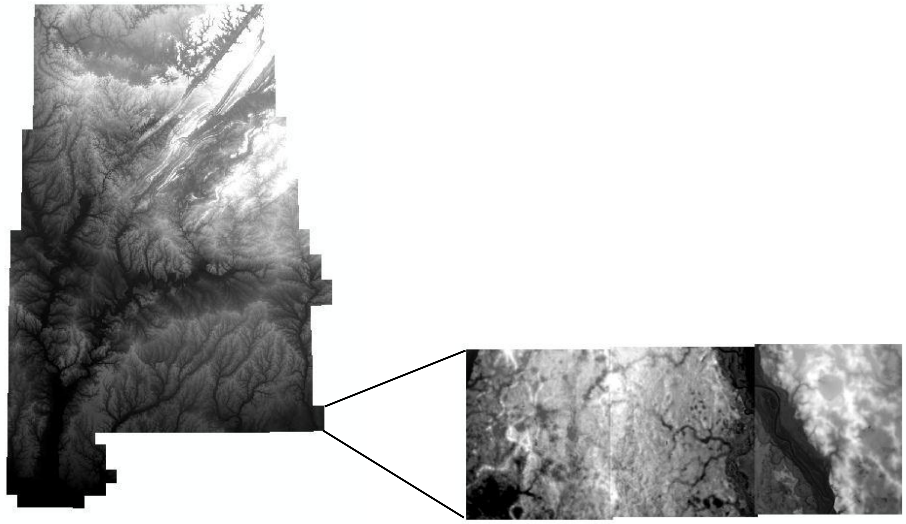

Fig. 2.2. Alabama 10m Digital Elevation Model mosaic image with three parcel zoom.

2.4.1.2. Fill Sinks

Each State mosaic image was processed through a 'Fill Sinks' model, downloaded from erdas.com, in ERDAS IMAGINE® 9.3. A sink in a DEM is a low point that cannot drain. The ERDAS® model identified the sinks by identifying elevations where the focal elevation point was the minimum elevation of a grid window surrounding that elevation point (Fig. 2.3). This process removed sinks in the DEM mosaic that were a result of error. The image mosaic was chosen for the input; a name and location were assigned for the output conditioned image. In the output window along with the name and location the Data Type was changed to 'Signed 16-bit' and no values were chosen to be ignored in the statistical calculations. Signed 16-bit was selected instead of 8-bit due to the change in elevation from the coastal portions of states to higher elevations. A 16-bit number is a binary number code that can store integer values that range from 0 to 32,767 including zero as a number. A signed number takes the first number and assigns it as positive or negative. A signed 16-bit can store integer values from -16,383 to +16,383. This range will cover the highest point on Mount Everest, in meters, to the deepest part in the

Marianas Trench. The ‘Fill Sinks’ model also truncates DEM integer values to the tenth decimal place. Tenth decimal place was all that was desired for the computations as satellite imagery is not generally precise enough to measure past that point.

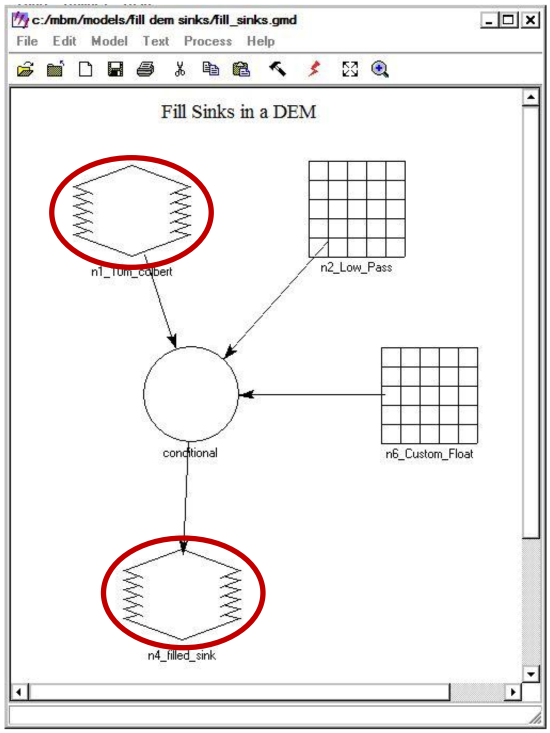

Fig. 2.3. ‘Fill Sinks’ ERDAS® 9.3 model, top red circle is input and bottom is output.

2.4.1.3. Slope and Aspect Calculations

Once the DEM parcels were combined into one mosaic image and conditioned through the ‘Fill Sinks’ model, the image was processed through separate ArcGIS® Arc Map™ 10 Spatial Analyst tools to obtain slope and aspect. The calculations of slope and aspect were later joined after further processing to create the Four Class Hazard Map.

Slope

To figure slope, the image was projected using ArcGIS® 10 Data Management Tools\Projections and Transformations\Rater\Project Raster (Fig. 2.4). The projection chosen was 'USA_Contiguous_Albers Equal_Area_Conic.prj' or Albers Equal Area (AEA). This projection of the state mosaic image was then used for slope calculation.

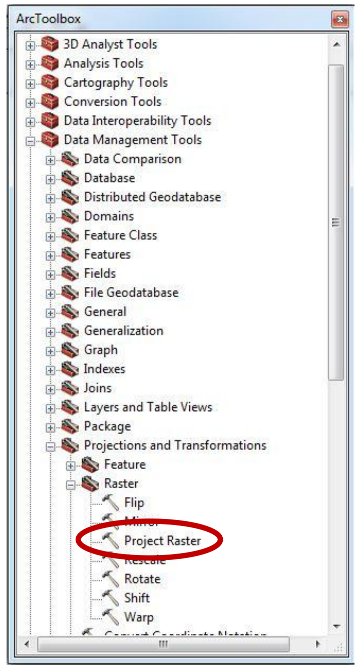

Fig. 2.4. ArcGIS® 10 Project Raster tool.

Slope was calculated using ArcGIS® 10 Spatial Analyst Tools\Surface\Slope (Fig. 2.5). A 'Fill Sinks' conditioned, AEA projected state DEM was input and an output location and name was assigned for the slope raster data set. Output measurement type was changed form 'DEGREE' to 'PERCENT_RISE' and the Z factor remained as the default of '1'.

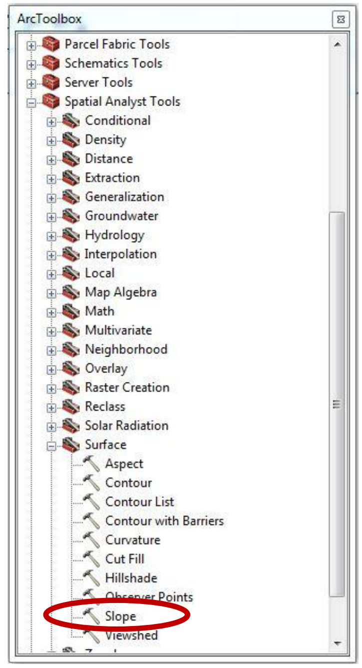

Fig. 2.5. ArcGIS® 10 Spatial Analyst: Slope tool.

Aspect was calculated using ArcGIS® 10 Spatial Analyst Tools\Surface\Aspect (Fig. 2.6). A 'Fill Sinks' conditioned state DEM, in the state's UTM projection, was input and an output location and name was assigned for the aspect raster data set.

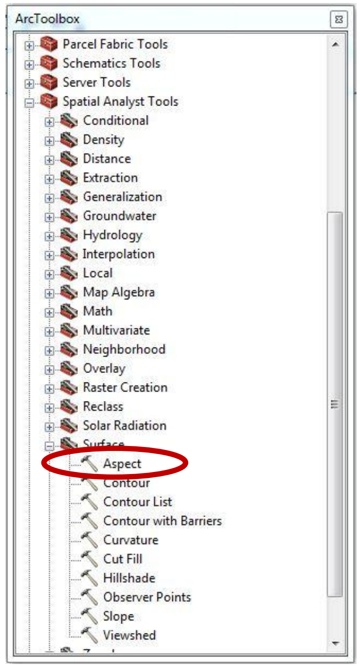

Fig. 2.6. ArcGIS® 10 Spatial Analyst: Aspect tool.

2.4.1.4. Slope and Aspect Reclassification

Both slope and aspect calculations were reclassified into the four hazard categories based on previous research (Eckhardt and Menard, 2008). Reclassification was carried out using ArcGIS® 10 Spatial Analyst Tools\Reclass\Reclassify (Fig. 2.7). The previous slope and aspect calculations were reclassified to numerical categories of 1, 2, 3, and 4 which corresponded with the values in Table 2.1. Slope classification used the 'Manual Method' classification choice with 4 breaks of which the 'Break Values' were in percent. The percent break values were entered as 5.1, 10.1, 15.1, and the last value was the maximum elevation value in the calculation statistics for each state's DEM. Aspect classification used the 'Manual Method' as well with 6 breaks entered as degrees. The values were entered as 0, 67.5, 112.5, 247.5, 292.5, and 337.5 to achieve the desired aspect degree intervals.

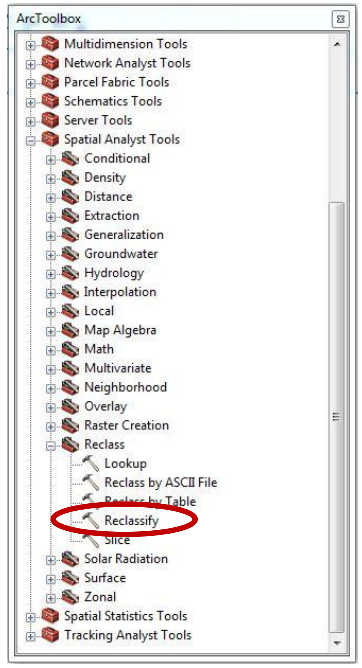

Fig. 2.7. ArcGIS® 10 Spatial Analyst: Reclassify tool.

Table 2.1. Slope and Aspect reclassified category values.

Predisposing Hazard Factors	
Slope	Aspect
1: 0 – 5.1%	1: 337.5° – 67.5°
2: 5.1 – 10.1%	2: 67.6° – 112.5° and 292.6 – 337.4°
3: 10.1 – 15.1%	3: 274.6° – 292.5°
4: > 15.1%	4: 112.6° – 247.5°

2.4.1.5. Weighted Overlay

The Weighted Overlay tool (Fig. 2.8) in ArcGIS® 10 allowed two sets of the same data types, raster in this application, to be combined with a percent influence or 'weight' allotted to each data set. At this point in the process the reclassified slope raster dataset was in Albers Equal Area and the aspect was in the Geographical Coordinate System corresponding with each states UTM zone.

The AEA projected slope and UTM state zone aspect raster datasets were added to the 'Weighted overlay table' box for the Weighted Overlay, Spatial Analyst tool. Based on field observations it was determined that 60% influence would be assigned to aspect and 40% influence to slope. Percentages were based on aspect leading to more stress as the site is more prone to weather conditions on a constant basis and slope is tied to water retention ability during a rainfall event. The output retained the four class categories by default.

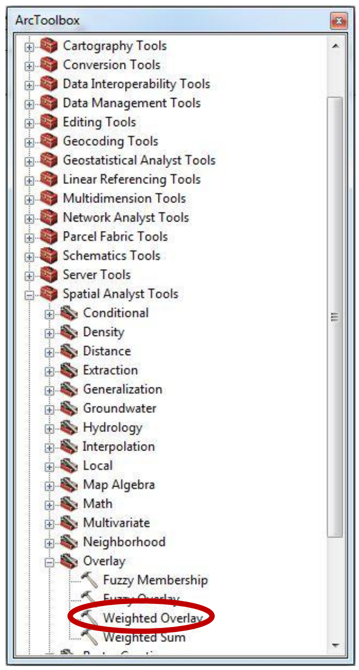

Fig. 2.8. ArcGIS® 10 Spatial Analyst: Weighted Overlay tool.

The product of the weighted overlay of an AEA slope and a UTM state zone aspect raster dataset was a UTM state zone Four Class Hazard Map (Fig. 2.9). At this stage, the maps were not defined by state boundaries and, using an extraction tool, were separated by state.

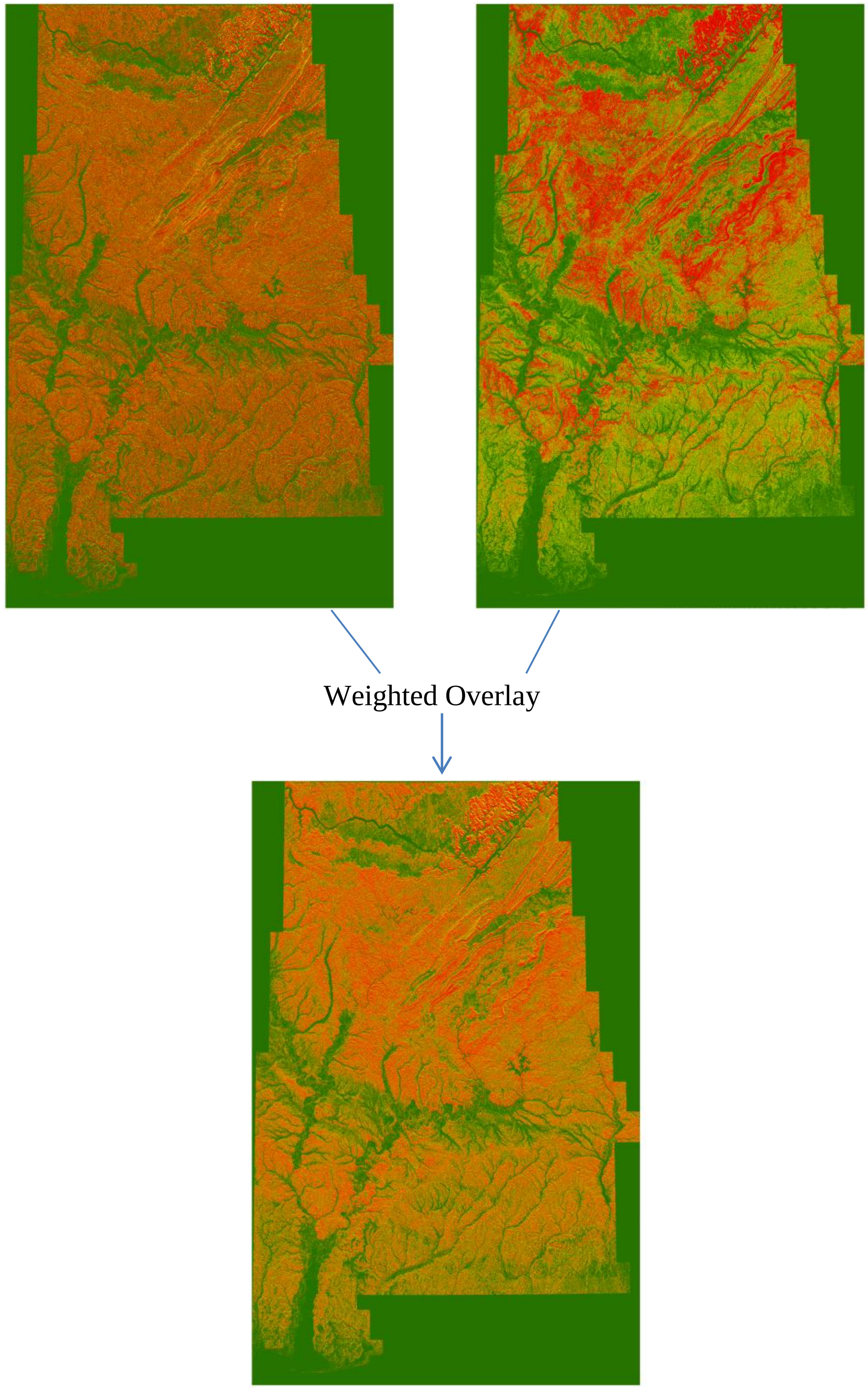

Fig. 2.9. Top left a reclassified aspect raster data set and top right a reclassified slope raster processed through ArcGIS® Arc Map™ 10 Weighted Overlay tool to produce the Four Class Hazard Map raster data set (Alabama).

2.4.2. Extraction

2.4.2.1. Extract by State Mask

Each Four Class Hazard Map was extracted by its state boundary exported from the ESRI® United States shape file in ArcGIS® 10. All extractions were implemented with ArcGIS® 10 Spatial Analyst Tools\Extraction\Extract by Mask (Fig. 2.10). The 'input raster' assigned as the Four Class Hazard Map created in the previous step. The 'input raster or feature mask data' was the coinciding state boundary and an 'Output raster' named was assigned and saved to a location. This process resulted in an extracted Four Class Hazard Map by each state's boundary (Fig. 2.11).

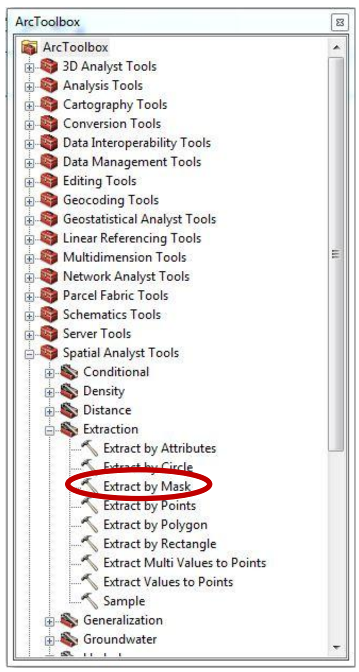

Fig. 2.10. ArcGIS® 10 Spatial Analyst: Extract by Mask tool.

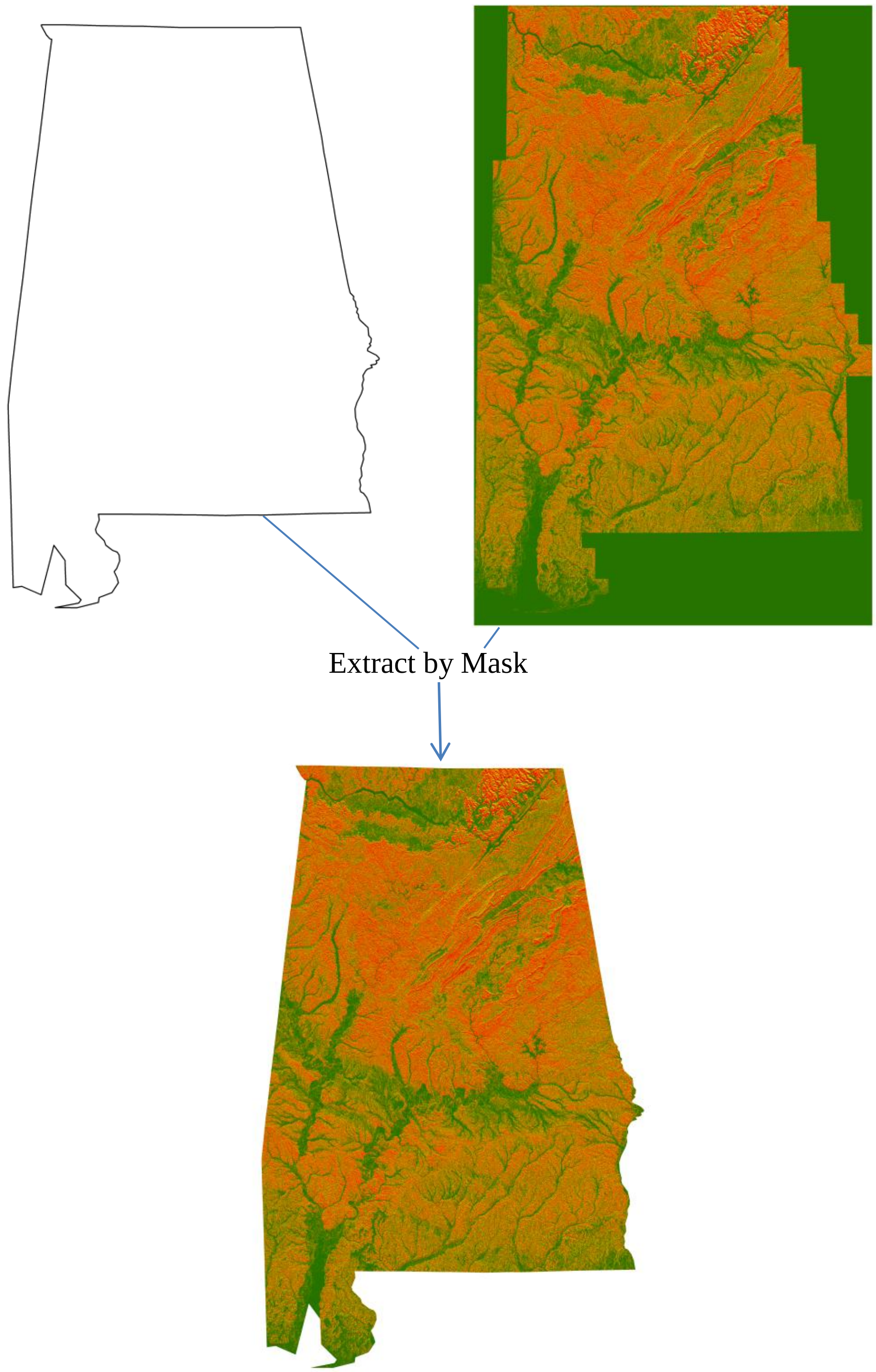

Fig. 2.11. State border used as a mask to extract State Four Class Hazard Map from unclipped State Four Class Hazard Map (Alabama).

2.4.2.2. Special State Extractions

Ten-meter DEMs were available for the majority of the southeast United States but not its entirety. A small part was unavailable in George County, Mississippi and many portions were not available in Florida (Fig 2.12). Florida and Mississippi Four Class Hazard Maps were clipped as a final process to remove areas of hazard that were not figured from DEMs (Fig. 2.13) using the Extract by Mask tool in ArcGIS® Arc Map™ 10.

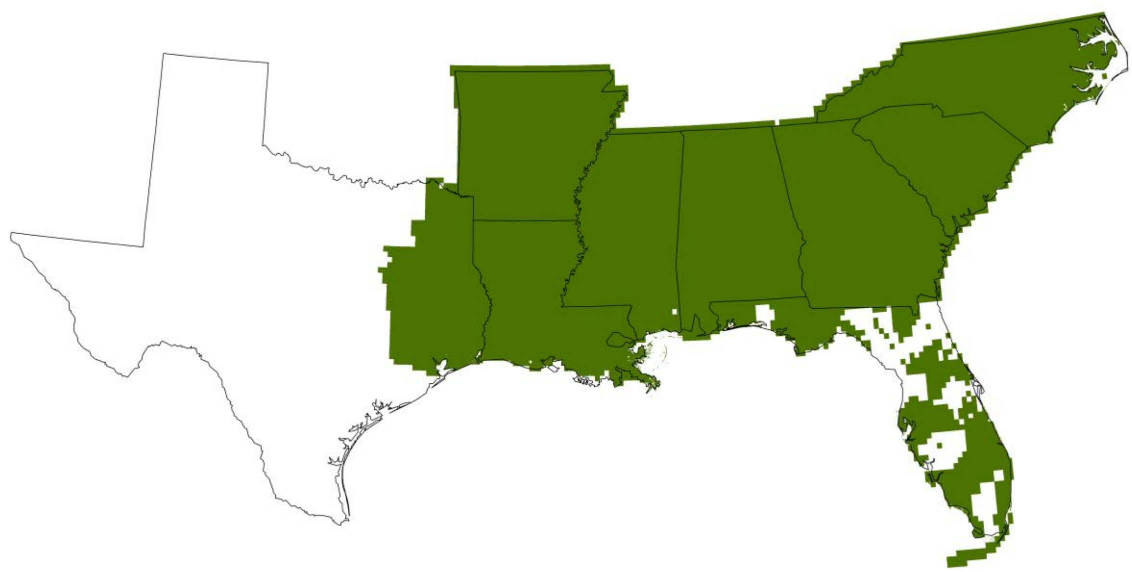

Fig. 2.12. Available 10m Digital Elevation Models shown in green for the study area of the southeast United States.

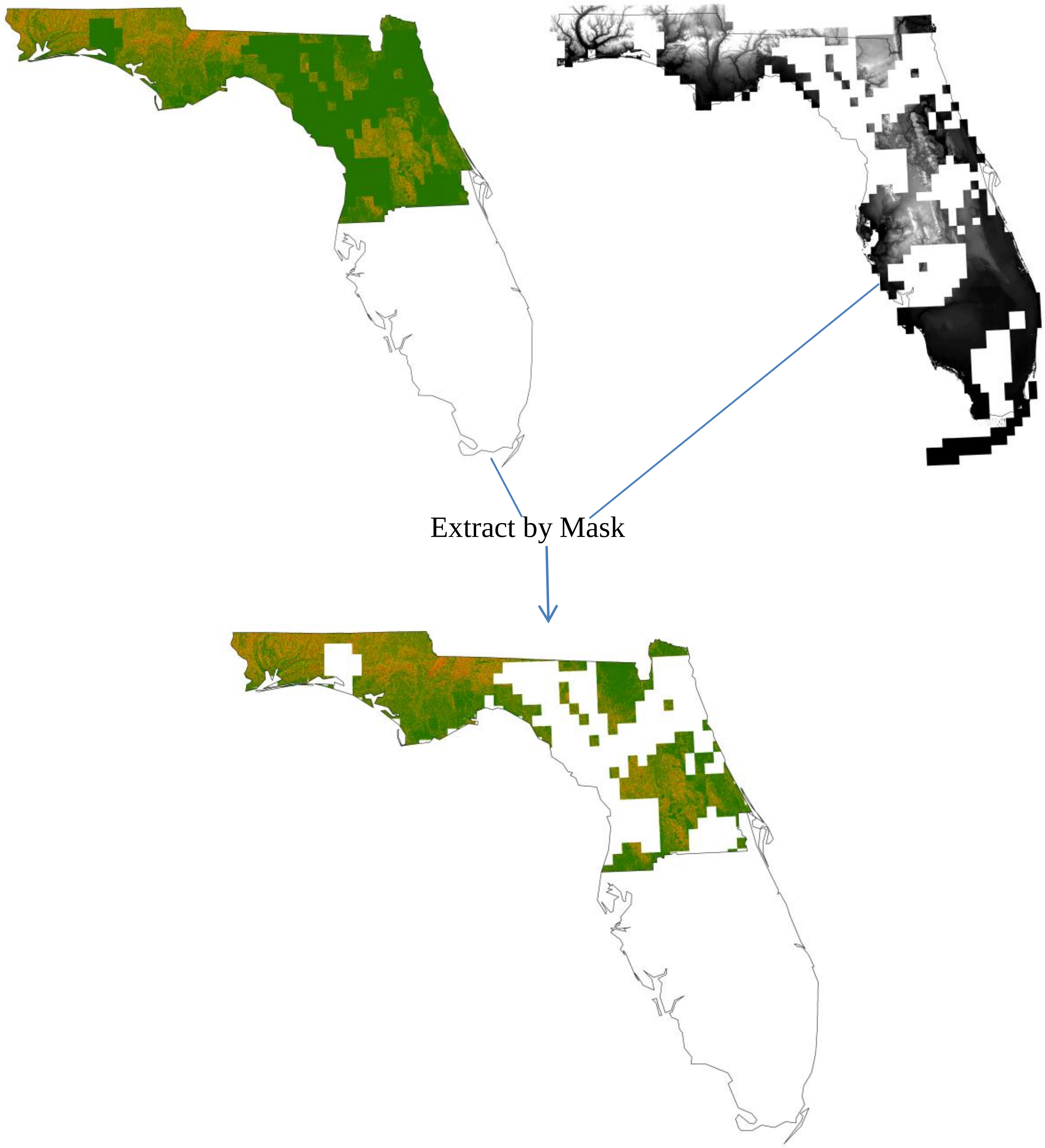

Fig. 2.13. Florida Four Class Hazard Map processed through ArcGIS® 10 Extraction by Mask tool using available 10m digital elevation model image as mask.

2.4.3. Loblolly Coverage/Risk

2.4.3.1. Coverage

Forest Health Technology Enterprise Team (FHTET), a department of the United States Forest Service, provided a loblolly pine (*P. taeda* L.) coverage layer for the contiguous United States. The most recent coverage version, Beta 3, not available to the public, was provided for this project. The loblolly coverage was created by a 30m pixel model using the criteria whether loblolly pine was present or absent. The model did not take loblolly density into account. The 30m cells were then aggregated to a 240m pixel, each 240m consisting of sixty-four 30m cells. The coverage was delivered as a 0-100% frequency; the number of 30m cells with loblolly pine present was divided by the total possible number, 64, within the 240m pixel to achieve a frequency percentage (Jim Ellenwood-FHTET Modeler, personal communication). For the purposes of the risk map a 60% frequency was chosen based on Loblolly Pine Decline field observations.

The loblolly pine coverage layer was then extracted by a mask (Fig. 2.14) of the state borders for the chosen states; Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Texas. The Southeast Loblolly Coverage was then separated by state using borders as masks to extract by mask (Fig. 2.14). For Texas and Florida only partial state areas were chosen due to the lower percentage loblolly range in those states (Fig. 2.15).

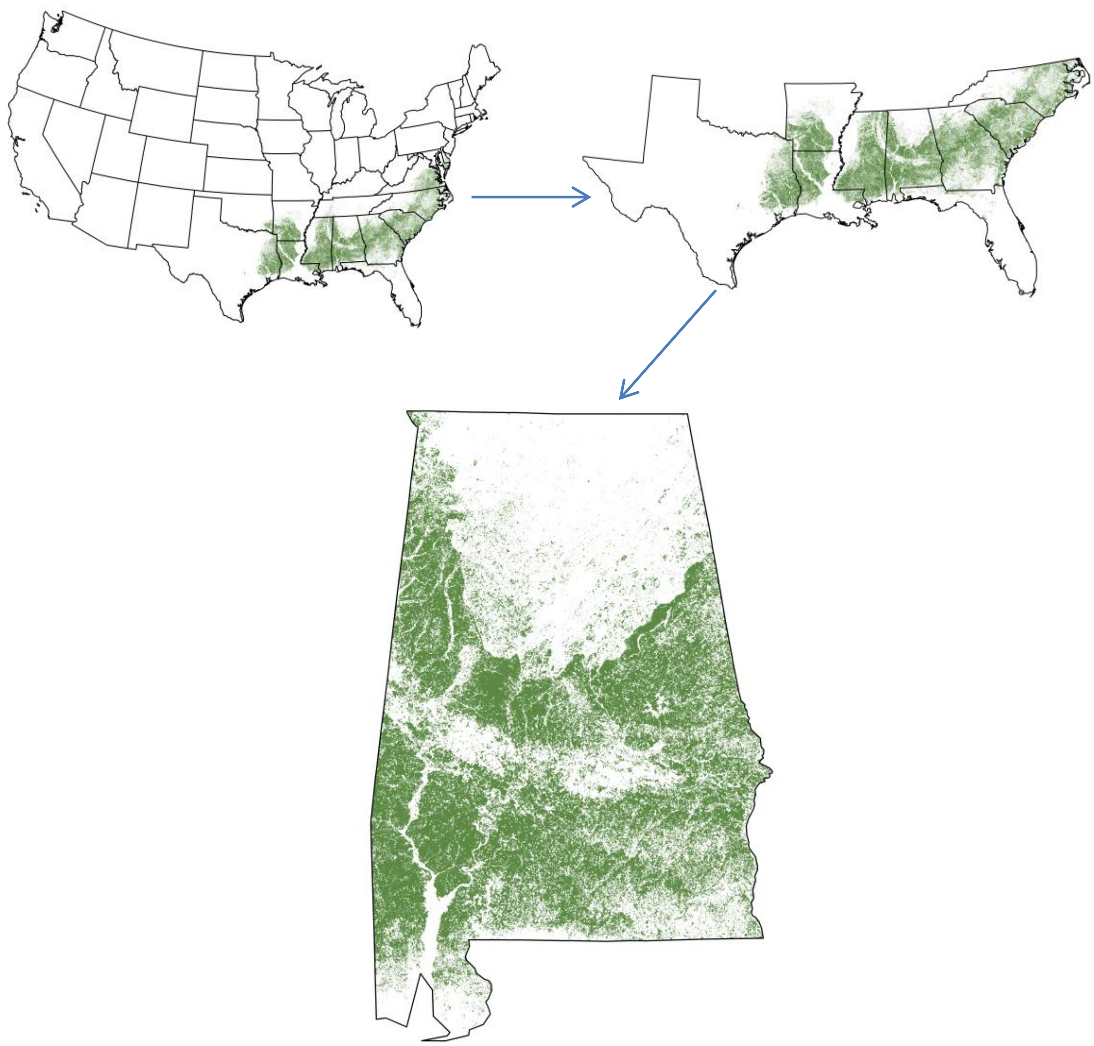

Fig. 2.14. The contiguous United States Loblolly Coverage reduced to the Southeast Loblolly Coverage then each State Loblolly Coverage selected (Alabama).

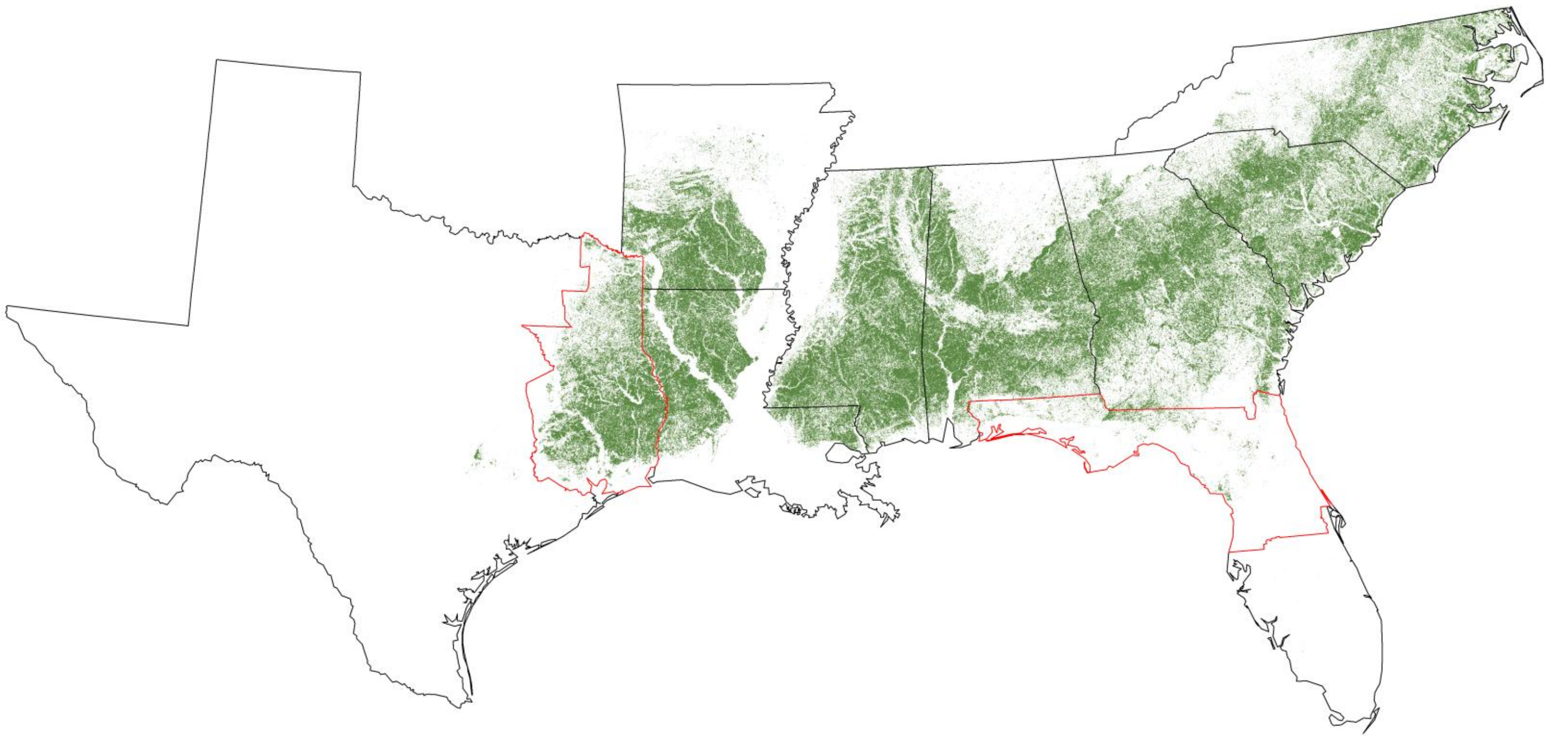

Figure 2.15. Southeast Loblolly Pine range with the areas of use for Texas and Florida demarcated.

2.4.3.2. Loblolly at Risk

The Loblolly Coverage files for each state were in a raster file format and the Four Class Hazard Maps were extracted using the Loblolly Coverage as a mask (Fig. 2.16) by State. The Loblolly State Coverage raster files were converted to shape files for each state and used as masks in an extraction. The extraction resulted in a map by state of the hazard sites on which loblolly pine were located according to the FHTET Loblolly Coverage file (Fig. 2.16).

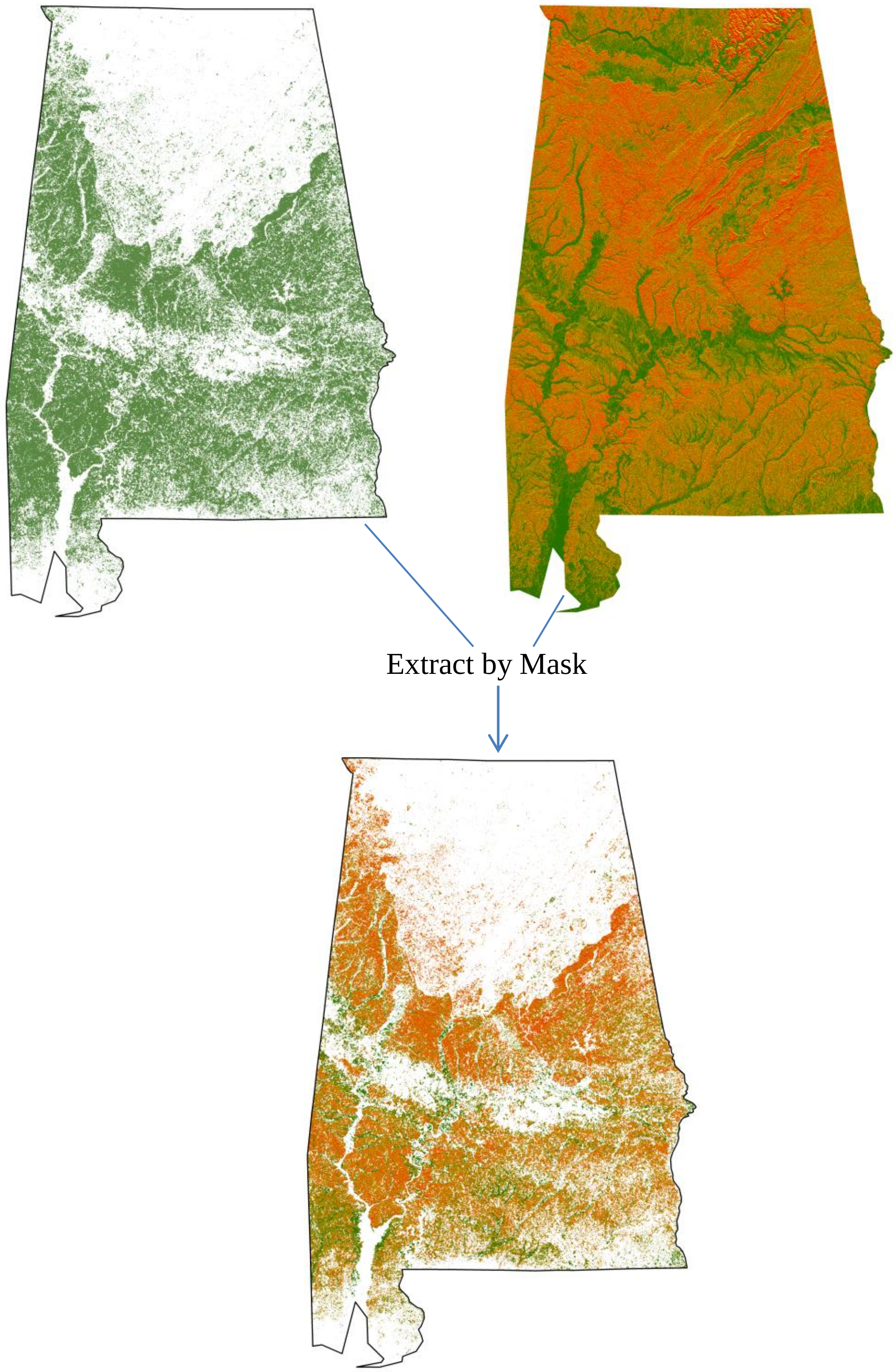

Fig. 2.16. Individual State Loblolly Coverage used as a mask on State Four Class Hazard Map to extract Loblolly Risk Areas by State (Alabama).

2.4.3.3. Area Calculations

The ArcGIS® 10 'Field Calculator' was used to calculate area in both hectares and acres and was done for each state's raster Four Class Hazard Map and Loblolly Risk Area Map. The attribute tables were accessed for each raster dataset and a new field was added for 'Hectares' and 'Acres' of the long integer 'Type'. The fields were created outside of an editing session then calculated inside an editing session and saved. The field calculator was used as mentioned and hectares were figured by the equation '[Count]/100' and area by '[Count]/40.47'. The 'Count' field was the number of 10 by 10m pixels, 100 m^2, in each of the four hazard categories. The calculations resulted in the number of hectares and acres in each of the four hazard categories per state for the Four Class Hazard Map and the Loblolly Risk Area Map. These calculations were processed on raster files before pyramids were built in order to obtain accurate calculations. Pyramids were built later to project all state maps as one.

2.4.4 Map Validation/Ground Truthing

2.4.4.1. Slope and Aspect Ground Truthing

Forest Inventory and Analysis (FIA) slope and aspect data were used as ground truth measures by United States Forest Service personnel. The reclassified slope and aspect datasets from this study were provided in raster datasets for use on ArcGIS® 10. A '.sql' or Structured Query Language statement was written with Oracle software to query the FIA database, extracting 'PLOT' and 'CONDITION'. A point file (shapefile/.shp) was created in ArcGIS® 10 using actual, not fuzzed or altered, X and Y coordinates. The point file was then exported and saved in the same projection as the state the file was created to truth. Spatial Analyst Tools\Extraction\Extract Values to Points (Fig. 2.17) was used, point features, PLOT and CONDITION data for each state, and raster by state were input to extract slope and aspect data by X and Y coordinates. This process was implemented for each state, creating a slope and aspect file for each state. The database files (.dbf) were converted into Microsoft Excel spreadsheets of slope and aspect per Southeast state with the X and Y coordinates for each FIA plot removed prior to receiving.

Using Microsoft Excel 2010, IF/THEN statements were created based on the predisposing hazard site conditions (Table. 2.1). The IF/THEN statements created a column stating whether the ground data matched the GIS derived data with an 'ok' or 'no good'. These 'ok' and 'no good' cells were calculated to receive a percent accuracy of the slope and aspect map readings compared to the FIA ground data. Tolerances were created for both slope and aspect to accommodate for errors that could have occurred in calculations and ground readings. No tolerance values were figured as well as +/- 1% for slope values and +/- 5, 10, and 15 degrees for aspect values.

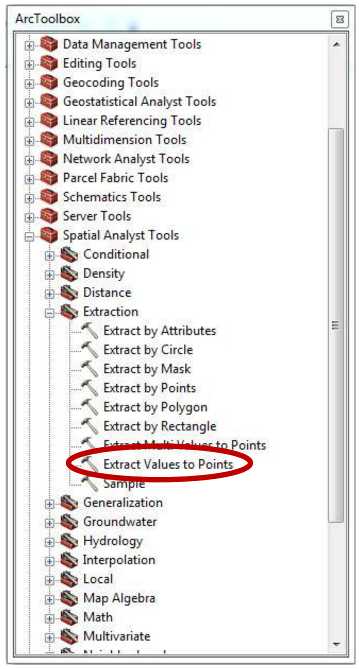

Fig. 2.17. ArcGIS® 10 Spatial Analyst: Extract Values to Points tool.

2.4.4.2. Ecological Ground Truthing

Positive and negative identifications of ophiostomatoid fungi from the Auburn University Forest Health Cooperative Database made from sampled loblolly pine roots in research plots were plotted on the Loblolly Pine Decline Hazard Map. The plot GPS coordinates were stored in the database then plotted on the Loblolly Pine Decline Risk Map using ArcGIS® 10 'Go To XY' tool (Fig. 2.18) in the main toolbar. Once a point was plotted its risk level was assessed.

The field plots consisted of a center plot and three subplots, consistent with the United States Forest Service Forest Health Monitoring plot design (Fig. 2.19) (Dunn, 1999). The center and subplots have a radius of about 7.3m. When the GPS plot coordinates were plotted on the Loblolly Pine Decline Risk Map, the center 10m cell that contained the point was considered to be plot center. This assumption had to be made as most of the points did not fall in the center of a 10m pixel due to GPS error and plot location. The 10m cells on the 10m resolution raster file were delineated by a Fishnet created in using ArcGIS® 10 Data Management Tools\Feature Class\Create Fishnet (Fig. 2.20). This 'Fishnet' put a geo-referenced grid down on the 10m raster file which was needed in areas that consisted of the same color pixels.

The 7.3m radius of each plot overlapped 9 pixels on the 10m raster (Fig. 2.21). These 9 pixels were averaged to achieve the risk rating of the plot. Numbers were assigned to the color pixels based on their risk level to achieve the average plot risk. Green/Low Risk =1, Yellow/Medium Risk = 2, Orange/High Risk = 3, and Red/Severe Risk = 4 (Fig 2.22).

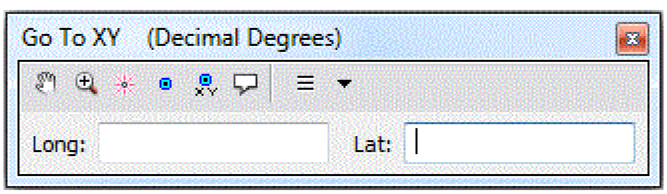

Fig. 2.18. ArcGIS® 10 Go To XY tool.

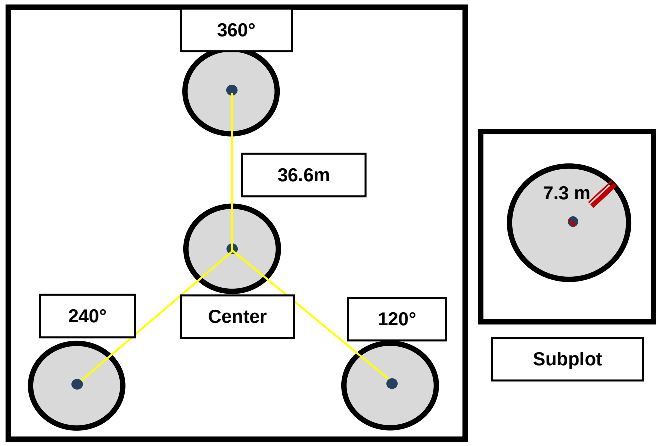

Fig. 2.19. Center plot and subplot Forest Health Monitoring layout.

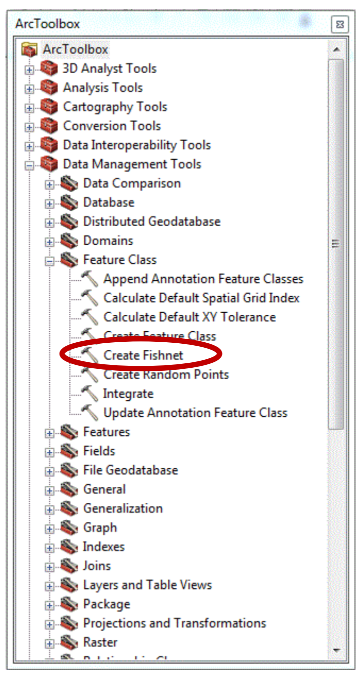

Fig. 2.20. ArcGIS® 10 Data Management Tools: Create Fishnet tool.

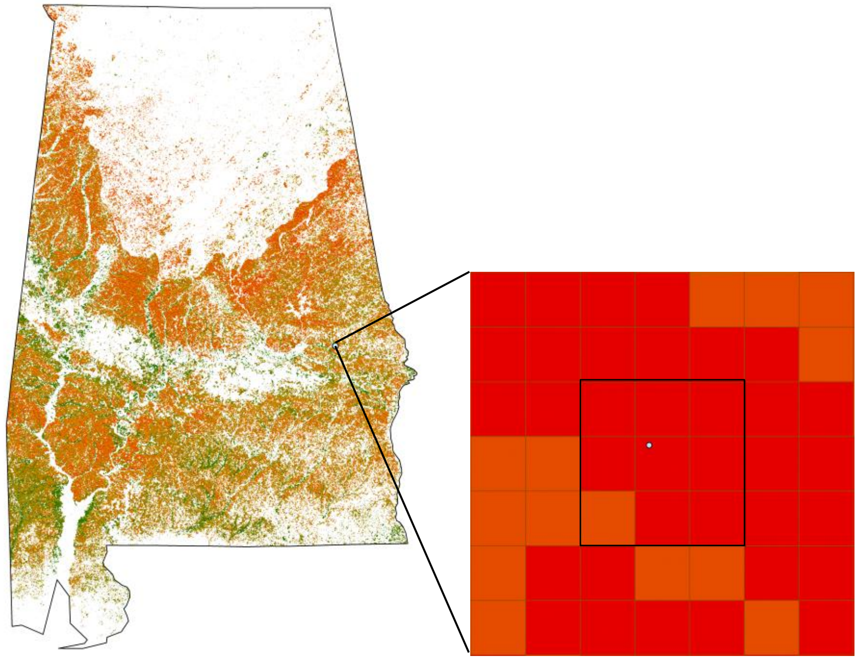

Fig. 2.21. Alabama Loblolly Pine Decline Risk Map with zoom of plotted point (Severe Risk).

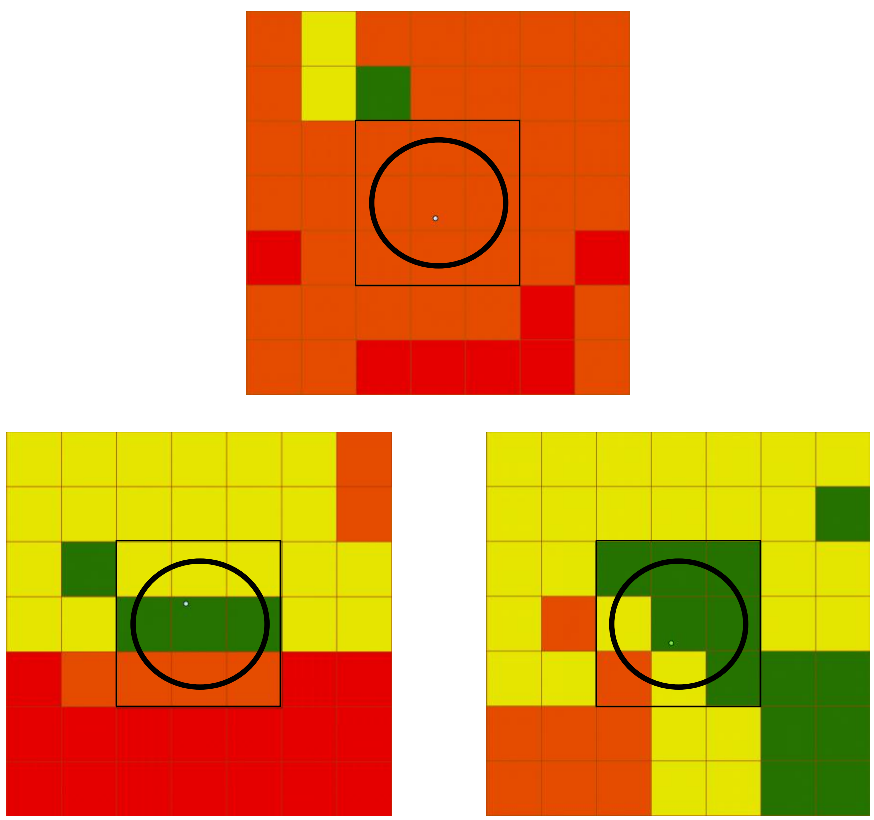

Fig. 2.22. Risk sites with plotted point and plot circle, top: High Risk, bottom left: Medium Risk, and bottom right: Low Risk.

2.5. Results

The southeast United States was mapped from east Texas, the 'Piney Woods', to North Carolina consisting of seven entire states, the northern half of Florida and east Texas. It covered 678 counties across 9 states and approximately 102,836,000 hectares. The Four Class Hazard Map (Alabama Fig. 2.23, Table 2.2; Arkansas Fig. 2.24; Table 2.3; Florida Fig. 2.25, Table 2.4; Georgia Fig. 2.26, Table 2.5; Louisiana Fig. 2.27, Table 2.6; Mississippi Fig. 2.28, Table 2.7; North Carolina Fig. 2.29, Table 2.8; South Carolina Fig. 2.30, Table 2.9; East Texas Fig. 2.31, Table 2.10) consisted of 49,190,997 ha in the Low hazard class, 20,306,790 ha in the Medium class, 26,761,872 ha in the High class and 6,854,100 ha in the Severe hazards class (Fig. 2.32, Table 2.11). The Loblolly Pine Risk Map (Alabama Fig. 2.33, Table 2.12; Arkansas Fig. 2.34; Table 2.13; Florida Fig. 2.35, Table 2.14; Georgia Fig. 2.36, Table 2.15; Louisiana Fig. 2.37, Table 2.16; Mississippi Fig. 2.38, Table 2.17; North Carolina Fig. 2.39, Table 2.18; South Carolina Fig. 2.40, Table 2.19; East Texas Fig. 2.41, Table 2.20) consisted of 13,203,103 ha in the Low hazard class, 7,700,494 ha in the Medium class, 9,819,890 ha in the High class and 2,346,953 ha in the Severe hazards class (Fig. 2.42, Table 2.21).

2.5.1. Loblolly Pine Decline Four Class Hazard Maps

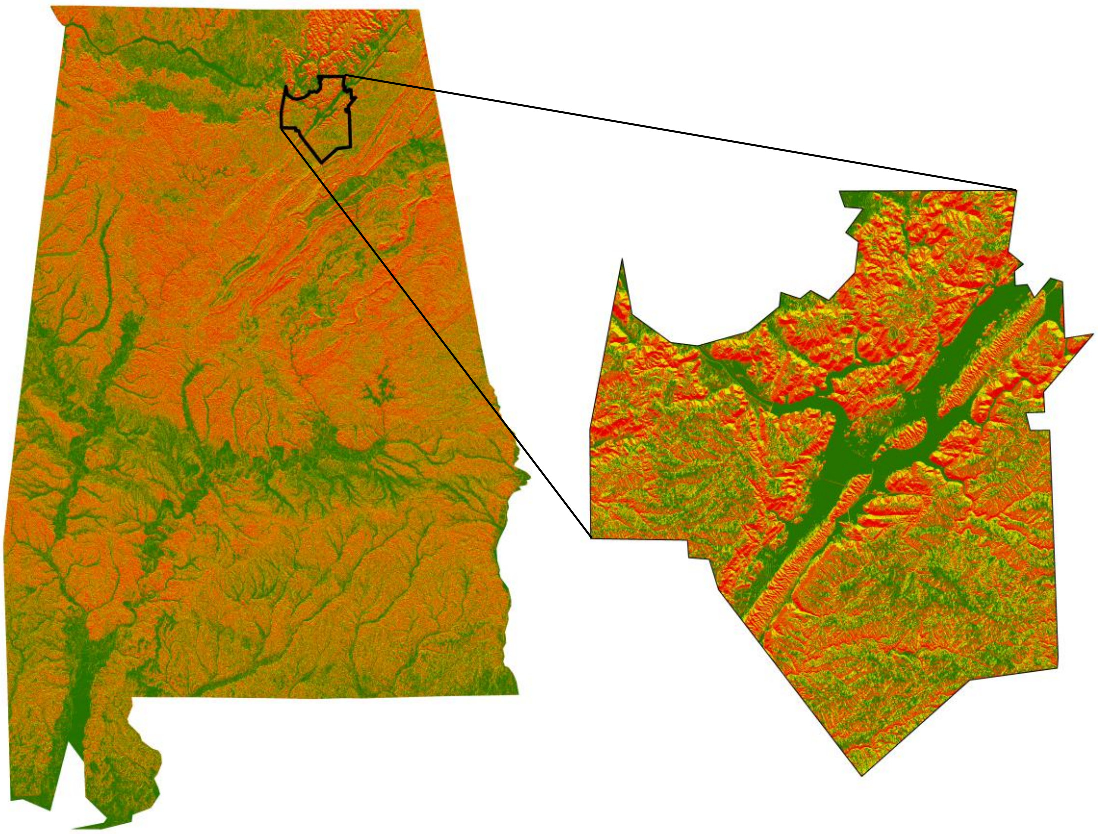

Fig. 2.23. Alabama Four Class Hazard Map with a zoom in of Marshall County.

Table 2.2. Alabama Four Class Hazard Map area calculations by class in hectares and acres.

Alabama Hazard Site Area				
Low	Medium	High	Severe	
4,397,919	3,182,964	4,378,961	1,426,200	Hectares
10,867,108	7,864,997	10,820,265	3,524,091	Acres

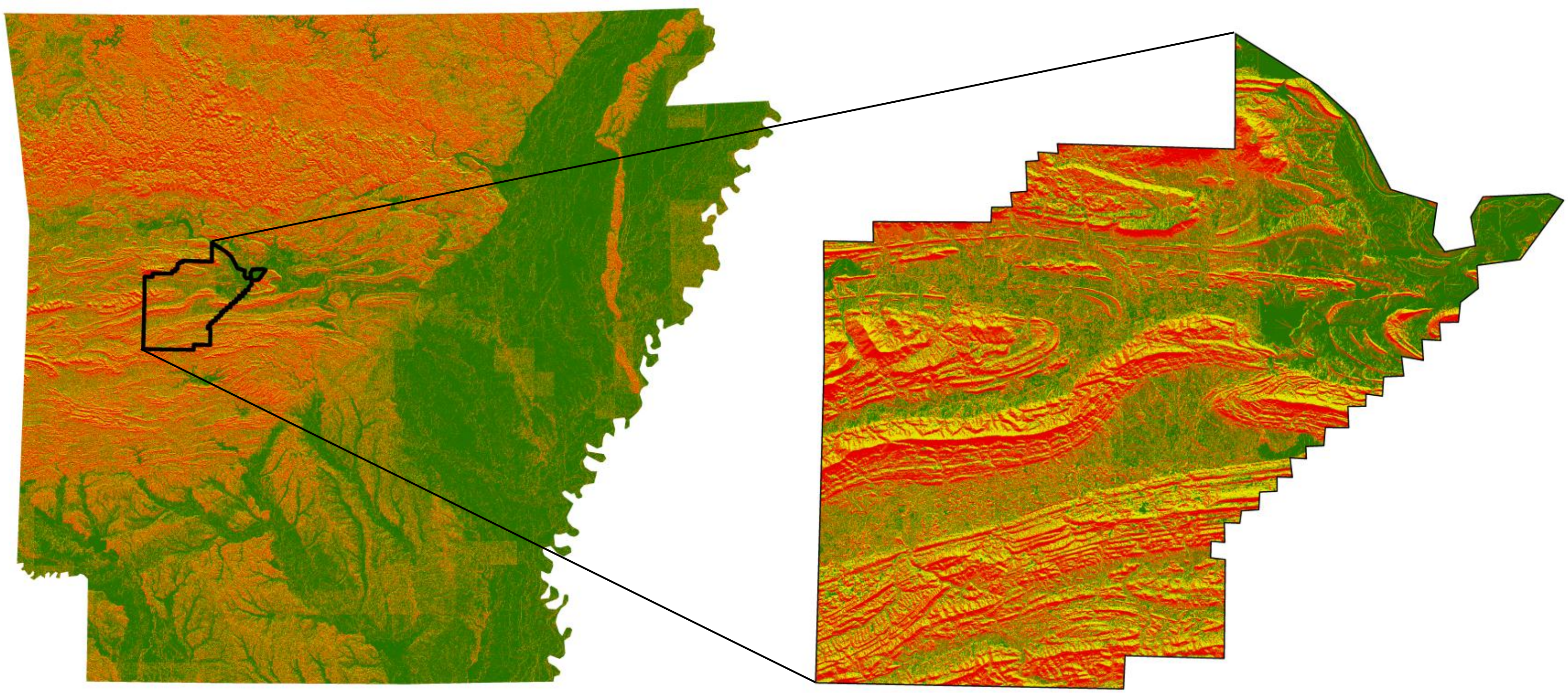

Fig. 2.24. Arkansas Four Class Hazard Map with a zoom in of Yell County.

Table 2.3. Arkansas Four Class Hazard Map area calculations by class in hectares and acres.

Arkansas Hazard Site Area				
Low	Medium	High	Severe	
7,032,372	2,734,882	3,747,354	1,372,216	Hectares
17,376,753	6,757,802	9,259,584	3,390,700	Acres

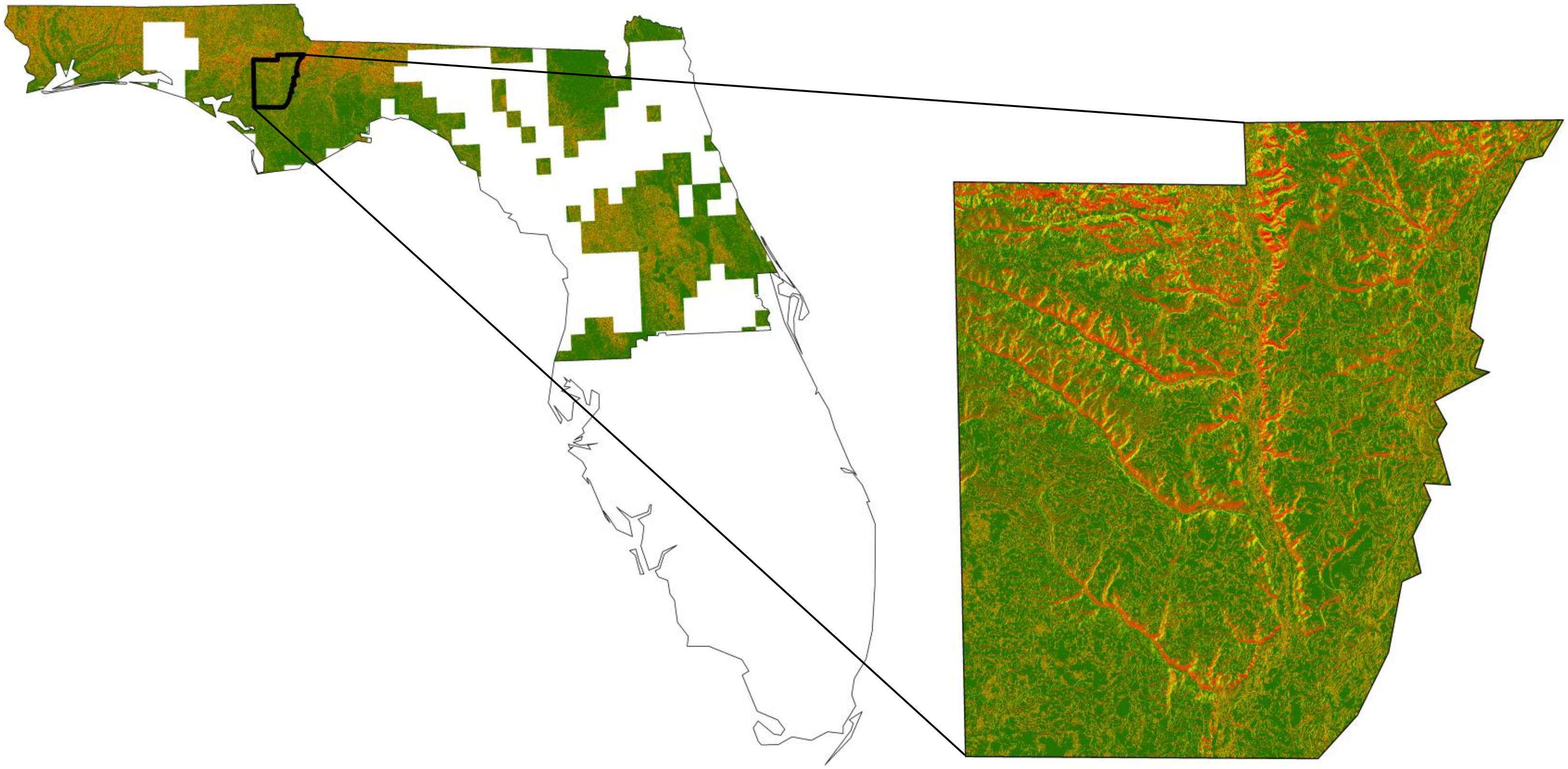

Fig. 2.25. Florida Four Class Hazard Map with a zoom in of Calhoun County.

Table 2.4. Florida Four Class Hazard Map area calculations by class in hectares and acres.

Florida Hazard Site Area				
Low	Medium	High	Severe	
3,140,648	743,506	919,539	54,046	Hectares
7,760,434	1,837,178	2,272,151	133,545	Acres

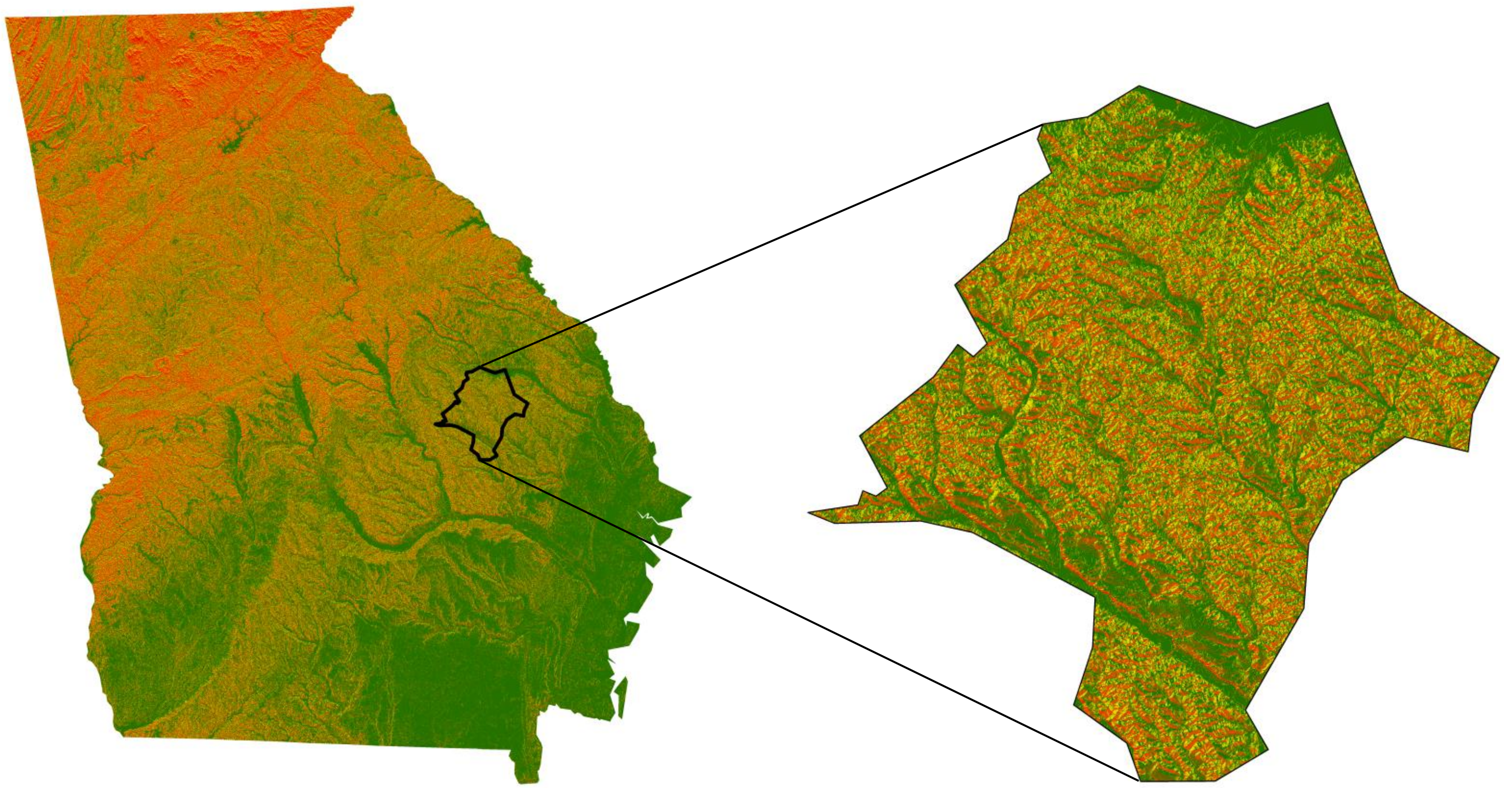

Fig. 2.26. Georgia Four Class Hazard Map with a zoom in of Emanuel County.

Table 2.5. Georgia Four Class Hazard Map area calculations by class in hectares and acres.

Georgia Hazard Site Area				
Low	Medium	High	Severe	
7,047,833	3,054,756	4,084,941	1,008,609	Hectares
17,414,957	7,548,200	10,093,752	2,492,238	Acres

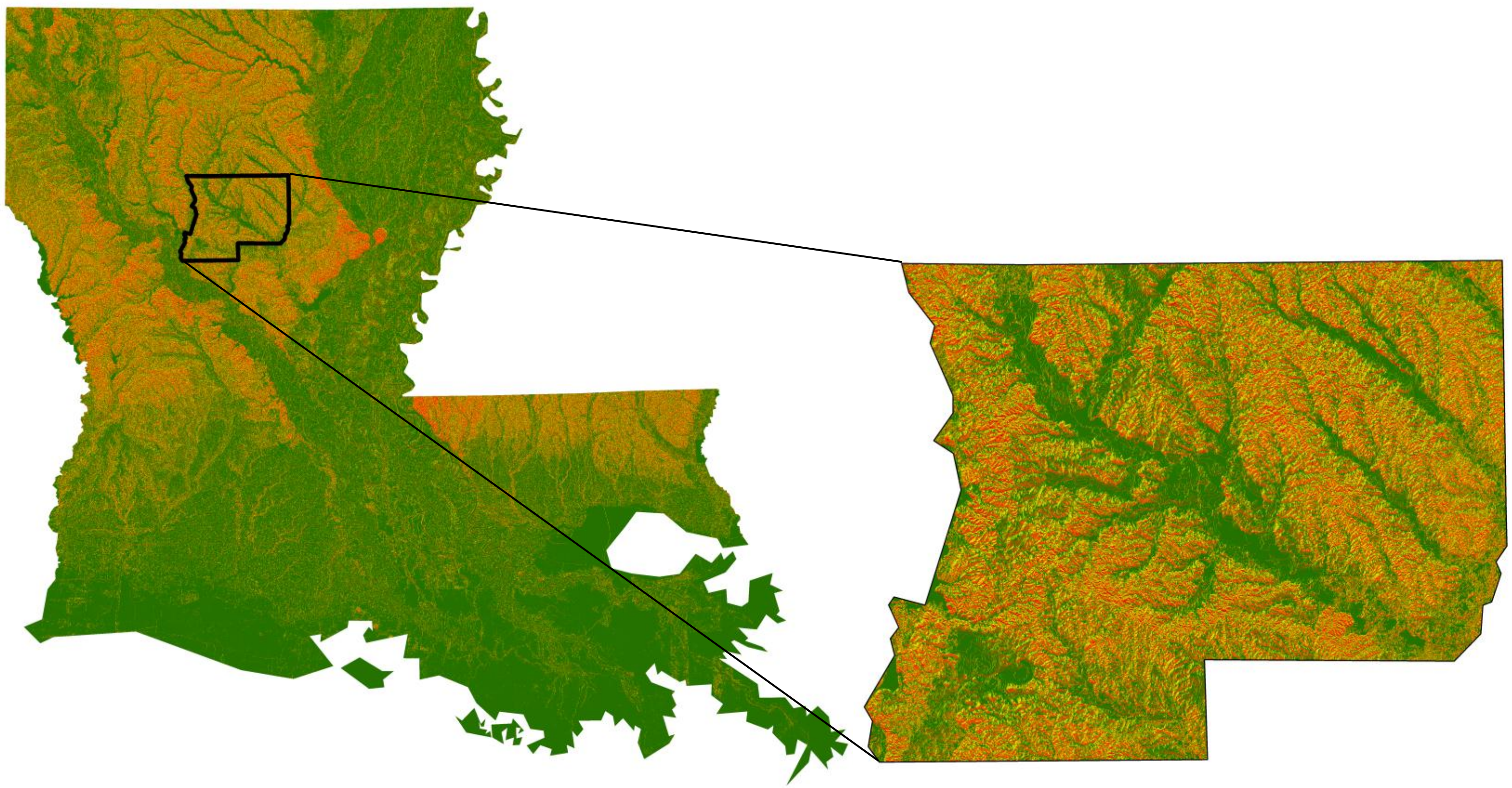

Fig. 2.27. Louisiana Four Class Hazard Map with a zoom in of Winn County.

Table 2.6. Louisiana Four Class Hazard Map area calculations by class in hectares and acres.

Louisiana Hazard Site Area				
Low	Medium	High	Severe	
8,381,799	1,744,490	2,054,096	233,074	Hectares
20,711,142	4,310,577	5,075,603	575,918	Acres

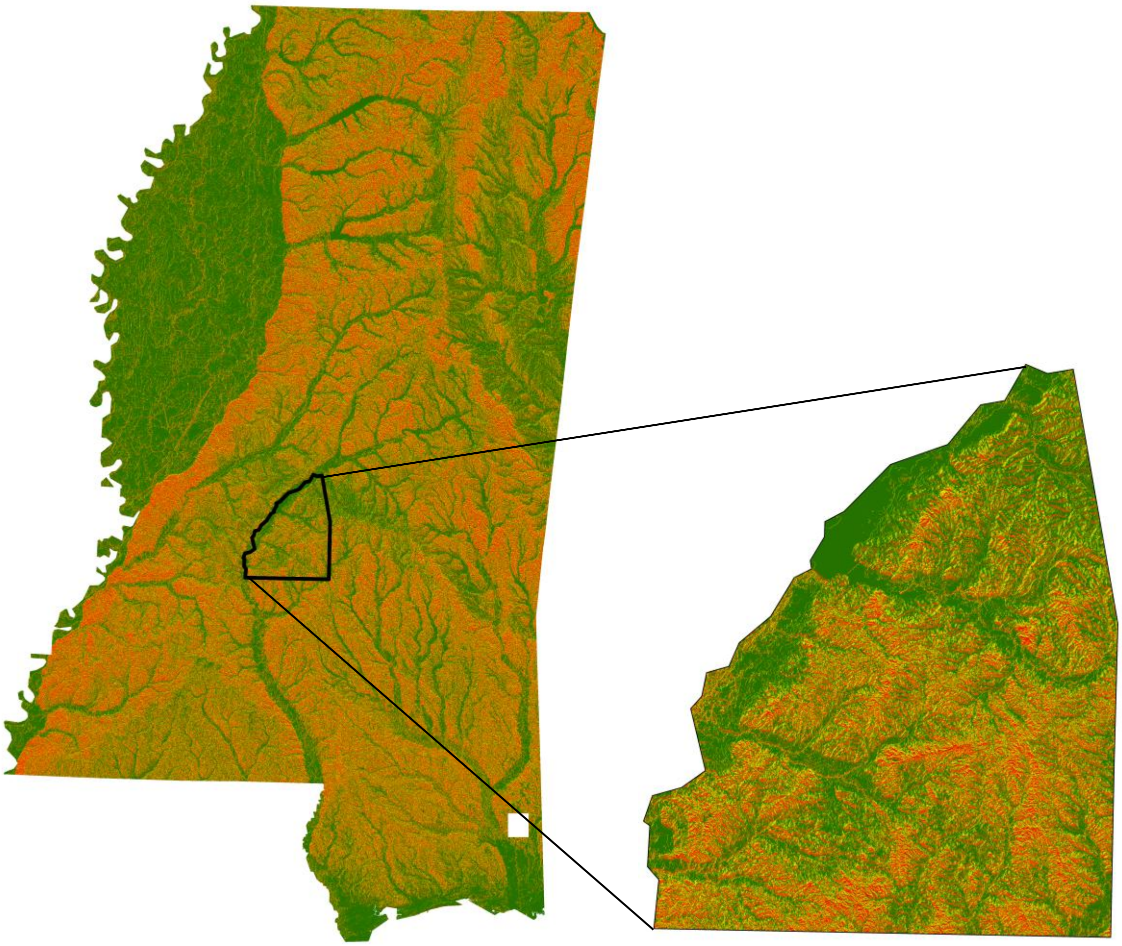

Fig. 2.28. Mississippi Four Class Hazard Map with a zoom in of Rankin County.

Table 2.7. Mississippi Four Class Hazard Map area calculations by class in hectares and acres.

Mississippi Hazard Site Area				
Low	Medium	High	Severe	
5,674,857	2,679,424	3,253,004	715,345	Hectares
14,022,380	6,620,765	8,038,064	1,767,594	Acres

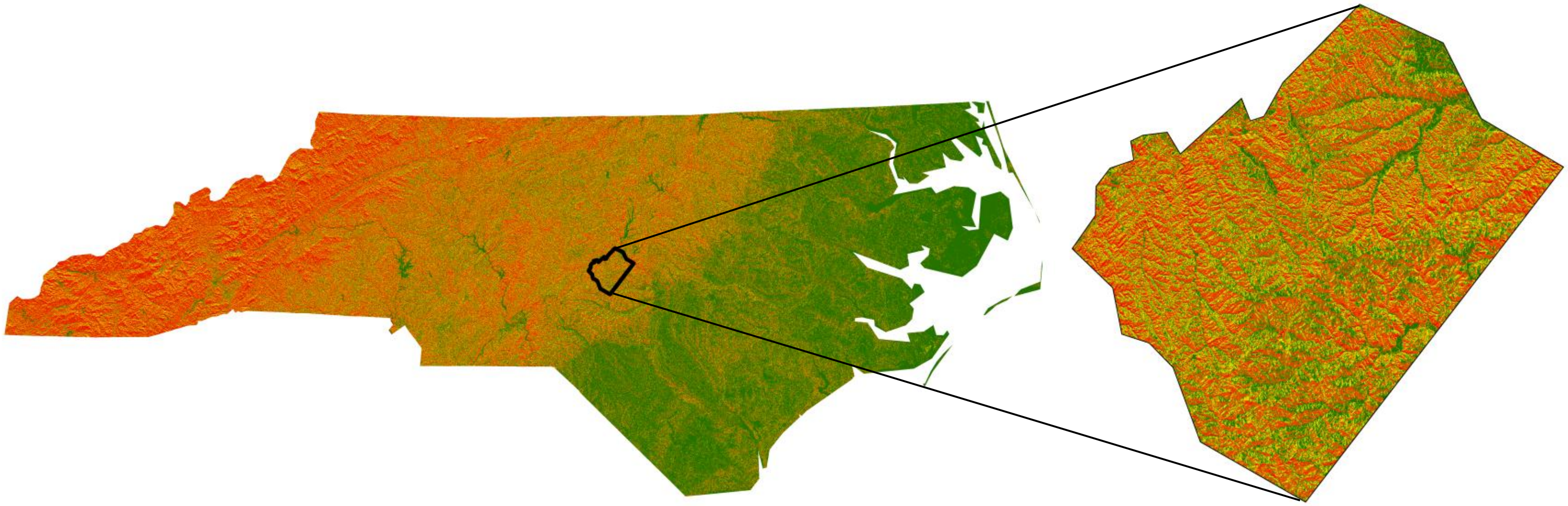

Fig. 2.29. North Carolina Four Class Hazard Map with a zoom in of Lee County.

Table 2.8. North Carolina Four Class Hazard Map area calculations by class in hectares and acres.

North Carolina Hazard Site Area				
Low	Medium	High	Severe	
4,397,919	3,182,964	4,378,961	1,426,200	Hectares
10,867,108	7,864,997	10,820,265	3,524,091	Acres

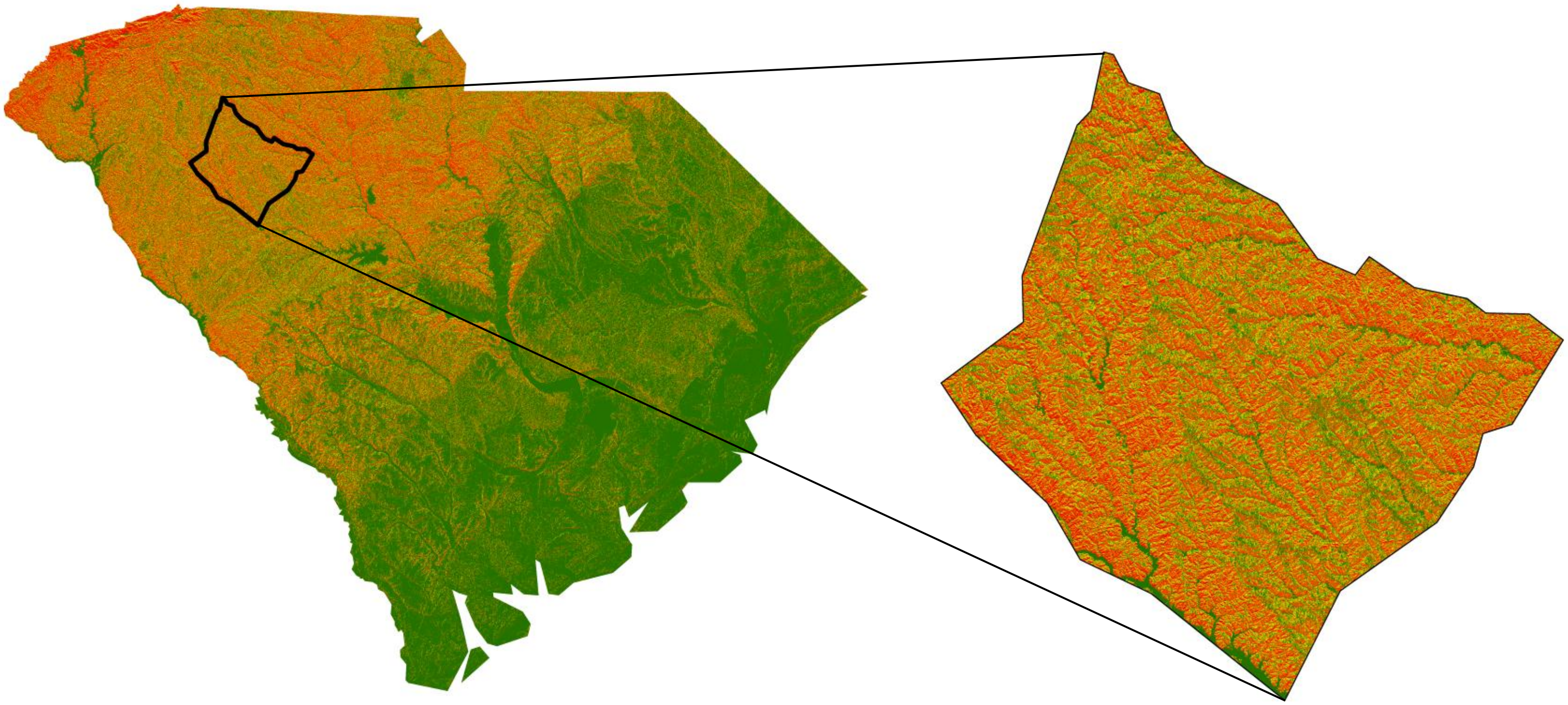

Fig. 2.30. South Carolina Four Class Hazard Map with a zoom in of Laurens County.

Table 2.9. South Carolina Four Class Hazard Map area calculations by class in hectares and acres.

South Carolina Hazard Site Area				
Low	Medium	High	Severe	
4,295,658	1,394,912	1,878,646	420,616	Hectares
10,614,425	3,446,780	4,642,071	1,039,328	Acres

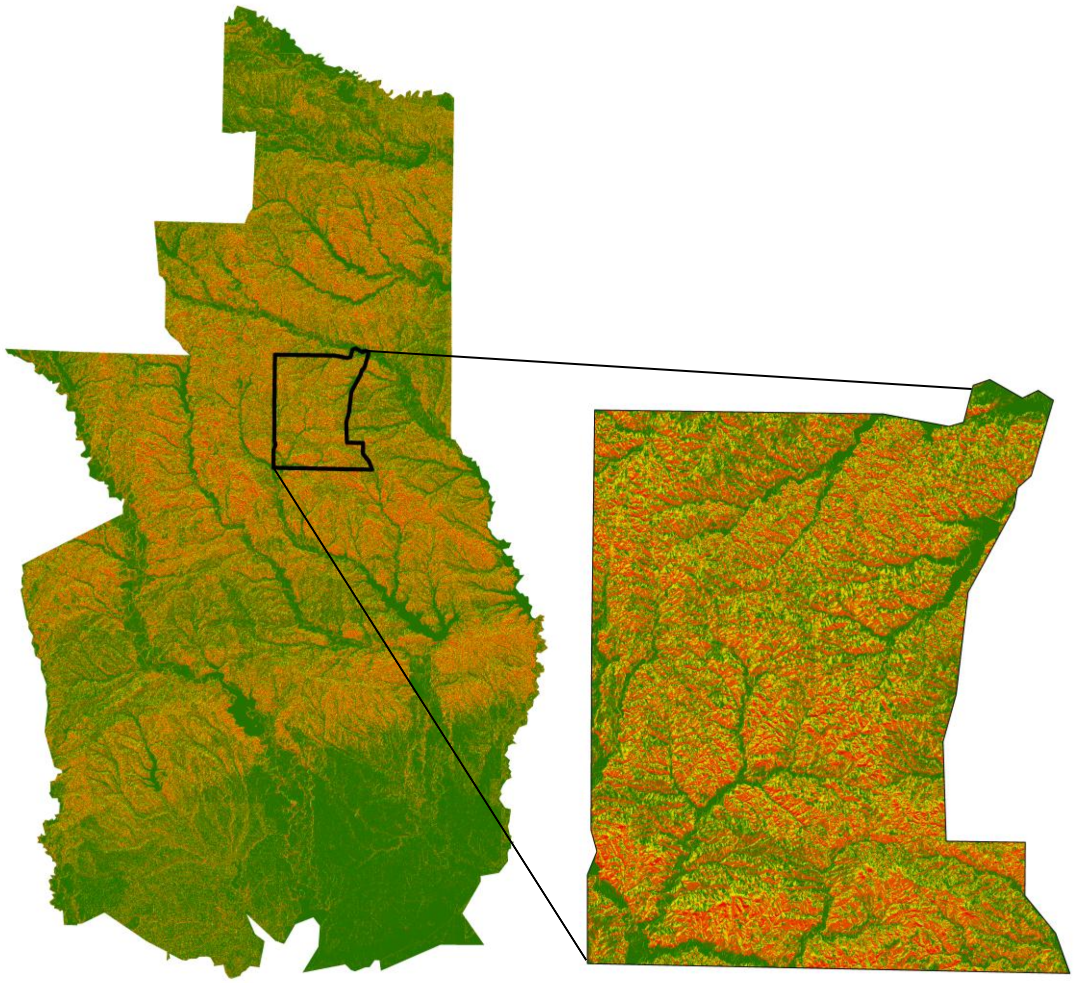

Fig. 2.31. East Texas Four Class Hazard Map with a zoom in of Rusk County.

Table 2.10. East Texas Four Class Hazard Map area calculations by class in hectares and acres.

East Texas (Piney Woods) Hazard Site Area				
Low	Medium	High	Severe	
4,821,992	1,588,892	2,066,370	197,794	Hectares
11,914,978	3,926,098	5,105,930	488,742	Acres

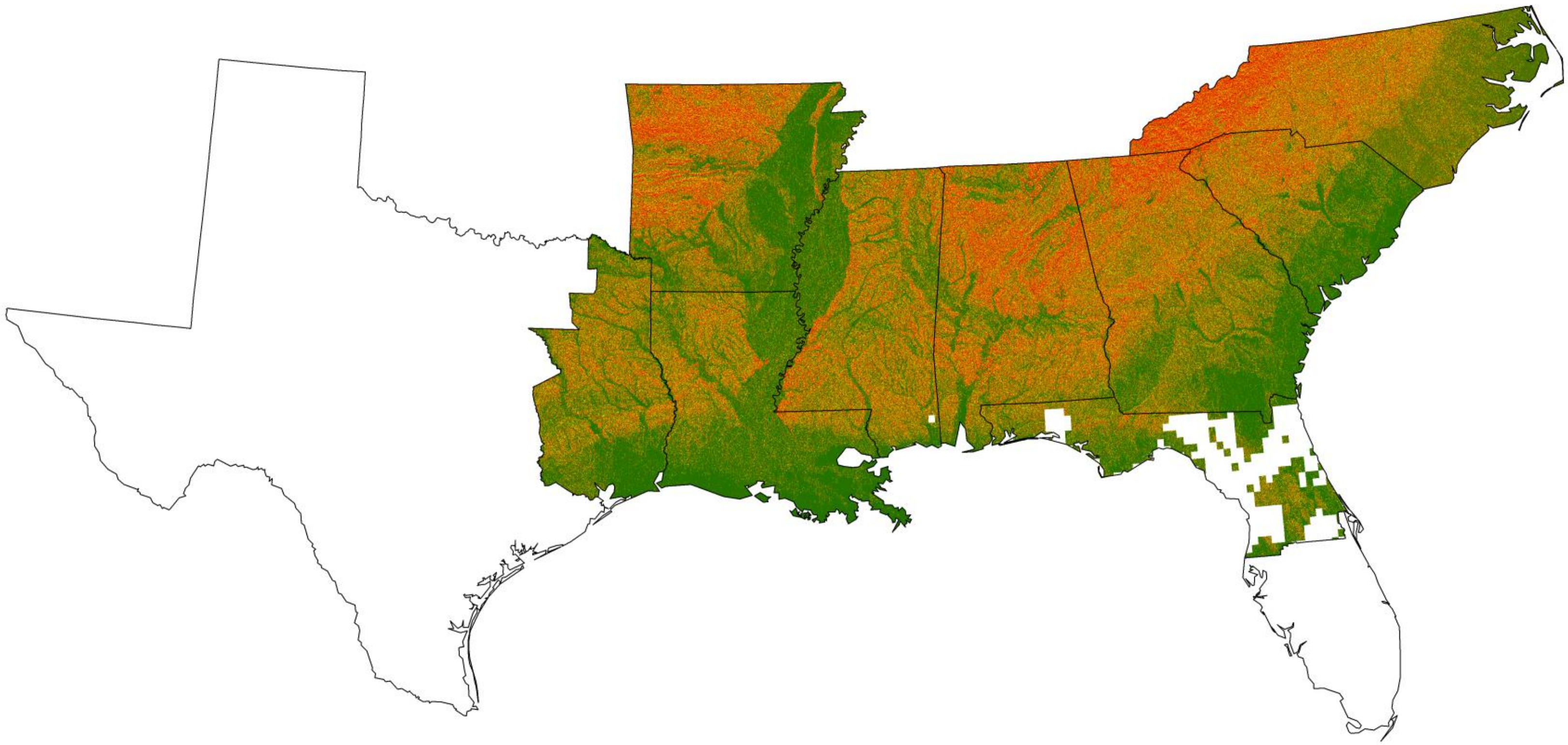

Fig. 2.32. Southeast United States Four Class Loblolly Pine Decline Hazard Map.

Table 2.11. Southeast United States Four Class Hazard Map area calculations by class in hectares and acres.

Southeast Loblolly Pine Decline Hazard Area				
Low	Medium	High	Severe	
49,190,997	20,306,790	26,761,872	6,854,100	Hectares
121,549,285	50,177,394	66,127,685	16,936,247	Acres

2.5.2. Loblolly Pine Decline Four Class Risk Maps

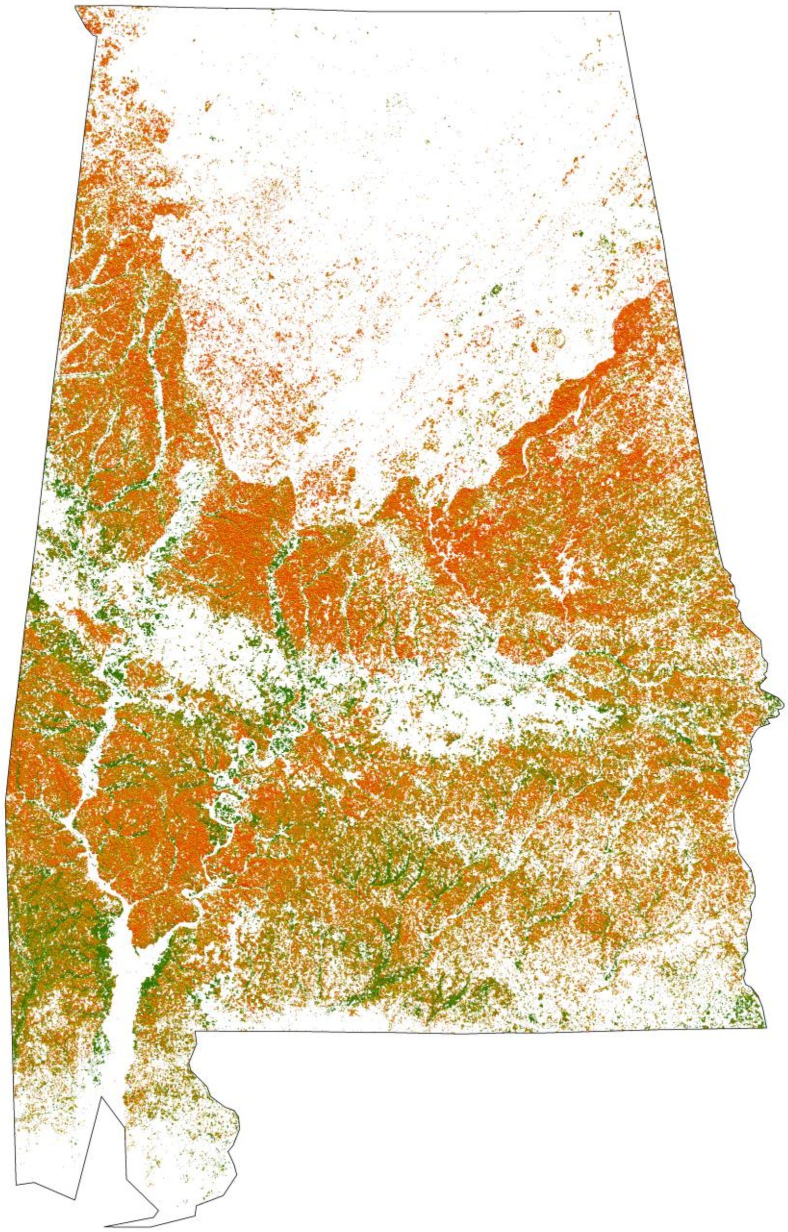

Fig. 2.33. Alabama Loblolly Pine Decline Risk Map.

Table 2.12. Alabama Loblolly Pine Decline Risk Map area calculations by class in hectares and acres.

Alabama Loblolly Pine Risk Area				
Low	Medium	High	Severe	
1,406,400	1,488,884	1,981,525	700,629	Hectares
3,475,167	3,678,983	4,896,281	1,731,230	Acres

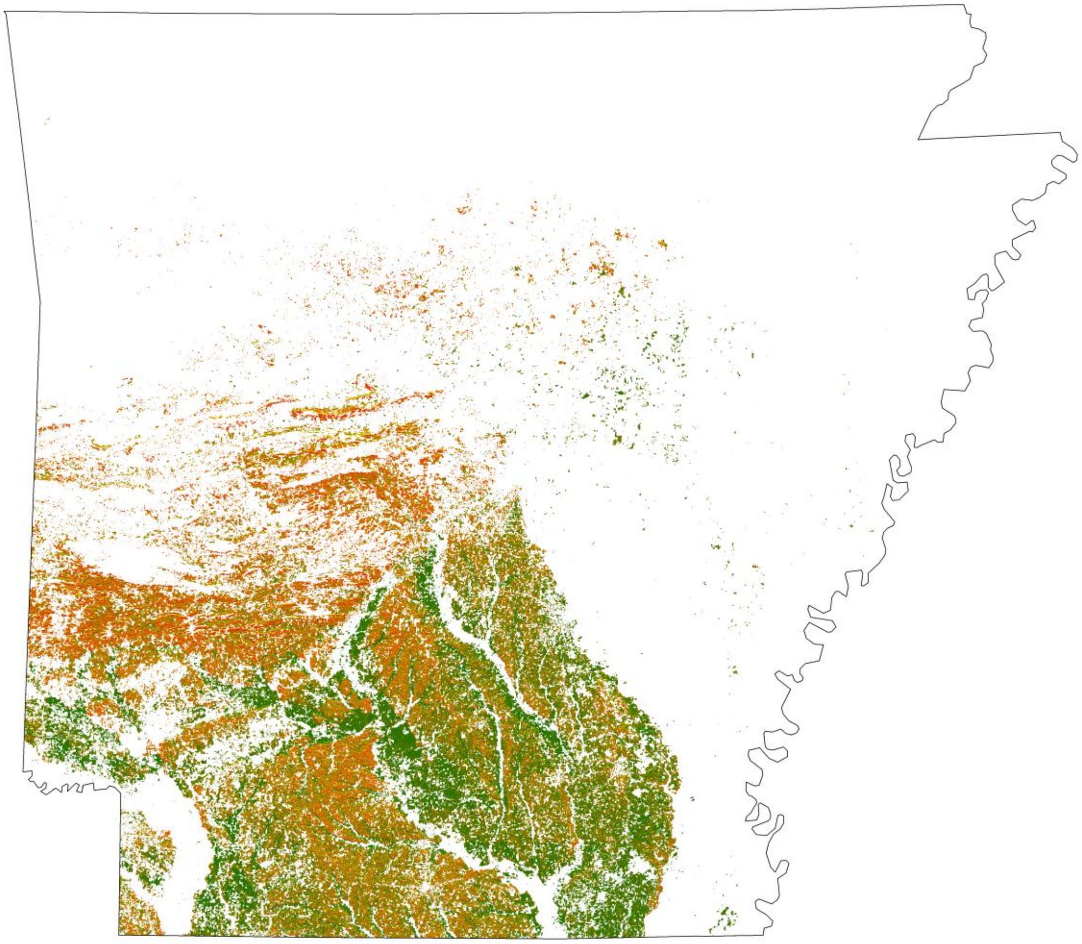

Fig. 2.34. Arkansas Loblolly Pine Decline Risk Map.

Table 2.13. Arkansas Loblolly Pine Decline Risk Map area calculations by class in hectares and acres.

Arkansas Loblolly Pine Risk Area				
Low	Medium	High	Severe	
1,326,379	589,816	833,463	179,345	Hectares
3,277,437	1,457,416	2,059,459	443,155	Acres

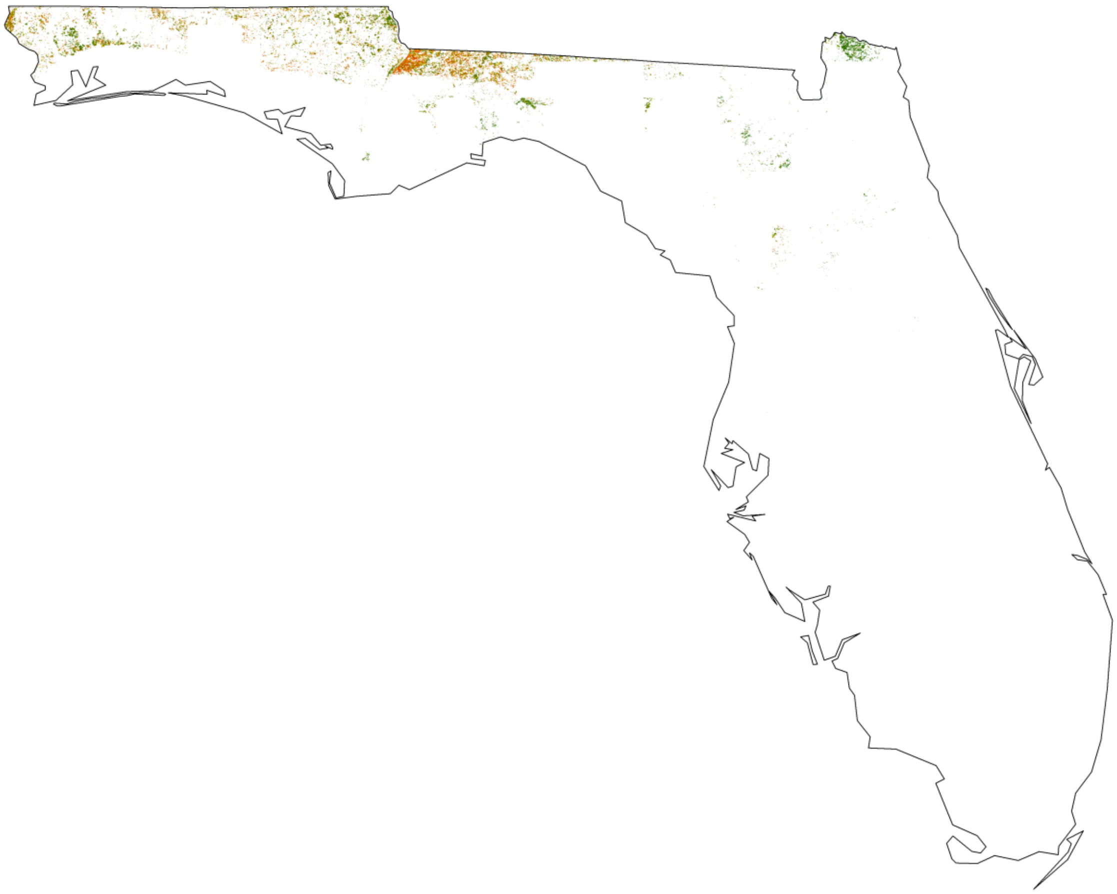

Fig. 2.35. Florida Loblolly Pine Decline Risk Map.

Table 2.14. Florida Loblolly Pine Decline Risk Map area calculations by class in hectares and acres.

Florida Loblolly Pine Area Risk				
Low	Medium	High	Severe	
106,937	53,688	67,778	8,408	Hectares
264,238	132,661	167,477	20,775	Acres

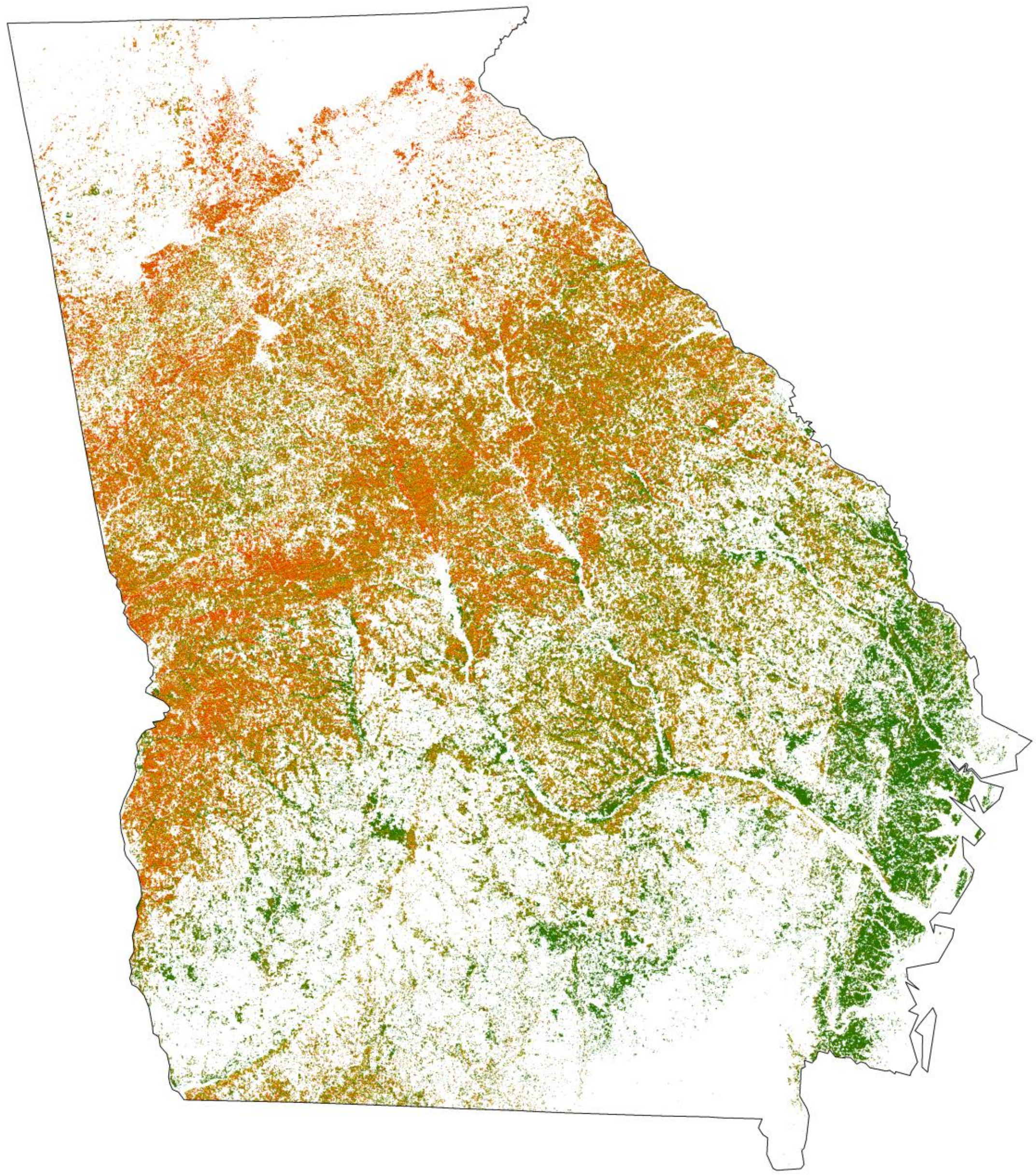

Fig. 2.36. Georgia Loblolly Pine Decline Risk Map.

Table 2.15. Georgia Loblolly Pine Decline Risk Map area calculations by class in hectares and acres.

Georgia Loblolly Pine Risk Area				
Low	Medium	High	Severe	
2,133,506	1,342,831	1,715,106	412,885	Hectares
5,271,821	3,318,090	4,237,970	1,020,225	Acres

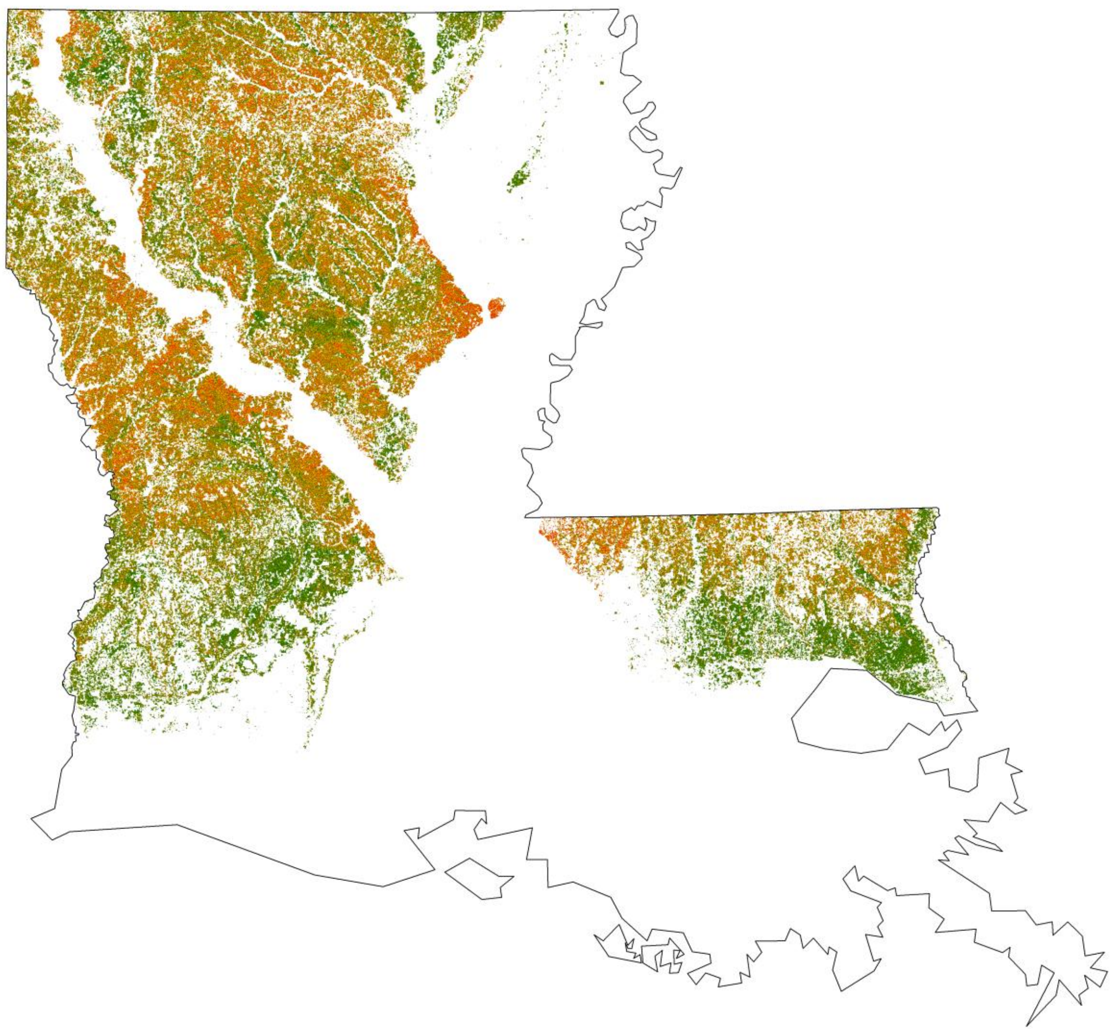

Fig. 2.37. Louisiana Loblolly Pine Decline Risk Map.

Table 2.16. Louisiana Loblolly Pine Decline Risk Map area calculations by class in hectares and acres.

Louisiana Loblolly Pine Risk Area				
Low	Medium	High	Severe	
1,425,540	867,496	1,034,115	159,269	Hectares
3,522,460	2,143,554	2,555,264	393,547	Acres

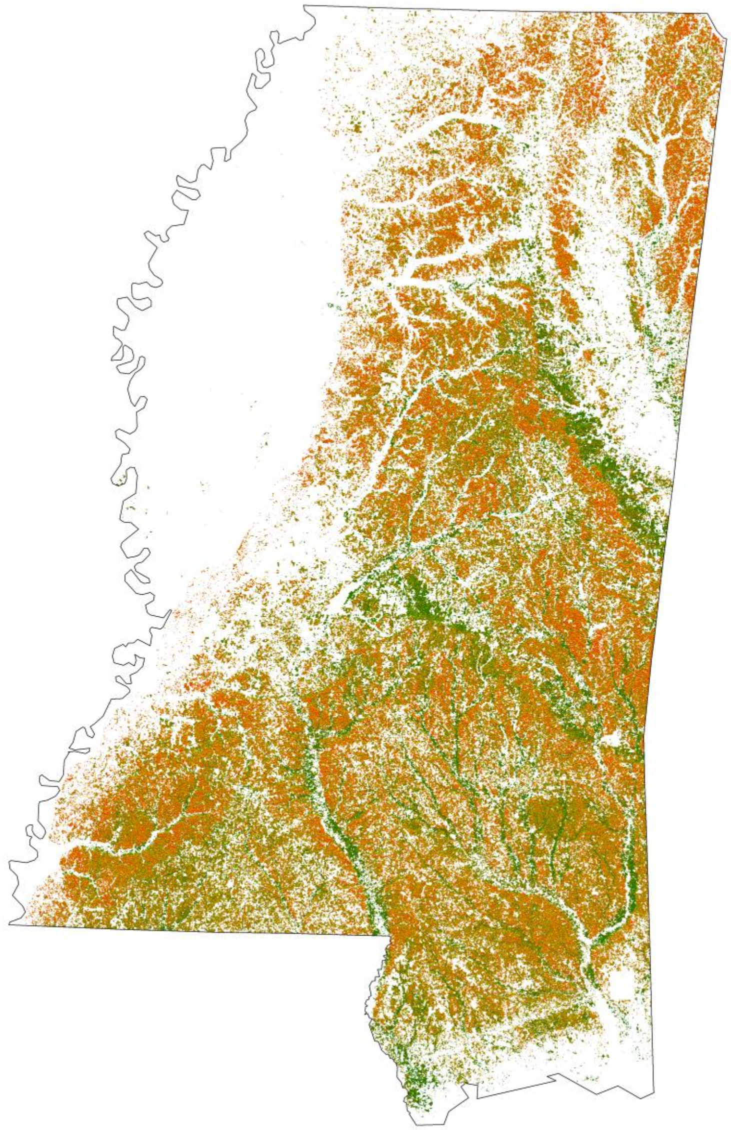

Fig. 2.38. Mississippi Loblolly Pine Decline Risk Map.

Table 2.17. Mississippi Loblolly Pine Decline Risk Map area calculations by class in hectares and acres.

Mississippi Loblolly Pine Risk Area				
Low	Medium	High	Severe	
1,767,852	1,453,300	1,729,991	461,004	Hectares
4,368,302	3,591,054	4,274,750	1,139,124	Acres

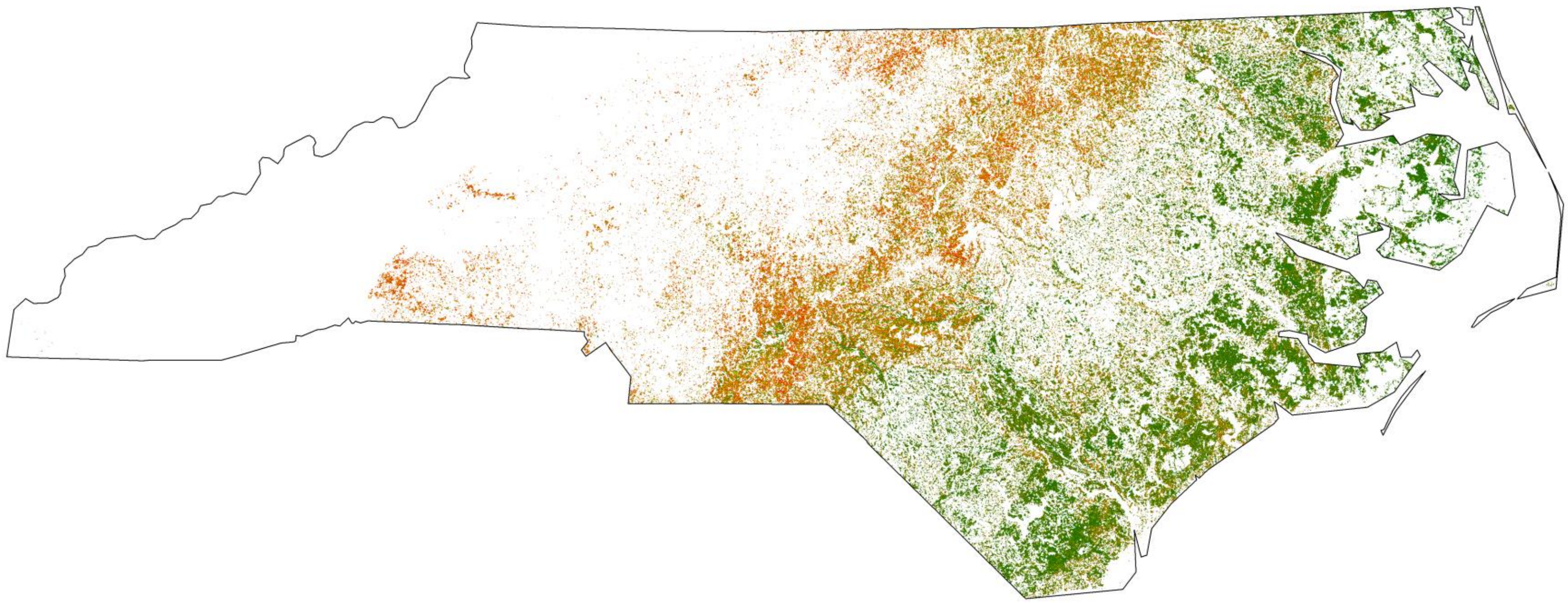

Fig. 2.39. North Carolina Loblolly Pine Decline Risk Map.

Table 2.18. North Carolina Loblolly Pine Decline Risk Map area calculations by class in hectares and acres.

North Carolina Loblolly Pine Risk Area				
Low	Medium	High	Severe	
1,622,277	553,250	733,791	131,140	Hectares
4,008,591	1,367,063	1,813,173	324,043	Acres

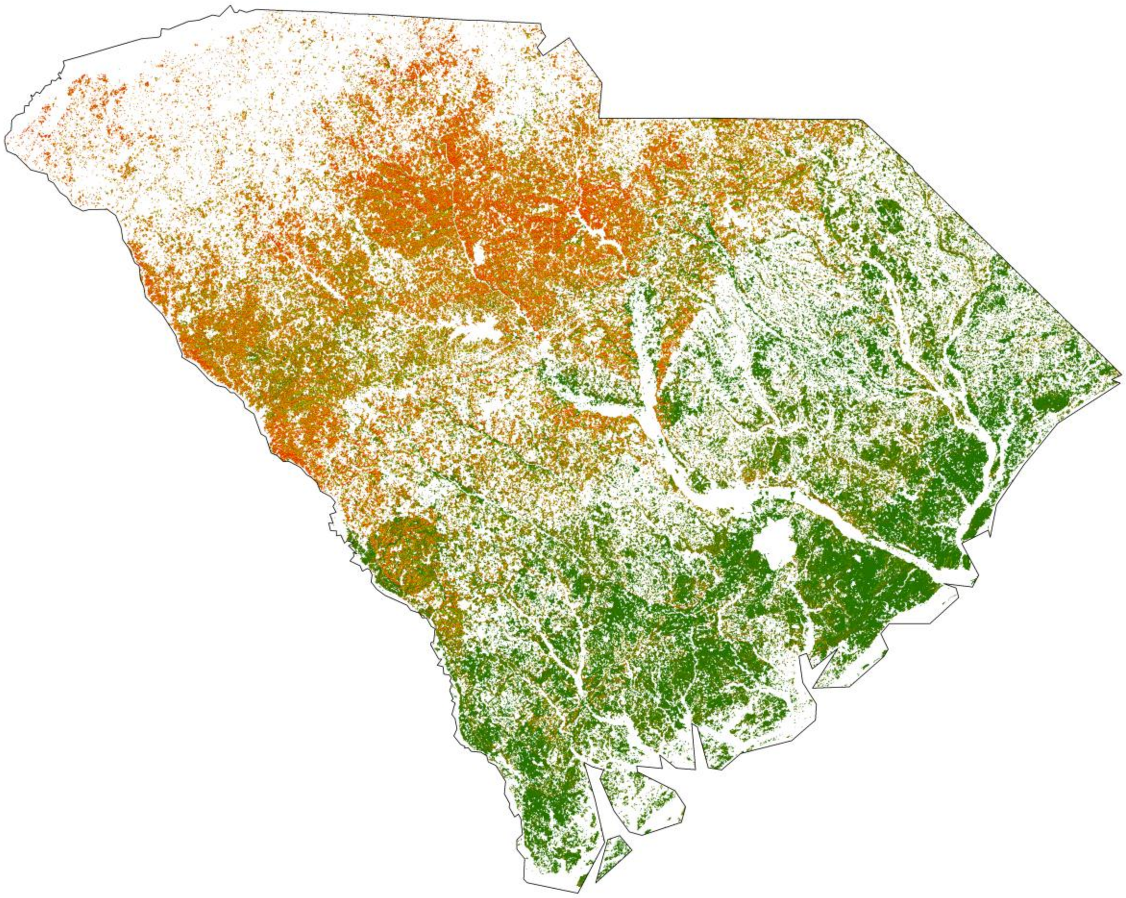

Fig. 2.40. South Carolina Loblolly Pine Decline Risk Map.

Table 2.19. South Carolina Loblolly Pine Decline Risk Map area calculations by class in hectares and acres.

South Carolina Loblolly Pine Risk Area				
Low	Medium	High	Severe	
1,899,762	665,845	858,344	192,780	Hectares
4,694,249	1,645,280	2,120,938	476,352	Acres

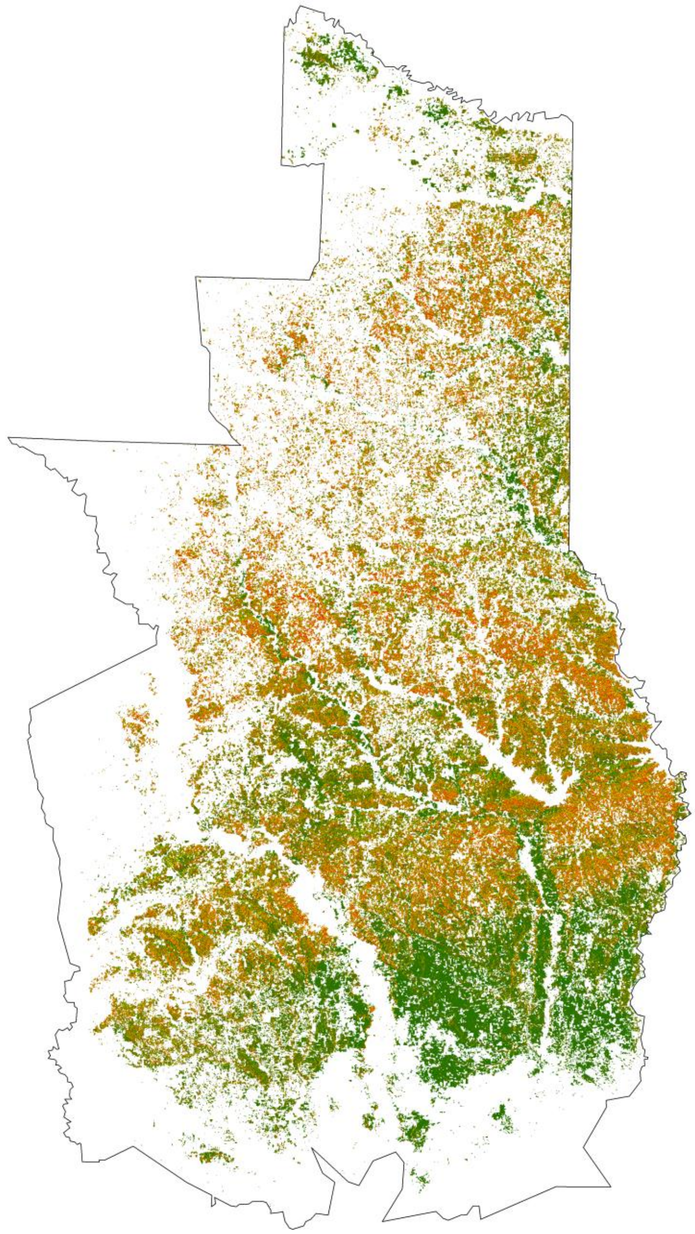

Fig. 2.41. East Texas Loblolly Pine Decline Risk Map.

Table 2.20. East Texas Loblolly Pine Decline Risk Map area calculations by class in hectares and acres.

East Texas Loblolly Pine Risk Area				
Low	Medium	High	Severe	
1,514,450	685,384	865,777	101,493	Hectares
3,742,155	1,693,560	2,139,304	250,786	Acres

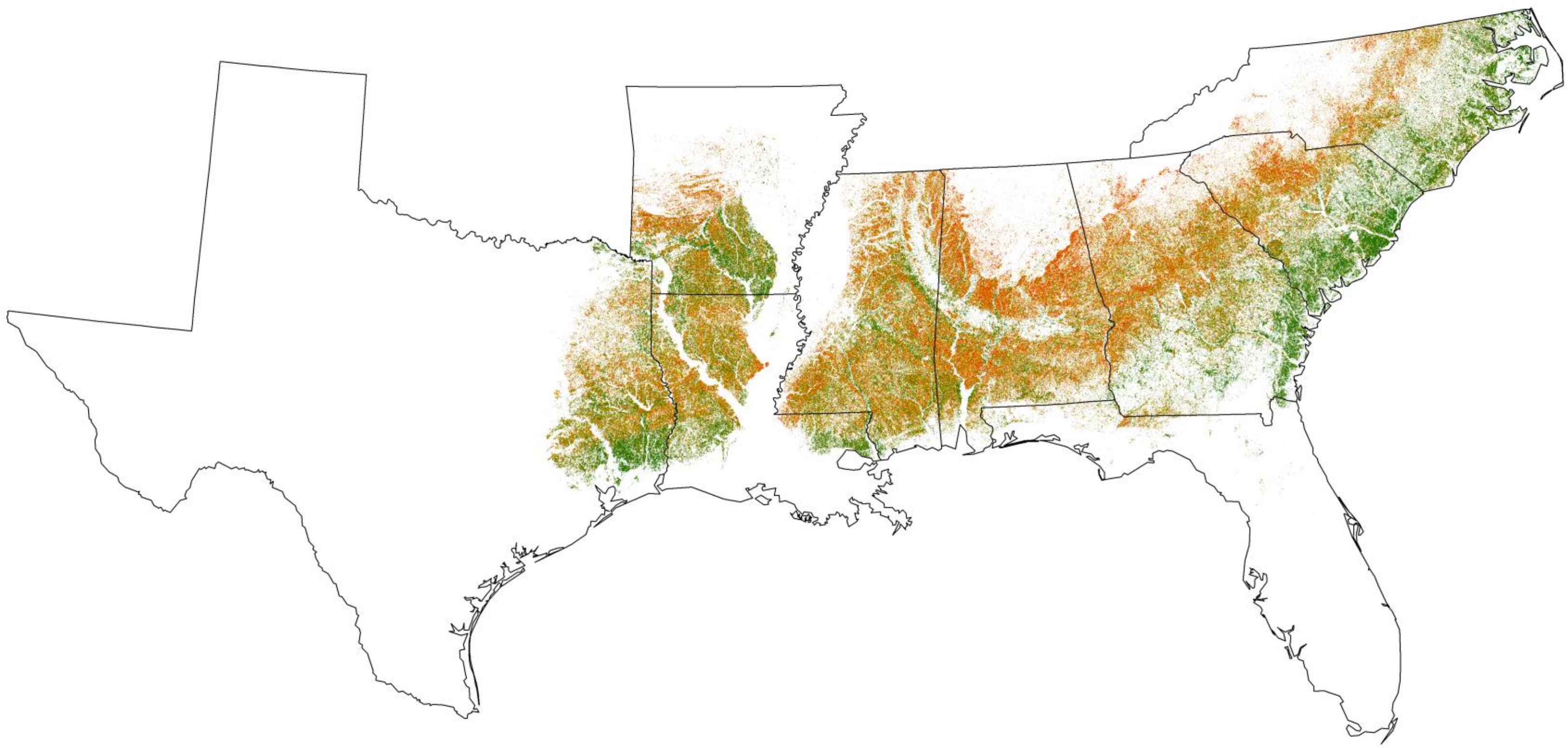

Fig. 2.42. Southeast United States Loblolly Pine Decline Risk Map.

Table 2.21. Southeast United States Loblolly Pine Decline Risk Map area calculations by class in hectares and acres.

Southeast Loblolly Pine Risk Area				
Low	Medium	High	Severe	
13,203,103	7,700,494	9,819,890	2,346,953	Hectares
32,624,420	19,027,661	24,264,646	5,799,237	Acres

2.5.3 Ground Truthing

The ground truthing of the slope and aspect ratings was processed on the slope and aspect raster files that were reclassified into categories of 1, 2, 3, and 4 based on previous research (Table 2.1). The state raster files were the last step before the Weighted Overlay was processed in ArcGIS® Arc Map™ 10 to create the Four Class Hazard Map. The +/- %1 slope tolerance (Table 2.22) and +/- 5, 10, and 15% aspect tolerance (Table 2.23) were selected to allow for errors in both field work and large area GIS computations. The range of possible slope (%) assessed was small with three of the classes falling below 15% slope and one class above 15% (Fig. 2.43). To compute the Four Class Hazard Map accuracy nearly 60,000 points, for both slope and aspect, for all 9 states were examined and processed together. Ground truthing was the percent accuracy of the Four Class Hazard Map for all eight sets of tolerance criteria (Table 2.24).

The ecological ground truthing plotted positive and negative identifications of LPD and the ophiostomatoid fungi associated with the tree mortality. A total of 243 plots were used from the Forest Health Cooperative database, spanning the southeast United States. Plots were located in Alabama, Georgia, Mississippi, and Texas. The plot risk was assessed as a percentage of the plots that fell in the various risk levels. Of the positive identifications recovered from the laboratory, 86% were in the Medium, High, and Severe Risk categories, 14% in Low Risk. The negative plots were figured on a percentage basis with 25% being in the Low Risk category. The overall ecological ground truthing accuracy of the LPD Hazard Map was 86%, calculated from the percentage of positive plots above Low Risk (Table 2.25).

There were 44 plots that did not fall on the LPD Risk Map. Therefore, the ecological ground truthing for these plots were administered on the LPD Hazard Map. These 44 misses or 18.1% of the 243 plots, speak to the accuracy of the loblolly coverage used to create the LPD Risk Map. The missed plots were comprised of enough loblolly pine that they met the 60% coverage criteria set as the coverage layer constraint.

Table 2.22. Southeast United States Four Class Hazard Map reclassified slope accuracy assessment (%).

Slope Accuracy (%)		
State	**+/- 0% Criteria**	**+/- 1% Criteria**
Alabama	54	62
Arkansas	58	65
Georgia	66	72
Louisiana	74	79
Mississippi	53	61
North Carolina	71	76
South Carolina	70	78
Texas	66	71

Table 2.23. Southeast United States Four Class Hazard Map reclassified aspect accuracy assessment (%).

Aspect Accuracy (%)				
State	**Tolerance +/- 0 degrees**	**+/- 5 degrees**	**+/- 10 degrees**	**+/- 15 degrees**
Alabama	57	60	63	66
Arkansas	65	66	67	69
Georgia	64	67	69	70
Louisiana	67	69	71	73
Mississippi	54	57	60	62
North Carolina	63	65	68	70
South Carolina	67	69	71	72
Texas	57	58	60	61

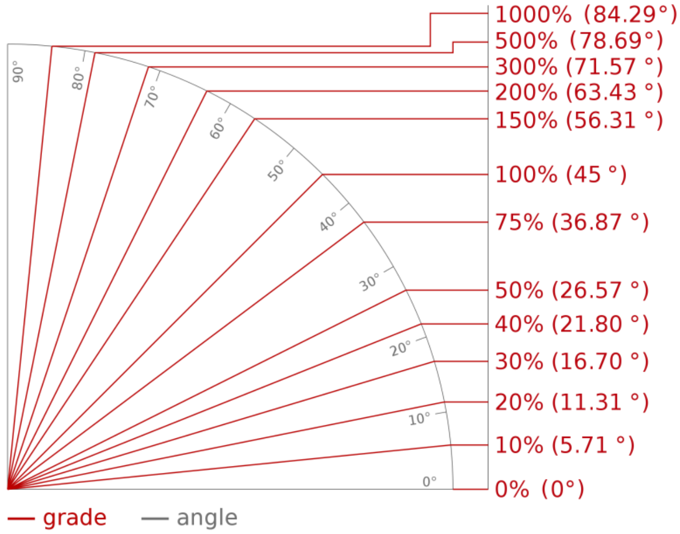

Fig. 2.43. Grade or percent slope, also in degrees, figured from rise over run

Table 2.24. Southeast United States Four Class Hazard Map accuracy assessment (%).

Map Accuracy (%)				
Slope: Y Aspect: X	**Tolerance +/- 0 degrees**	**+/- 5 degrees**	**+/- 10 degrees**	**+/- 15 degrees**
Tolerance +/- 0%	63	64	65	66
Tolerance +/- 1%	65	66	68	69

Table 2.25. Ecological ground truthing results, plots based on fungal presence or absence.

Ecological Ground Truth Plot Results				
Hazard Level	**Positive Plots**	**%**	**Negative Plots**	**%**
Low	25	14	17	25
Medium	70	40	28	41
High	52	30	19	28
Severe	28	16	4	6
Totals	175	100	68	100

2.6 Discussion and Conclusion

This development of Loblolly Pine Decline hazard and risk maps for the entire southeastern United States has the potential to save millions of dollars. The hazard map created in this study will allow land managers to better understand the potential tree mortality in their stands as they carry them to full rotations. These would include the proper planting of stems per acre, number of thinnings, and species selection are all key issues that will assist a land manger when using the map. These maps will ultimately allow land managers, both large and small, to better accomplish their objectives.

In this study the states were processed individually for reason of file size computations. This was an important note as the final Four Class Hazard Map was to span the southeast United States from Texas to North Carolina. The individual states appeared seamless as was expected because they were each a DEM mosaic processed as a whole. Once the individual maps were joined in one workspace the seamless look of the individual states was also present between states. This homogenous, interstate flow of the map indicated that the same processes were sequentially implemented for each state. The methods outlined in the work were properly followed for each state resulting in a successful joining of the individual state maps. Individuals from the United States Forest Service's Forest Health Technology Enterprise Team (FHTET) stressed this in conversations and seminars as an important aspect of large area maps.

The slope and aspect accuracy assessment numbers were derived from 60,000 ground truth points using FIA data from the United States Forest Service. This amount of ground truthing resulted in, at the high end, 70% accuracy. The tolerances for the accuracy assessment allowed less than 5% error for both slope and aspect. For 100%

slope, or 45°, only 1% error was tolerated. The highest aspect tolerance of 15° allowed approximately 4% error. These tolerances were strict for a reason, if the tolerances became too large then hazard levels could overlap and adjacent levels would have been accepted as either. This was especially true for the slope values as they were a small fraction of the possible slope values and close intervals. Even without strict error tolerances the 70% accuracy was favorable for a map covering this large of an area. The strict tolerances added to the strength of the hazard map accuracy.

To increase the robustness of the LPD hazard map ecological ground truthing was implemented using positive and negative LPD fungal plot identifications from the Forest Health Cooperative database. Using positive and negative LPD fungal points made sense to further validate the hazard map by way of an ecological assessment. An overall accuracy of 86% was figured from the percentage of positive plots that fell on Medium, High, and Severe Hazard sites (Table 2.25). While only 25% of the negatives plots fell in the Low Hazard category there was reason. The plots that fell in the Medium, High, and Severe Hazard categories were located on sites of minimal or no disturbance. The hazard of these sites can still be correct but with minimal or no disturbance the loblolly pine are at little increased risk. The lack of increased risk from minimal or no disturbance in a disturbance driven decline complex validates the negative identification of fungi from the tree roots. This high of an accuracy assessment further validates the criteria and methods from which the LPD hazard map was created.

The 44 plots that did not fall on the risk map, out of 243 plots attempted, helps to assess the accuracy of the Beta 3 loblolly pine coverage. Based on the database plots an 81.9% accuracy was derived. This extra truthing adds to the LPD risk map, giving validity to the models which created the coverage layer used as a mask to extract the risk map from the hazard map.

Future positive identifications of Loblolly Pine Decline from the Forest Health Dynamics Laboratory and Forest Health Cooperative at Auburn University will be able to be added to the map to make it more robust. Added information from topographical and ecological standpoints will enhance the LPD hazard and risk maps as management tools and continue to assist in the comprehension of this complex decline.

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