

**ANALYSIS OF FLORISTIC DIVERSITY OF *AILANTHUS ALTISSIMA* MILL.
SWINGLE (TREE OF HEAVEN) AND CO-OCCURRING NATIVE TREE
SPECIES IN NORTHEASTERN MARYLAND**

by

John C. Fry

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Geography

Winter 2010

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This manuscript is dedicated to my mother and father, for their unconditional love and understanding through the college years of my life. It is also dedicated to anyone who gains knowledge through the reading of this and builds off of the efforts in which I put forth in this thesis.

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ABSTRACT

Invasive species, along with habitat loss and fragmentation, are major factors attributed to biodiversity decline and ecosystem alteration (Vitousek, 1996; Williamson, 1996; Pimentel, 2000; Flory, 2009). *Ailanthus altissima* (Mill) Swingle, an invasive tree species, has been regarded as the “most serious threat to natural areas” both damaging and strongly invasive to native Maryland habitats (McKnight, 2004). In order to preserve biodiversity in Maryland forested habitats, biodiversity studies incorporating Geographic Information Systems (GIS) with traditional inventory methods need to be completed. The purpose of this work is to study a suburban habitat that has experienced an influx of *A. altissima*. This thesis incorporates historic aerial imagery, shapefile production and plot inventories which included identifying tree species and measuring diameter at breast height (dbh).

The study was conducted in two forested plot areas located in Fair Hill Natural Resources Management Area in northeastern Maryland. The two plot areas were similar in size, but differed in shape and proximity to transportation routes. Nineteen circles measuring 314m² in area were studied in total. A tree inventory was taken for each circle with the species, and dbh in cm recorded for all tree species greater than 5cm dbh. Other data resources included historic aerial imagery and dendrochronological data. The aerial images were used to view forest cover of image year, and used to develop GIS layers of forest edges. The data layers of the forests were used to calculate area, perimeter, and shape index. Dendrochronological data were also collected and allometric age equations were developed.

The hypotheses in this study involved examining the diversity, and the year of entry of *A. altissima*. Due to the effects of *A. altissima* and its ability to form monocultures, areas where the species are present should have values that indicate levels of lower biodiversity compared to areas where the species is not present (Hypothesis one

(H1)). Hypothesis two (H2) concerns edge effects acting on the forest plot and greater stand densities and dbh of *A. altissima* should be seen in edge circles compared to interior circles. Due to a sale from private ownership to the state of Maryland, the sale could have ushered in the species. If the entry of *A. altissima* was prior to 1975, then hypothesis three (H3) will be disproved while if the year of entry is after 1975 then H3 would be confirmed. The fourth and final hypothesis (H4) investigates shape indices and years with higher shape indices would indicate entry periods for the species. Data involved in examining this hypothesis involves shapefile examination, tree ring analysis and historic aerial imagery analysis.

It was found that H1 was confirmed by the means that circles with *A. altissima* possessed lowered diversity in general than circles without the species. It was found that *A. altissima* were contained in 12 out of the 19 circles sampled and of the 12 circles, only three circles contained less than 50% of the circle as *A. altissima*. Results in this study did not confirm that interior circles had greater biodiversity and smaller dbh than exterior circles. However, only two interior circles were present in this study, and each varied in biodiversity and age of circle. Circle C contains 68% of the total species as *A. altissima* and contains dbhs of trees estimated of having an age of 45 years while the other interior circle, circle E, contains 52% of the species *A. altissima* and has trees estimated at 24 years. It was found that the sale of ownership did not clearly support the introduction of *A. altissima*, which does not support H3. However, for plot R273 circles 8 and 9, it was estimated that year of entry of *A. altissima* was around 1980, which could support H3, but entry of trees in Gallaher Rd Plot were estimated prior to 1970. The final hypothesis, H4, was found to be validated and years with higher shape indices indicated entry time frames for *A. altissima*. For GALRD plot, a general trend of shape indices from more distended shapes to more compact shapes were seen over the imagery time

frame, while for R273 plot, shape indices fluctuated over the time period and years with higher indices saw introduction of *A. altissima* in the following years.

1 INTRODUCTION

1.1 Biological invasions and loss of biodiversity

Tens of thousands of species have spread from their natural homes with many of these species making an impact on human life (Elton, 1958). Some 50,000 exotic species have been estimated to have been introduced into the United States, with some of the introduced species being beneficial, such as introduced food crops and livestock, but some of the species cause detrimental effects to the economy and the environment (Pimentel, 2000; USBC, 1998). In the United States, it is estimated that there are over 2,000 exotic plant species present, with more than half of the species being described as noxious weeds, threatening the biodiversity of native ecosystems at different levels across the United States (U.S. Congress, 1993; Vitousek, 1996; Williamson, 1996; Sneed, 1996; Cox, 1999; Pimentel, 2000; Cadotte, 2006; Honu, 2006). The presence of these species can be blamed on the actions of our ancestors, as many of the species have been brought to the United States for a specific reason, such as medicinal use, aesthetic appeal, or wildlife conservation, but the species since have fell into ill-repute in today's environment and have caused economic and environmental problems (Hoshovsky, 1988; Vitousek, 1996, 1997; Pimentel, 2000; Honu, 2006). Pimentel (2000) estimates that invasive plants cost over \$34 (US) billion a year while estimating that all types invasive organisms grouped together costs over \$136 (US) billion (See Table 1.1). The total cost values given include economic losses and damages as well as control costs.

Table 1.1 Economic annual costs of invasive plant species in the United States (Pimentel, 2000).

Plant Type	Total Cost (Million \$)
Purple loosestrife	45
Aquatic weeds	110
Melaleuca tree	3-6
Crop weeds	26,400
Weeds in pastures	6,000
Weeds in lawns, gardens, golf courses	1,500
Total Cost (All plant species)	> 34,000

As described in Executive Order 13112 of February 3, 1999, the definition of alien species is, with respect to a particular ecosystem, any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem (Clinton, 1999). Executive Order 13112 also gives a definition for invasive species. The definition given by Executive Order 13112 for invasive species is an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health (Clinton, 1999). When describing invasive species in this thesis, the term ‘invasive species’ will refer to any species, including seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to an ecosystem and its introduction will likely cause economic or environmental harm or harm to human health.

Elton (1958) has described an ecological explosion as an “enormous increase in numbers of some kind of living organism” and has also described the chief elements that can be seen in alien species invasions. The chief factors attributed by Elton as causing ecological explosions are the historical element, the ecological feature element, and the consequence of introduction element. The historical element is traced through the writings of man and the evident species invasion is often tied to the actions of man, whether it is the purposeful introduction of the species or the accidental introduction of

the species. Based on the invading species ecological features, the extent of the species presence will be realized. These features are the biological features of the species; what method of reproduction, where the species is located, and the beneficial biological factors against native species. The consequence of introduction determines what actions are needed to control the species (*i.e.*, How much of a factor is its invasion? How much should be spent on controlling the species?).

Invasive species, as described by the Maryland Department of Natural Resources (MDDNR), can be defined as species that show a tremendous capacity for reproduction and distribution throughout its new home; and, also has a negative impact on environmental, economic, or public welfare priorities (McKnight, 2008). The state of Maryland has indicated that *A. altissima* is an invasive tree species considered to be the “most serious threat to natural areas” both damaging and strongly invasive to native Maryland habitats. (McKnight, 2004).

1.2 The *Phragmites australis* example

Invasive species can also affect humans by not having a great economic cost, but affecting certain livelihoods and recreation practices. The perennial wetland grass species, *Phragmites australis* (Cav.) Trin. ex. Steud. (referred to as *Phragmites* hereafter), has invaded wetland habitats of the United States with great success and much effort has been put forth in understanding and controlling this detrimental invader (Ailstock, *et. al*, 2001; Bachmann, 2002; Silliman and Bertness, 2004; Walker, 2005; Maheu-Giroux and de Blois, 2005; Rudrappa et al., 2009). It has been considered one of the most aggressive non-native plants encroaching upon coastal systems (Van der Putten, 1997) and is impeding on the habitat of native *Typha angustifolia* (Cattail). The invasion of this species and displacement of natural biota, such as the cattail, has caused a decrease in waterfowl habitat, affecting hunters especially in the coastal Mid-Atlantic

States. The influx has also caused a nuisance to boaters and birdwatchers due to general dislike aesthetically, and due to a decrease in bird habitat.

Phragmites australis is a perennial macrophyte grass (1.5-4.0m tall) that grows in marshes, swamps, streams, lakes, ponds, wet wastelands (Duke, 1983) and can be found along anthropogenic linear wetlands, such as road, railroad and agricultural ditches (Maheu-Giroux, de Blois, 2005). The presence of *Phragmites* can also be used as an indicator of anthropogenic indicator as it tends to prefer disturbed land (Klemas, 2007). The species is native to Eurasia and Africa but can be found throughout the world. In the United States, evidence supports that *Phragmites* did occur thousands of years ago in New England marshes (Orson, 1999), but it was not a major invader until a more resistant and aggressive genotype was introduced in the late 1800s (Saltonstall, 2002). This aggressive genotype has seeds that spread profusely being dispersed by the wind. These seeds form vigorous systems of rhizomes and stolons, which form dense stands of monotypic communities (Best *et. al.*, 1981; Hara *et. al.*, 1993; Marks *et.al.*, 1994). The species also has been identified in having the allelochemical compound gallic acid (3,4,5-trihydroxybenzoic acid) which causes root death in native susceptible plants and could be a factor in *Phragmites* forming dense monocultures (Rudrappa *et al.*, 2007).

By forming dense monocultures and having the ability to supplant native populations makes *Phragmites* a wetland management problem. This problem is complicated by the fact that anthropogenic activity often leads to promulgation of *Phragmites* as it can grow on disturbed environments. This makes control of the species difficult as controlling methods involve burning, insect introduction, and chemical application which could affect adjacent human populations. Control has also come at costly price to landowners and taxpayers. In Delaware, *Phragmites* is controlled by spraying of herbicide in late summer, and a controlled burn of the dead canes in winter, requiring three or more years to eradicate (DNREC, 2007). Costs of this application

could be addressed locally through payment by landowners, but nationally, costs could be felt by taxpayers through legislation that would authorize \$375M in developing “rapid response teams” for species control (USS, 2002; USHR, 2002; Walker, 2005).

1.3 The major problem with *Ailanthus altissima*

As is common with *Phragmites*, *A. altissima* does share negative characteristics. *Ailanthus altissima* is widely recognized by biologists and natural resource managers to not only negatively affect natural resources and native species, but also known to have a negative economic impact on agriculture and natural resources (MISC, 2003). In common with *Phragmites*, *A. altissima* shares the negative characteristics of having allelochemical properties, forming monotypic communities, and being associated with anthropogenic activity. However, with *A. altissima*, this species is not only isolated to wetland environments but to urban, suburban, and is now being introduced to previously undisturbed rural environments.

Having the ability to produce allelopathic chemicals, forming monotypic communities, and being associated with anthropogenic activity has lead *A. altissima* to be considered one of Maryland’s most serious threats to natural areas by being both damaging and strongly invasive (McKnight, 2008). The species is considered to be a threat to natural areas and damaging as it not only displaces native trees which can be economically profitable, but also has been known to damage foundations (Hu, 1979) and cause dermatitis in some cases (Muenscher, 1944). Since this species is involved with human interactions with the environment, human development into suburban and rural habitats could bring about a change in forest structure as *A. altissima* will be more likely to invade new habitats.

1.4 Purpose of study

The purpose of this work is to study a suburban habitat which has experienced an influx of *A. altissima*, and to gain knowledge on forest structure dynamics over a time period of over 70 years. A goal of this research is to help characterize a certain forested landscape type. The habitat being studied is a deciduous eastern United States suburban forest in the hinterland of major cities. This type of habitat was colonized by Europeans starting in the 17th century and changed from a wooded habitat to agricultural practices, and the eventual reversion to wooded forests starting in the early 20th century (Matlack, 1997). The reversion back to forest for this particular site contained large amounts of *A. altissima* growth in certain areas and this was partly due to human interference on these sites. As this species is a species which shows correlation to areas with human interaction and disturbance, the development of these forested suburban habitats will ultimately usher in a spread of this invasive species into areas which had been previously unaffected.

1.5 Hypotheses

The introduction of invasive alien plants may at first increase the diversity of a region, but after time, due to the physiological advantages invasive species may possess, these areas will experience a decrease in diversity. Statistical approaches such as the Simpson's index of diversity and Shannon index of biodiversity can be used to analyze areas where *A. altissima* may have caused a reduction in biodiversity (Simpson, 1949; Shannon, 1948). Research methodology used in the hypotheses is similar with recent studies regarding invasive species spread by taking into account edge-effects, and dendrochronology of *A. altissima* (Yates, 2004, Siccama, 1999). Due to the effects of *A. altissima* and its ability to form monocultures, areas where the species are present should

have values that indicate levels of lower biodiversity compared to areas where the species is not present(Hypothesis 1 (H1)).

Hypothesis two (H2) suggests edge effects acting on the forest plot with stand densities and diameter at breast height (dbh) values of *A. altissima* of the circles at the edge compared to the interior. This analysis will apply to Gallaher Road (GALRD) plot as Route 273 (R273) plot does not have interior circles due to the shape of that plot.

Tree ring data coupled with historic aerial imagery will estimate the age of each *A. altissima* sampled giving the year which Fair Hill Natural Resources Management Area (FHNRMA) experienced introduction of the species. The hypothesis is due to the sale from private ownership to state ownership in 1975 with the sale to state ownership could have ushered in the species. The sale to state ownership led to a re-growth of forested areas and a decrease in farming activities, and with the decrease in farming activities, a decrease in tending to certain forest areas happened. The hypothesis (H3) tested if the date of introduction was prior to 1975 state ownership would not have led directly to the introduction of the species.

Hypothesis four (H4) analyzes shape indices to provide evidence if years with higher shape indices would indicate an entry of *A. altissima*. This hypothesis will look at forest shape change through historic imagery, and age of *A. altissima* in each circle.

These hypotheses will provide an analysis of the presence of *A. altissima* in FHNRMA in the two study plots. Although, this study does not provide a time series in which counts of the species were conducted, it will provide an examination of the plots at the circle level in which biodiversity between the plots could be examined. An historic aerial image time series and the input of dendrochronological data will provide an estimate of the amount of time *A. altissima* has been present. Having a basis of present

levels of this invasive species could foster future studies in which species area change is the main focus.

2 *AILANTHUS ALTISSIMA*: PHYSIOLOGICAL ECOLOGY AND INVASIVE PROPENSITY

2.1 Taxonomic information

Ailanthus altissima is a member of the family *Simarubaceae*, a mostly tropical tree family that is in the order *Sapindales*. The taxonomic level with descriptors of each level's characteristics is seen in Table 2.1. In the genus *Ailanthus*, there has been described up to 30 species but the amount of species in the genus is under taxonomic debate (Davies, 1942; USDA NRCS, 2008; USDA ARS, 2008).

Table 2.1 Taxonomic characteristics of *Ailanthus altissima*.

Taxonomic Level	Scientific Name	Descriptor
Kingdom	Plantae	Plants
Subkingdom	Tracheobionta	Vascular plants
Superdivision	Spermatophyta	Seed plants
Division	Magnoliophyta	Flowering plants
Class	Magnoliopsida	Dicotyledons
Subclass	Rosidae	
Order	Sapindales	
Family	Simaroubaceae	Quassia family
Genus	<i>Ailanthus</i> Desf.	<i>Ailanthus</i>
Species	<i>Ailanthus altissima</i> (P. Mill.) Swingle	Tree of heaven

2.2 Physiology/Physical advantages

Ailanthus altissima can be identified by its odd-pinnately compound leaves in opposite or nearly opposite leaflets having a length of 20-60 centimeters (Hu, 1979). The

leaflet pairs numbering is highly variable, and can be paired from four to thirty five leaflets (Hu, 1979), but generally the leaves are paired in numbers between 13 and 27 (Zheng, 2005). The individual leaves are red-tinged, papery, ovate, and rounded at the base with two to four glandular teeth (Zheng, 2005; Hu, 1979). The leaves are 7-13cm long and 2-5.4cm wide with an upper side that is deep green and an underside that is grayish green (Zheng, 2005). The foliage of *A. altissima* can withstand smoke and dust better than most trees, and it can survive conditions of acidic soils which have been associated with mines (Munz, 1973). When the leaves are sprouting from the soil, they are yellowish-green and vary in size and vary in number of divisions; from unifoliolate, trifoliolate, pentafoliolate, or pinnately compounded (Hu, 1979). The leaf structure of *A. altissima* can be seen in Figure 2.1.

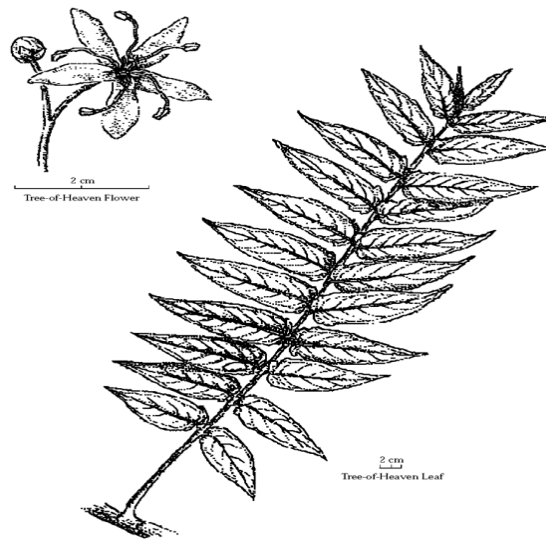


Figure 2.1 *Ailanthus altissima* leaves and flower (Bugwood Network, 2003).

Ailanthus altissima is a deciduous tree of about 20m in height (Zheng, 2005), but can reach heights of 27-30m (Kowarik, 2007). The tree can survive past 100 years and by producing clonal offspring the individuals can be considered nearly immortal (Kowarik, 2007). The individual stems of *A. altissima* only live a relatively short time (30-50 years) but the species' ability to sprout and seed prolifically allows for the formation of dense thickets of stems which could persist for a period of time (Burch, 2003). The tree can produce viable seeds at an age of 2-3 years while a single tree can produce hundreds of thousands of winged seeds per year (Miller, 1990; Wardle 2006). Dense thicket formation is aided by *A. altissima*'s ability to reproduce vegetatively through root suckers (Miller, 1990, Kowarik, 2007). *Ailanthus altissima* has also developed a variable root structure which has permitted the species to be successful in different soil types, as seen in Figure 2.2

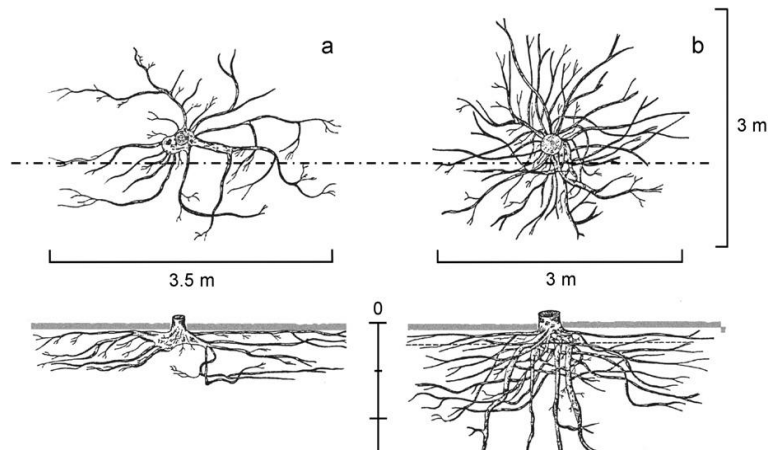


Figure 2.2 Variable root structure in different soil types; a) 21-year-old tree b) 25-year-old tree (Taken from Kowarik, 2007 (Adapted from Farago, 1964)).

It has been thought that *A. altissima* could not compete with native species in the interior of the forest, usually having higher numbers along the edges of forests. This could be due to the species responding to edge-effects, a phenomenon where the edge experiences different abiotic factors than the interior, or the numbers could be higher at edge due to it being the first area in which the invasive species encounters (Honu, 2006, Matlack 1993). Although, rather intolerant of shade, studies have shown that it is a gap-obligate species, taking advantage of canopy gaps in the interior of the forest and becoming established in these gaps (Kowarik, 1995; Knapp and Canham, 2000). Regardless of where *A. altissima* becomes established, thickets will normally develop due to the species physiology.

The thickets of stems formed by *A. altissima* compete with other pioneer species and are aided by *A. altissima*'s allelopathic compounds which are found in the leaves and roots of the species (Mergen, 1959; Heisey, 1996; Burch, 2003). The chemicals are found to be toxic to numerous woody and herbaceous species (Lawrence,

et. al., 1991; Heisey, 1996). Invasive species that have allelopathic compounds not only affect nearby organisms, but alter key ecosystem-level processes as well as structures of plant communities (Wardle *et al.*, 1998; Call, 2003).

It has been found that *A. altissima* can adversely affect humans directly. Dermatitis has been reported in some cases where humans have come in contact with the leaves of *A. altissima* (Muenscher, 1944). Also, leaf pollen has been known to cause allergies in certain individuals (Blumstein, 1943). Its roots can frequently enter cisterns and wells which can give an unpleasant taste to the water (Davies, 1942; Hu, 1979) as well as stomach pains and upsets (Mergen, 1959). Copious amounts of leaf stems shedding from the tree cause a difficulty in cleaning streets and gutters, as well (Feret, 1985). The tree has no or little commercial value as the wood is light, soft, weak, and open grained, which could be used for cabinet making, wooden ware, charcoal, or pulpwood, but no large planting has been used for commercial use (Davies, 1942).

Not only affecting humans, *A. altissima* also affects animal's feeding patterns. It was found by Apsley and McCarthy (2004) that the species is unpalatable to white-tail deer. Also, the presence of *A. altissima* can also deter cows from eating grass near their stalks (Pammel, 1911). This could be a factor in farms which are experiencing widespread *A. altissima* intrusion or farms which are in proximity to roadways which act as travel vectors for *A. altissima* seeds.

2.2.1 Allelochemicals

It has been found by Mergen (1959) that the allelochemicals found in *A. altissima* are "extremely toxic" to 58% of the species involved in the study. The study involved applying *A. altissima*'s extract to a tree species which had been cut on its bark down to the pith. It was found of those slash-pine and hardwoods treated, the treated tree

experienced noticeable wounds in the xylem and veins of the leaves above the cut, and the leaves wilted more rapidly when the plants were growing actively (Mergen, 1959). Mergen (1959) deduced the pathway in which the allelochemicals spread was through the transpiration stream, as wilting and damage occurred more rapidly when the conditions favored transpiration. The species *Pinus strobus* L. (eastern white pine) and *Fraxinus americana* L. (white ash) were unaffected by *A. altissima*'s extract and *Cornus florida* L. (flowering dogwood) and *Liriodendron tulipifera* L. (yellow poplar) had only some seedlings that were slightly affected (Mergen, 1959).

Allelopathic chemical application to other species reported by Heisey (1990 A, B) states that “this experiment provides strong evidence that toxins are released from *A. altissima* roots into the soil.” The allelopathic compound found in the wood, leaflets, bark and root bark is called ailanthone (N=372) (viewed in Figure 2.3), in which the highest concentration of ailanthone occurs in the root bark (Heisey, 1990 A, B; Heisey, 1996). Pulverized root bark and leaflets lose their toxic allelopathic chemicals in seven days or less, indicating that allelopathic chemicals from these origins decompose rapidly in the soil (Heisey, 1990). Stemflow does not add appreciable amounts of allelopathic chemicals to the soil, but the roots of *A. altissima* provide continuous release of the allelochem into the soil (Heisey, 1990).

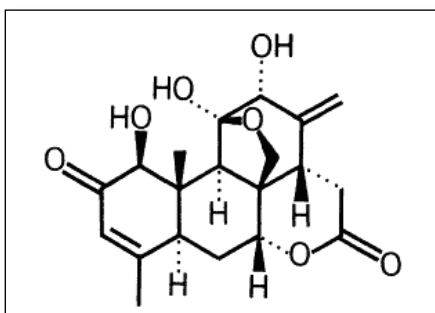


Figure 2.3 The chemical structure of Ailanthone (Heisey, 1996).

2.3 Areas of growth

The species *A. altissima* has a native range of eastern China, but since introduction to Europe in the 1740s, the species has proliferated into a secondary range of temperate climates worldwide.

2.3.1 Native range

The genus *Ailanthus* is native to Southeast/Central Asia, the East Indies, and Northern Australia (Davies, 1942). Although most of the species in *Ailanthus* are endemic to Asia and Australia, the species *A. altissima*, a native of northern and central China, has become naturalized in North America since introduction in the late 18th century (Davies, 1942). Figure 2.4 shows the native area of the species, with variant subspecies also shown on the map (black boundary/white circles). *Ailanthus altissima* is shown in the dark gray and can be seen in most of the eastern part of China. This area of China covers areas that experience a humid subtropical/tropical climate while areas in the secondary range experience generally colder climates. As seen in Figure 2.5, the native range of *A. altissima* covers hardiness zones 7 to 9, while *A. altissima* in the secondary

range covers a wider variety of hardiness types (Figure 2.6). Compared to the native range populations of Asia, North American populations are considerably different on 11 of 14 growth traits with the North American trees being taller, allocating less biomass to roots than stems, and having greater leaf areas (Feret and Bryant, 1974).

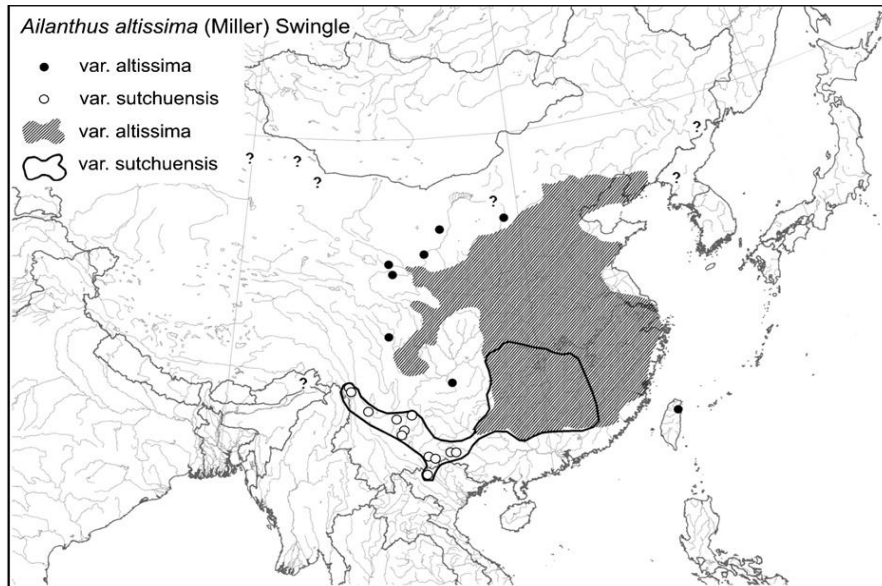


Figure 2.4 Native area of *Ailanthus altissima* and related species *Ailanthus sutchuensis* (Kowarik, 2007).

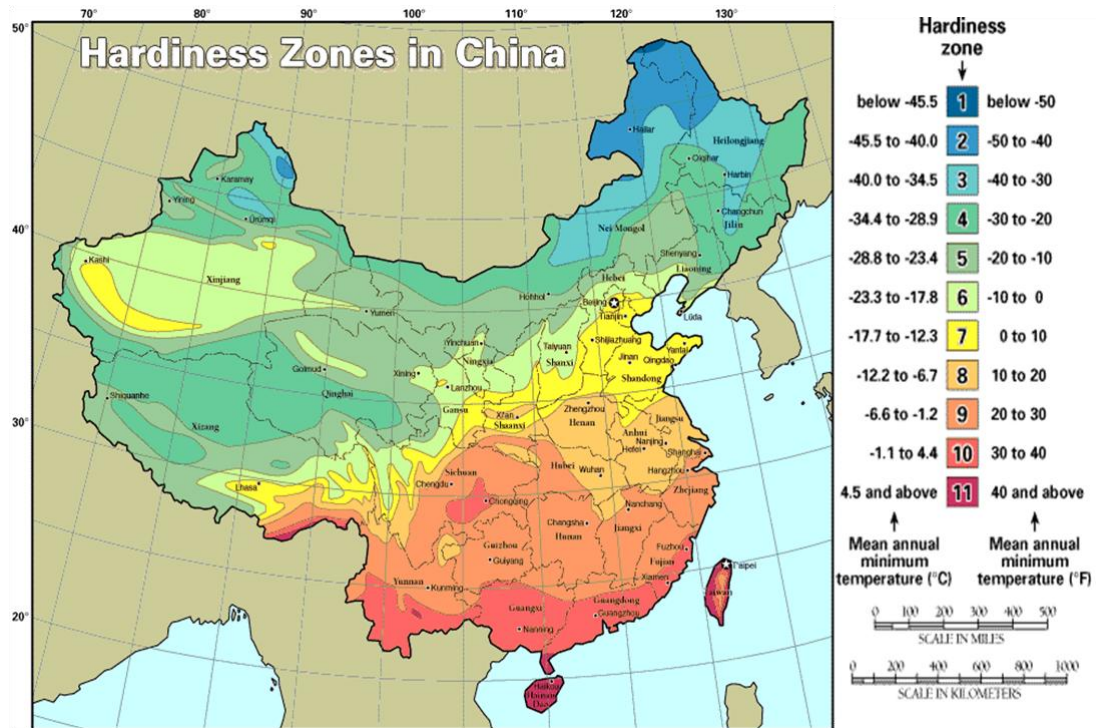


Figure 2.5 Hardiness zones in China (Widrechner, 2009).

2.3.2 Secondary range

Out of its native range of China, *altissima* has developed a secondary range, consisting of all the continents except Antarctica (Figure 2.6). When comparing the native range and the secondary range, *A. altissima* in its native range is not weedy and rarely occurs within city limits which are not in accord to the secondary range where it has been termed an urban or a plant associated with disturbed environments (Hu, 1979). In China, it grows in villages or in suburbs as isolated trees with straight, tall boles and rather flat crowns, as compared to areas in the secondary range, such as the United States, where the tree is usually found in disturbed areas, urban environments and along transportation routes (Hu, 1979). Hu (1979) has stated that the difference in locations and tree structure in both the ranges is dependent on differences in ethnobotany of the two

ranges. In China, the tree is revered for its cultural and medicinal significance, while in the secondary range, it is not usually cared for, making the tree grow into thickets if not tended.

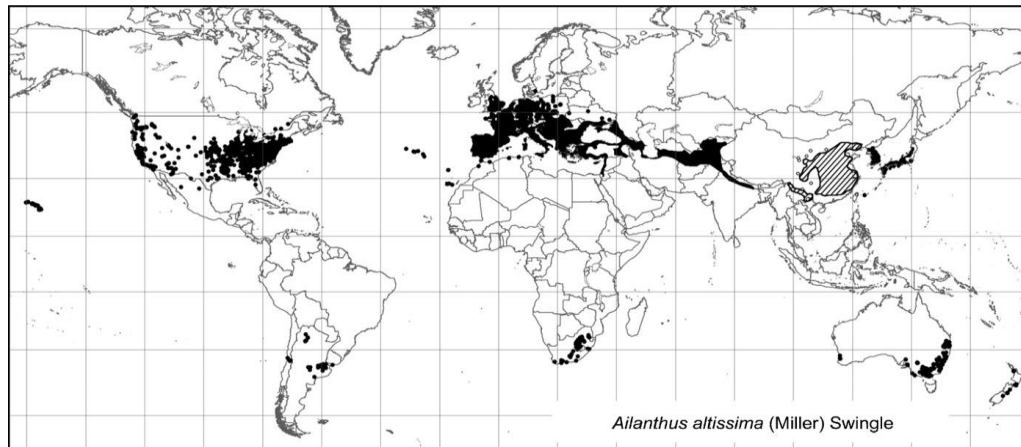


Figure 2.6 Native range and secondary range of *A. altissima*. Native range is seen as hatched marks and is situated in Eastern China. Black dots indicate areas where the species has been introduced (Kowarik, 2007).

As seen in Figure 2.6, *A. altissima* has a native range of eastern China and a secondary range which has developed due to species introduction. The species was introduced to Europe in the 1740s and then outward from Europe to temperate climates worldwide. From Europe, the introduction to North America has been well documented.

2.4 History of invasion

From its native range in China, *A. altissima* seeds were sent to Europe in the mid 18th century, and from the introduction in Europe, the seeds were subsequently brought to the United States. The spread of *A. altissima* in the United States can be examined through two modes of introduction. The first mode of introduction can be attributed to eastern American nursery owners in the late 18th century wanting to bring in

a tree that was in popularity in Europe (Guerrin-Manville, 1862; Davies, 1942; Hu, 1979; Feret, 1985;). The other mode of introduction was in California, where Chinese workers brought the tree due to its revered cultural significance (Hoshovsky, 1988).

2.4.1 Introduction to Europe

The introduction of *A. altissima* to Europe in 1751 led to the introduction of the species to North America. In 1751, Father Pierre d’Incarville, a missionary to China, sent back fruits of *A. altissima* in exchange with the Royal Society of native European plants (Guerrin-Manville, 1862; Davies, 1942; Hu, 1979; Feret, 1985;). A reason for import to Europe was that Father d’Incarville thought the tree was *Toxicodendron vernicifluum* (Stokes) F. Barkley (lacquer tree or varnish tree), a tree known for its sap which can be polymerized to form lacquer for use on tableware and other surfaces (Hoshovsky, 1988). Although not *T. vernicifluum*, early records indicate that its reception in Europe and North America was very favorable, possible due to its tropical looking foliage. Due to its tropical appearance, it was widely distributed by nurseries for general planting (Davies, 1942). When *A. altissima* was introduced to Europe it was planted on roadsides, in public parks, and on estates.

The tree was used as a food source for *Bombyx cynthia* (silkworm) which produced a silk superior in quality than that produced on the mulberry tree (*Morus* L.) (Guerrin-Manville, 1862; Feret, 1985). The production of silk led to cultivated *A. altissima* plants throughout the European continent and England in the middle of the 19th century (Guerrin-Manville, 1862; Feret, 1985; Howard 2004).

2.4.2 Introduction to North America

Since the introduction of *altissima* into North American happened via the east and west coasts, there are also differences between California populations and

populations in the eastern United States. In general, and not related to climatic or edaphic features, California populations grow taller than eastern populations (Kowarik, 2007). Compared to the native range populations of Asia, North American populations are considerably different on 11 of 14 growth traits, with the North American trees being taller, allocating less biomass to roots than stems, and having greater leaf areas (Feret, 1974). Since the introduction of *Altissima* into North America in the late 1700's, there have been significant alterations of genetic content, with the influencing factor possibly being the plants with the best growth performance and propagation (Feret, 1974). This change in genetic content, with having the best adapted plant passing its genes, could explain why growth differences are not influenced by climate or edaphic features, but genetic variance.

2.4.2.1 Introduction to eastern United States

The species was introduced into eastern North America on two recorded instances, in 1784 in Philadelphia by William Hamilton, and in 1820 by the nurseryman, William Prince, of Long Island (Davies 1942; Hu, 1979). The Prince and Parsons Nurseries of Flushing, Long Island, New York, helped distribute the species in the New York region, and soon popularity of the species spread to other urban centers such as Boston and Baltimore, due to the species ability to tolerate the dirt and pollution of these cities (Hu, 1979). The conditions were favorable for the species, allowing it to spread rapidly along transportation routes, such as roadways, highway embankments, railroad tracks, sidewalks, utility right-of-ways, and also along buildings, fences and waste places such as abandoned lots and mines (Davies, 1942; Munz, 1973, Hu, 1979). It has been noted that as early as 1888 *A. altissima* had escaped ornamental garden planting and had become naturalized in Virginia, where Curtiss (1888) noted that the species “runs wild in Virginia and neighboring states.”

There have been some cases in the United States where the species had undergone afforestation practices which could have led to the proliferation of the species. In *Garden and Forest*, C.S. Sargent, the director of the Arnold Arboretum, describes *A. altissima* in high regard, as being a tree with great value in lumber as a fuel source, being able to grow in poor soil, and being hardy enough to sustain the drought and dust of the city (Sargent, 1888). Having the ability to grow in marginal areas with poor soils may have been attractive to policy makers interested in reforestation in the latter 1800's. *Ailanthus altissima* thrived in areas that had experienced widespread deforestation due to agricultural practices since the beginning of European involvement in the eastern United States (Jones, 1926; Matlack, 1997). However, planting the tree for afforestation purposes produced some detrimental results. As reported by Hu (1979), afforestation has brought the knowledge that *A. altissima* is a fierce competitor with native species, and not suitable for planting in drier areas, such as the Great Plains states. Hu also indicated that older trees (older than 30 years) begin to deteriorate due to the brittleness of the wood, causing the tree to have deformed crowns when the branches break in storms and high wind. Primarily planted first as an ornamental, *A. altissima* had underwent afforestation, but the extent of the afforestation is not known and how much this attributed to the United States range is not known.

2.4.2.2 Introduction to western United States

It is believed that the introduction of *altissima* to the western United States was due to the input of Chinese immigrant workers in the late 1800's and the reverence they had for the tree (Ferret 1985, Hoshovsky, 1988). *Ailanthus altissima* had widespread use as a Chinese folk medicine, having uses as astringent, antispasmodic (suppresses spasms), anthelmintic (expels parasitic worms), parasiticide and narcotic, as well as specific applications in treating diarrhea, dysentery, heat ailments, epilepsy, asthma,

seborrhea and scabies (Moussalli, 1939; Hu, 1979; Howard, 2004). Traditional Chinese medicine has also indicated that different physiological features of *A. altissima* could be used to treat many symptoms. The roots were used to treat mental illness, the leaves used to treat boils, abscesses, and baldness, the bark used to treat a number of intestinal ailments and prolapsed rectum, while the fruits used as a haemostatic to treat blood in the feces and urine (Hu, 1979).

While having various medicinal uses, it also has cultural significance in China since history had been recorded in that country. *Ailanthus altissima* became known to the Chinese people as “spring tree,” due to the enlargement of buds forecasting the return of warm weather (Hu, 1979). The enlargement of the buds is usually later for *A. altissima* compared to other deciduous trees, and their appearance in spring was a sign of hope in the next harvest in traditional Chinese culture. Hu (1979) talks about the cultural significance of the species by stating the rhyme from rural northern China-“As the unfolding buds of ailanthus appear, the helpless white eyes of the starving people turn clear.” Since this tree had been used for remedies and cultural significance to the Chinese people, it had been brought to America’s west coast by the Chinese workers in the gold rush and railroad eras, and began to spread across the Californian terrain (Hoshovsky, 1988). In present day California, *A. altissima* is found in cismontane regions and found near old dwellings and mining settlements (Munz and Keck, 1973; Hoshovsky, 1988). Robbins et al. (1951) described locations of establishment in California in the counties of Solano and Marin, and in the areas of Pleasants Valley, Berkeley, Vacaville, Petaluma, San Adreas, Angel’s Camp, Columbia, and other areas in the Sacramento Valley. These locations are areas surrounding the cities of Sacramento, San Francisco, and Oakland, California. The *A. altissima* distribution in Figure 2.7 indicates that the range supplied by Gilman and Watson (2006) does not cover the regions above. The range supplied by Gilman and Watson (2006) is mimicking the United States Department of Agriculture’s

(USDA) plant hardiness zones in which the species can suitably grow. The hardiness zones in which *A. altissima* can grow suitable are plant zones 5A through 8A (Gilman, 2006).

2.5 Presence of *Ailanthus altissima* and control policy

The range and state legislative classification of *A. altissima* appears in Figure 2.7. The gray states indicate those states where there is no recorded presence based on findings of the USDA National Resources Conservation Services' PLANTS database. Those states colored green indicate where there is a recorded presence, but the plant is not considered invasive, based on the findings of the WeedUS database (Swearingen, 2006). The red states are those in which the presence of *A. altissima* is considered invasive based on the WeedUS database. The individual state's considering the species as invasive follows the definition of invasive species given by Executive Order 13112, where the introduction of the species will likely cause economic or environmental harm or harm to human health. The range in Figure 2.7 indicates the suitable USDA hardiness zones in which the tree is most likely to grow (Gilman, 2006).

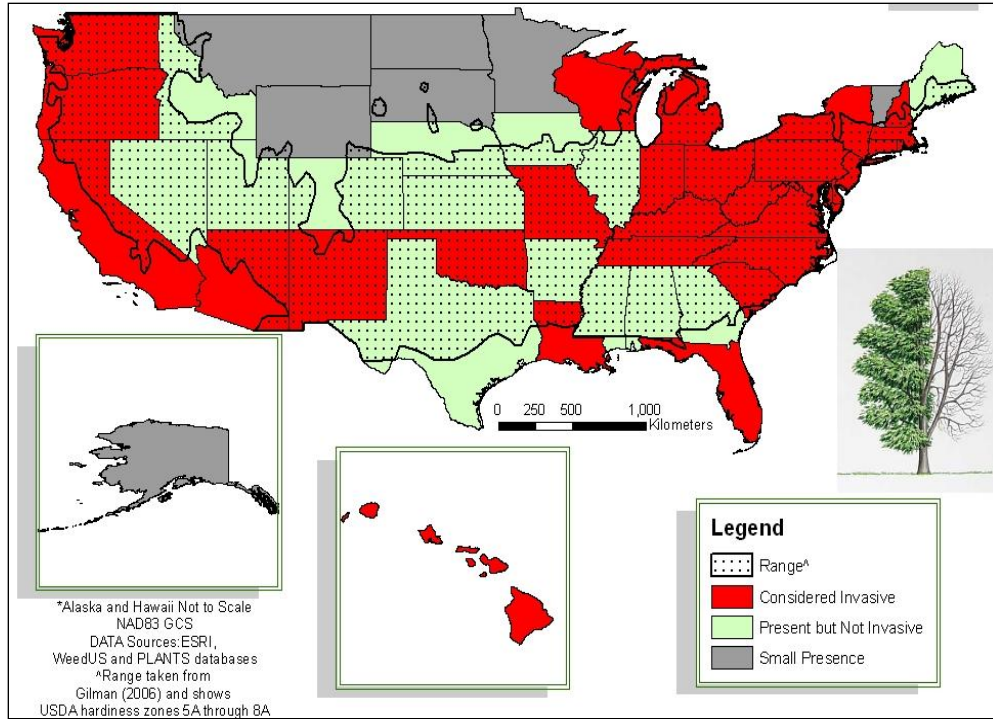


Figure 2.7 *Ailanthus altissima* in the United States.

The distribution and regulation of *A. altissima* in Figure 2.7 is a guideline and descriptor of where the tree could grow and what states have considered the species invasive. The PLANTS database gives the *A. altissima*'s presence at the county level, and the database shows that all states (with the exception of Ohio) do not have all the counties having *A. altissima* introduced. The county level distribution maps do not show many spatial trends, as the counties with *A. altissima* are sporadically distributed in most states. However, a spatial trend could be seen in the state of New York, as the counties in the eastern portion of the state are concentrated in a linear north-south track in which Interstate 87 (New York State Thruway) is located, and the presence of *A. altissima* in these counties could be a result of the proximity to this highway route (Figure 2.8).

promise in being able to control a targeted species and not affecting other tree species. The use of the two weevils is under investigation by laboratory tests at Virginia Tech University and investigation at host ranges in China and in the United States (Ding *et al.*, 2006b).

Webster (2006) stated that having an effective control of woody exotic species can be expensive and a long-term effort that usually requires a combination of mechanical treatments, targeted herbicidal applications, and continued monitoring. It has been found that controlling the species by means of cutting and mechanical means is very difficult and the best means of control is with systematic herbicidal applications. Manual cuttings can actually stimulate resprouting and increase overall stand density (Burch, 2003). Manual cutting and mechanical control methods of *A. altissima* include hand pulling of young seedlings, cutting or chopping stems, girdling the stems, and hand digging the rootstocks (Hoshovsky, 1995). However, it is suggested that these types of control be avoided as the species tends to thrive after these measure are conducted.

Control of *A. altissima* in oak forests by thinning and burning has been studied by Hutchinson *et al.* (2004). The study by Hutchinson (2004) involved the counting of pre treatment forest numbers of *A. altissima* and treating the study plot by either burning, thinning, or burning and thinning in combination. The findings were that the combination of thinning and burning opened the canopy of the forest, fostering the growth of *A. altissima* species, and causing them to proliferate. This study illustrates the fact that forest sustainability and restoration techniques could cause the proliferation of *A. altissima* if careful techniques are not taken.

Herbicidal applications can control woody plants and can target the spread of *A. altissima*. However, with any type of herbicidal application, the desired results may not be found due to the correct species not being targeted or due to excess dieback of non-targeted species. In regards to herbicidal control of *A. altissima*, herbicidal

application generally has better control of the species spread than manual control, however large-scale and long-term herbicidal application is expensive and time consuming (Burch, 2003, Ding, 2006b). It was found by Burch (2003) that optimal control of *A. altissima* spread was achieved by low volume herbicides treatment. The herbicide combination of Garlon 4® (triclopyr ester) and Tordon K® (picloram salt) proved to be the best way to control *A. altissima* spread after two years after initial treatment. These basal treatments were tested in comparison with manual cutting.

2.7 Future use for *Ailanthus altissima*

When *A. altissima* is present in large sizes and abundance and cannot be sufficiently eradicated, research has been conducted in the use of its wood products in order to profit off of the species. Traditionally, the species has been used in healthcare from use as astringent to use as a narcotic, but in 21st century America, the tree is not typically used as a natural remedy. Use of the tree for its wood in America has not really been realized as the tree is not used or planted for commercial lumber. However, presence of the species in large amounts could foster markets as its timber could be used to make cabinetry, furniture, cellulose manufacture, pulp, and woodwork. The State of Virginia has indicated that *A. altissima* is present as the state's most abundant exotic invasive species, having an estimated timber volume of 48,241,041 ft³ (largest timber volume is *Liriodendron tulipifera* at 4,628,662,842 ft³) or 0.2% of all timber species (Becker, 2006a). With this volume, the State of Virginia has conducted research in the feasibility of the tree's use as lumber and charcoal, and found that some of the wood was warped when the wood was being sawn, especially in pieces sawn near the heartwood, but most of the wood was reported to be defect free (Becker, 2006b). Future study on the feasibility of the tree's use must be conducted, as the species should only be used for

lumber products in areas where the species is prevalent, and the tree should not be planted due to the risk of escape into habitats containing native species.

3 STUDY AREA/METHODS

3.1 Study area

The study site is located in 2,272 hectare (22.72 km²), Fair Hill Natural Resource Management Area (FHNRMA) in northeastern Maryland (39° 43' N, 75° 50' W). As seen in Figure 3.1, FHNRMA borders Pennsylvania on the north and the eastern boundary is one half-mile from the Delaware border.

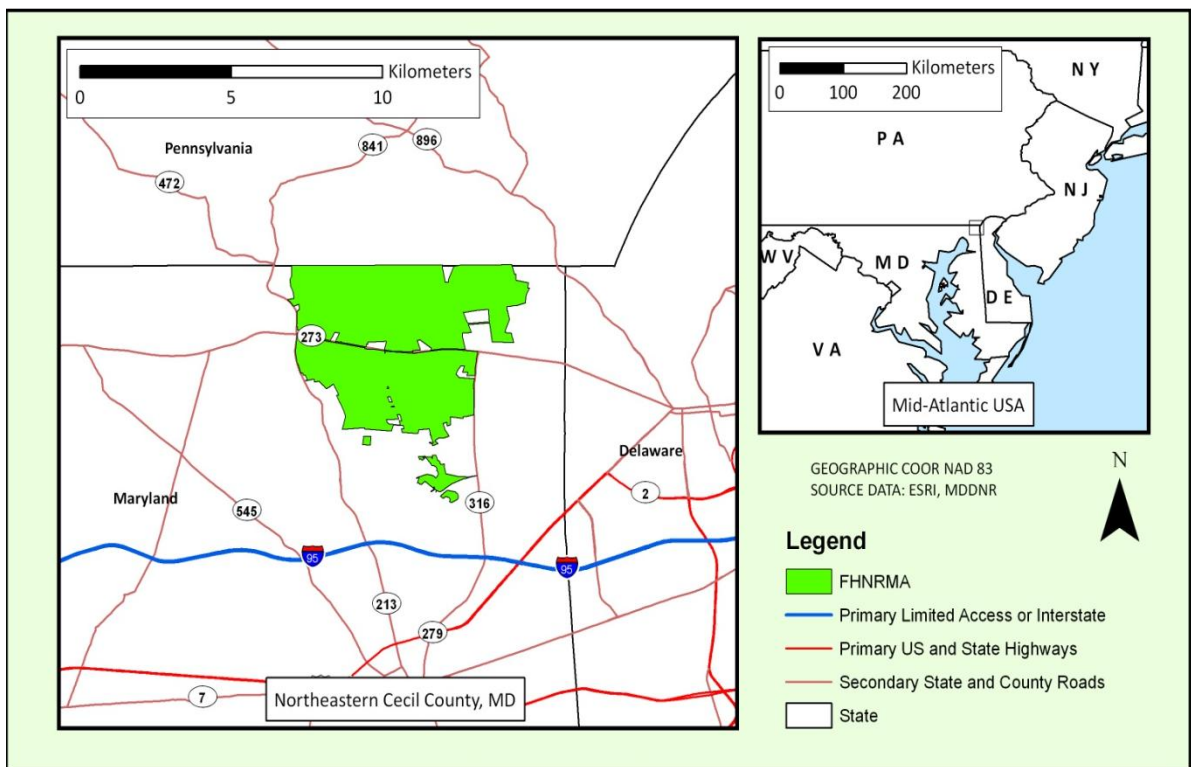
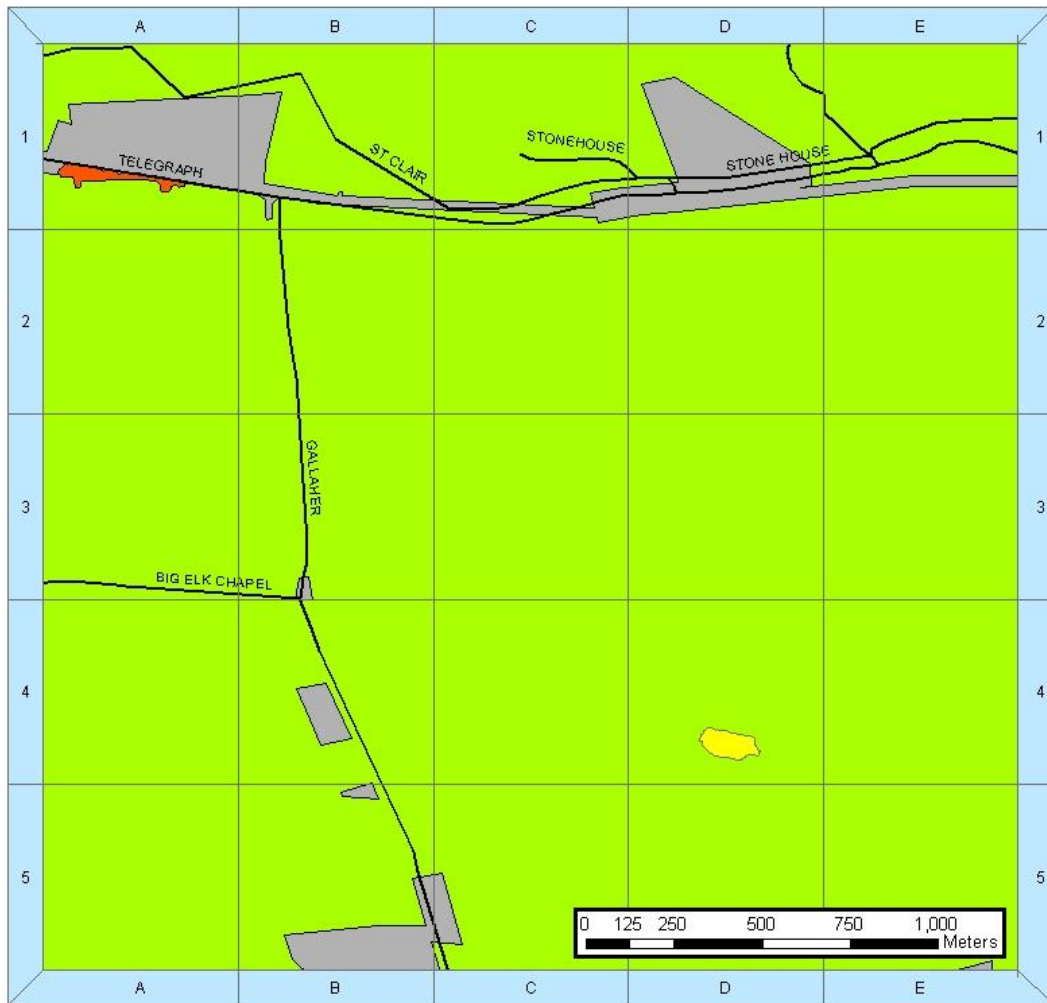


Figure 3.1 Study area location in Cecil County, MD, USA.

In Figure 3.2, the position of each plot in FHNRMA is shown. The Route 273 (R273) plot is found at location A-1 in Figure 3.2 just south of Telegraph road (Maryland Route 273). Gallaher Road (GALRD) plot located in cell D-4 (Figure 3.2) is situated

about 1km east of Gallaher Road. There is a farm road extending from the intersection of Big Elk Chapel Road and Gallaher Road in cell B-3 which allows for access to GALRD plot. The R273 plot is located off of Maryland Route 273, a two lane highway extending from Rising Sun, MD in the west to the Delaware state line, where the road becomes Delaware State Route 273. In Maryland, it is the main east-west route for the rural communities of Rising Sun, MD, and Calvert, MD. The GALRD plot is located south of farm access road inside FHRMA. The road is made of gravel and dirt and extends from the intersection of Big Elk Chapel road and Gallaher Road in the west to across Big Elk Creek, to its termination east of the creek. The traffic on this road consists of hikers, bikers, horse, and the occasional motor vehicle.



Legend

- Roads
- Gallaher Rd Plot
- Route 273 Plot
- Fair Hill NRMA
- Cecil County, MD
- Pennsylvania

NAD 83 GCS



Plot
Reference
Map
Fair Hill NRMA

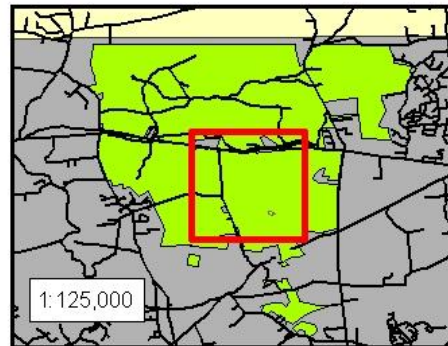


Figure 3.2 Plot area reference map of Fair Hill NRMA.

3.2 Climate

The annual average temperature is 12.2°C with an annual mean total precipitation of 122cm as described by the Office of the Maryland State Climatologist, Department of Atmospheric and Oceanic Science, at Conowingo Dam, Maryland. The climate has four distinct seasons and has fairly even precipitation throughout the year. The climate can be classified as Koppen Dfa. Warm summers, cold winters and even levels of precipitation throughout the year are typical of the Koppen Dfa climate.

3.3 Soils

The soils of FHNRMA are mainly composed of the Glenelg and Manor series (Figure 3.3). Both of the soil types are native to the uplands of Piedmont region of the United States. In Figure 3.3(left panel), the red shape indicates R273 plot. The primary soils of the plot are GeB2, GeA and GeC2 (USDA, 1973). These soil types are part of the Glenelg series. GALRD plot contains the soil MIC2 which is part of the Manor series. This specific soil type is at risk of erosion if the soil is to be worked (USDA, 1973).

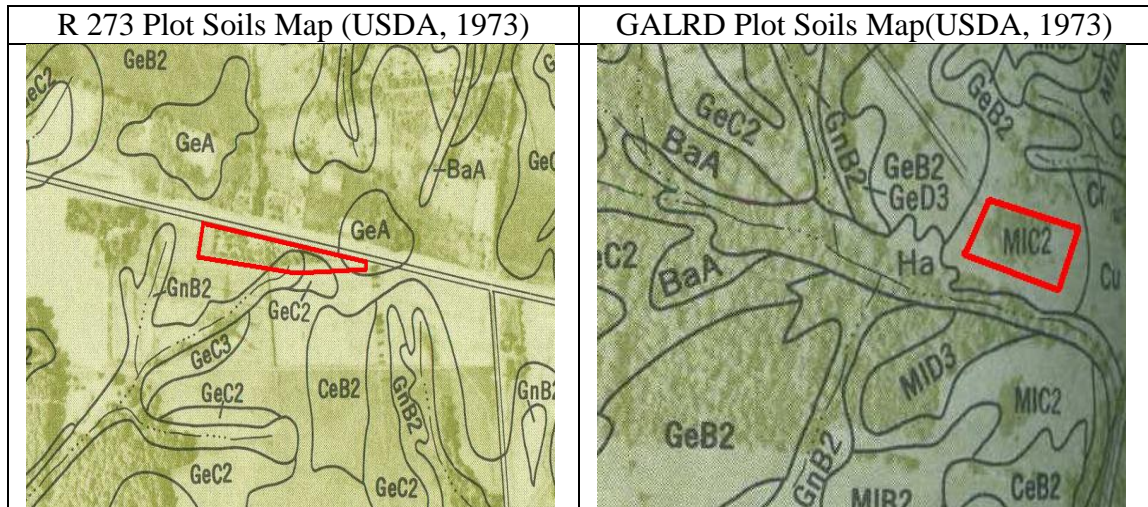


Figure 3.3 Soils maps of study area plots taken from USDA soil map. Red shapes indicate general area of study plots.

Glenelg series has the characteristics of being deep, well drained, nearly level to moderately steep soils while the Manor series consists of gently sloping to moderately steep, well drained to excessively drained soils of upland regions (USDA, 1973). Both of the soils have hardwoods as the major vegetation and the soils are important to farming because of warming temperatures in early spring and both being workable. It is unknown whether one soil type promotes *A. altissima* proliferation over the other. Both soils are well suited for agricultural activities with moderate to high soil moisture capacity and the ability to support *A. altissima*. This is confirmed by its presence in both plots in this study.

3.4 Previous Land Use

The proximity of FHNRM to the large urban centers of Wilmington, DE, Philadelphia, PA, and Baltimore, MD is of significant importance to the history of the forest tracts at FHNRM. Previous to the arrival of Europeans, the study area was covered by a mixed-deciduous forest with the dominate species being oaks, hickories,

and American chestnut (*Castanea dentata* Marsh Bork.; Braun, 1950). During the colonization period and the increased growth of three urban centers, many of the forests in the hinterlands were cleared for wheat production, fuelwood, or for the construction of those cities (Jones, 1926; Coleman *et al.*, 1984). By 1800, the hinterland of Wilmington, DE and Philadelphia, PA was markedly bare of forest, resulting in no examples of old-growth, pre-European forests surviving at the end of the twentieth century (Williams, 1989; Matlack, 1997). Forest re-growth was not experienced in the Wilmington, DE hinterland as the region had fertile land for agriculture, and the land was not reverting back to forest which was atypical of the rest of the eastern United States at the time period around 1930 (Baker, 1931). The mid-twentieth century saw the change from predominantly agricultural land use to rapid suburbanization (Matlack 1997).

The area surrounding FHNRM was known to be settled by the Susquehannocks and Delaware tribes before the arrival of Europeans (Fair Hill Environmental Foundation Inc (FHEFI), 2007). European settlement transformed the region through the years 1650-1900 causing much of the farm settlement patterns to be in accord with the traditions of the English countryside (FHEFI, 2007). William du Pont Jr. bought the Fair Hill area in 1926 and continued to amalgamate the surrounding farms into the property until sale to the state of Maryland in 1975. William du Pont Jr. built a racetrack, numerous bridges over the Big Elk Creek, horse trails for fox chasing, and fenced in a major portion of the property for cattle farming activities. Since the sale of the property to the state in 1975, there has been a continuance in equestrian activities, as well as the public recreation activities of hiking, angling, mountain biking, hunting, and bird watching.

Maryland Department of Natural Resources (MDDNR) now administers the property as a Natural Resource Management Area. The land is used primarily for public

recreation. The MDDNR (2000) states the “stewardship goals are ecosystem based development strategies that take account for:

1. Altering the management of certain hayfields to coincide with grassland bird nesting seasons;
2. Increasing interior forest habitat through afforestation;
3. Managing deer herds to protect forest habitat;
4. Eliminating exotic invasive species;
5. Conducting soil tests on every hayfield to gauge accurate nutrient requirements.”

The MDDNR specifically states its stewardship goals pertaining to FHRMA are eliminating exotic species. Based on field examinations, exotic invasive species are present in FHRMA and cause a threat to the biodiversity of the region. Not only *A. altissima*, but the exotic invasive tree species *Paulownia tomentosa* (Thunb.) Sieb. & Zucc. Ex Steud. (Princess-tree), and *Rosa multiflora* Thunb. (Multiflora Rose) are present and causing a change in forest biodiversity by forming monocultures in certain areas (personal observation).

This study will provide better knowledge of the spread of *A. altissima* in this region and help FHRMA and MDDNR develop future tactics to stop its spread. Moreover, the study will build off the base of knowledge of *A. altissima* spread and help to gather insight on what land use practices enable the species to spread.

3.5 Specific study plots

Fair Hill Natural Resource and Management Area was chosen as a study site because it offers an area of past agricultural use not built into residential and commercial developments. It also contains forested ecosystems which have experienced an increase of forested area since the 1930s with the presence of *A. altissima*, a species known for

growing in disturbed and urban environments. Since most of the mid-Atlantic region of the United States has experienced a landscape transformation from agricultural use to either residential/commercial or forest, results found in FHNRMA can be projected elsewhere. Plot inventories were taken at each of the two plots with the sampling area of 314m². Sampling was conducted as circles with radius of 10m. The sampling of R273 plot was conducted parallel to Maryland Route 273 with a 10m non-sampled region between each of the nine sampled circle areas along the transect. The sampling method for plots R273 and GALRD are shown in Figure 3.4 and Figure 3.5.



Figure 3.4 Route 273 Plot transect locations.

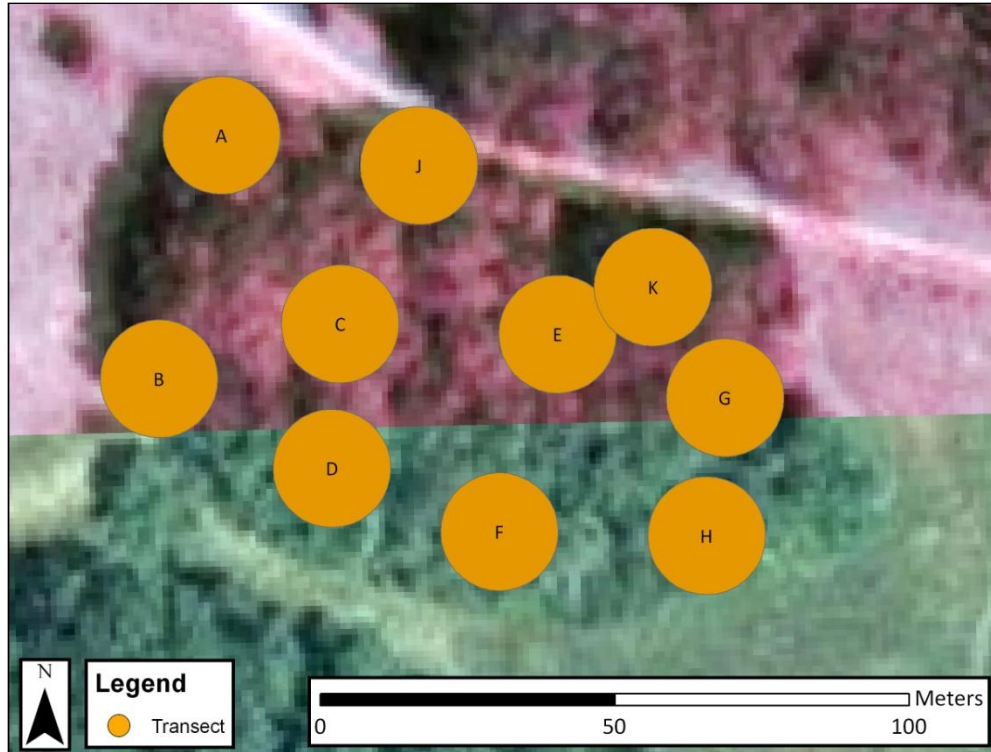


Figure 3.5 Gallaher Rd plot transect locations.

For the GALRD plot, three parallel transect lines were conducted parallel to the access road. There were eight exterior or edge sample circles and two interior sample circles. The two lines of exterior transects and the one line of interior sample circles had a gap of about 10m between each circle. Circle center points had their locations noted by GPS and tape measure was used to locate 10m from the center point for the sampling area. The tape measure was also used to measure the 10m between each sample circle. Some error occurred into staking each circle as some of the regions that were sampled were heavily thicketed with *Smilax glauca* Walter (cat greenbrier), which posed a challenge to accessibility due to the thorns of the species and required the center points to be slightly shifted.

In each of the 19 sample circles, species type and dbh value were taken of all tree species greater than 5cm dbh. Trees less than 5cm dbh were not sampled. Specific tree ring analysis of *A. altissima* was done in order to develop an allometric equation relating tree age versus dbh. Tree rings from twelve trees were analyzed for an estimate when each circle experienced an influx of *A. altissima*. There were five (5) trees analyzed from R273 plot and seven (7) trees from GALRD plot. The trees were taken from the forest floor or selectively cut. Trees greater than 5cm dbh were chosen from the forest floor as they have already fallen.

Historic aerial photographs were scanned from the United States Department of Agriculture (USDA) Soil Conservation Services (SCS) field office in Elkton, MD. The scanned images were brought into Desktop ArcGIS 9.2 (ArcInfo) (ESRI, 2006) and georeferenced a 2005 National Agricultural Inventory Program 1 meter resolution true color image for the study area in the NAD 83 StatePlane Maryland FIPS projection. Table 3.1 presents the names and years of the aerial images used in this study. Each of the georectified images resulted in less than 1 meter RMS error based on using coordinate system and map. A 2007 image for the study was available but it was not used due to a break in data over the GALRD site. A GIS layer in shapefile format was made of each plot for each of the years. The developed GIS layers consisted of digitizing the edge of forest blocks or tree areas which contrasted from the grass or road background. Some of the older images were not as clear as the new images, so layer production in those images were not as accurate as the new images. The area and perimeter of each of the forest plots was calculated using the Calculate Geometry option since a shapefile is a simple nontopological format. The shape index of each shapefile was calculated by the equation below. The shape index equation relates the shape (S) to the area (A) and perimeter (P) of the forest block (Langley, 2005).

$$S = (P/3.54) * \sqrt{A}$$

The shape index was obtained to determine when invasive species were likely to enter a forest fragment. Higher indices indicate the plot having a greater perimeter to area ratio and usually foster species introduction due to edge-effects.

Table 3.1 Aerial images used in analysis

Name of Image	Program/Institution	Date
ANI-16-23	Soil Conservation Services, Elkton, MD	Summer 1938
ANI-2K-41	Soil Conservation Services, Elkton, MD	Summer 1952
ANI-1T-85	Soil Conservation Services, Elkton, MD	Summer 1958
ANI-3DD-107	Soil Conservation Services, Elkton, MD	Summer 1964
R273 1972	Soil Conservation Services, Elkton, MD	Summer 1972
GALRD 1972	Soil Conservation Services, Elkton, MD	Summer 1972
24015-380 (29R)	Soil Conservation Services, Elkton, MD	Summer 1980
1988	Soil Conservation Services, Elkton, MD	Summer 1988
DOOQ Z18 1m	USGS EROS Data Center	Spring 1995
Philadelphia Region Urban Area Orthoimagery	USGS EROS Data Center	May 2002
National Agricultural Inventory Program	USGS EROS Data Center	Summer 2005
National Agricultural Inventory Program	MD DNR	Summer 2007

3.6 Simpson index for tree species diversity

Edward H. Simpson developed a diversity index called the Simpson's index of diversity that represents the probability that two individuals randomly selected from a sample will belong to different species (Simpson, 1949). The index is a simple calculation of biodiversity and is used in this study to examine the diversity among the sampled trees in each circle. This equation does not give a clear definition of what a "species" is, but for this study, a species is defined as a sampled species of tree ≥ 5 cm dbh. Simpson's index of diversity is calculated as,

$$D = 1 - \sum (n/N)^2$$

where D equals the diversity of a population, n is the total number of organisms of a certain species and N equals the total number of organisms in all species (there are a few ways to write this relationship, but the relationship written in the way below gives a straightforward result as greater numbers mean greater diversity). This equation gives values between 0 and 1 with a diversity equaling 0 indicating a population that is completely homogeneous while a value of 1 equals a population which is completely heterogeneous. When diversity (D) is calculated, lower D values indicate lower diversity or a more homogeneous population, and higher D values indicate greater diversity or a more heterogeneous population.

3.7 Shannon-Weiner index

The Shannon-Weiner Index is an ecological biodiversity equation which takes into account uncertainty in measuring the species type of an individual. It was based on information theory and developed by Claude Shannon in 1948 (Shannon, 1948).

$$H' = - \sum (p_i \ln p_i)$$

The term p_i equals the fraction of individuals belonging to the i -th species and H' equals the diversity of the population.

4 RESULTS

4.1 Plot inventory analysis

Plot inventories were taken throughout 2007, and in each of the 19 sample circles, tree species were counted and dbh taken of species ≥ 5 cm dbh. It was found that *A. altissima* species were in 12 of the 19 total circles that were sampled. In the Gallaher Road plot, all of the 10 circles contained *A. altissima*.

4.1.1 Gallaher Rd plot

Displayed in Figure 4.1, *A. altissima* is the most abundant species in the plot. The stand density of *A. altissima* was 468 stems ha^{-1} with *Sassafras albidium* (Nutt) Nees at 61 stems ha^{-1} , *Prunus serotina* Ernh at 45 stems ha^{-1} , *Platanus occidentalis* L. at 38 stems ha^{-1} , *Carya spp.* at 19 stems ha^{-1} and *Junglans nigra* L. at 16 stems ha^{-1} . The other species not mentioned have stem densities less than 10 stems ha^{-1} .

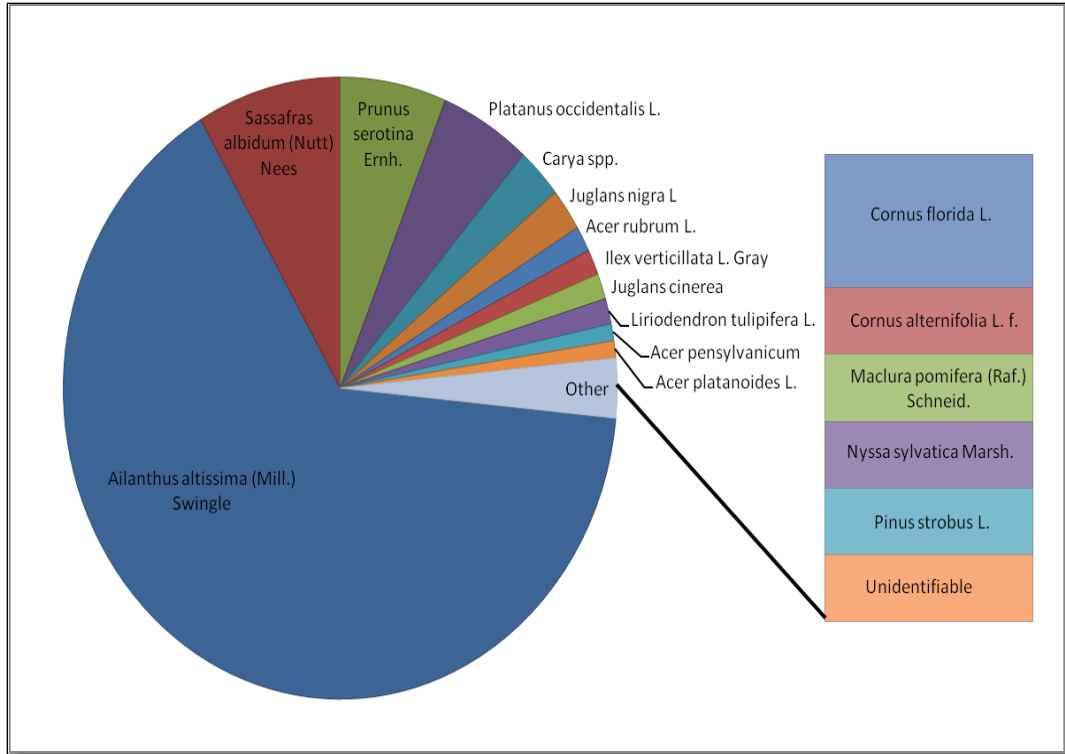


Figure 4.1 Stand composition Gallaher Road Plot.

In Table 4.1 below, the stand densities of all species including *A. altissima* can be seen at the circle level. The circle that contains the greatest amount of stems per hectare is circle D. Circle D contains 1083 stems per hectare and has 85% of that total stand density comprised of *A. altissima*. Circle A has the greatest percentage of stems that are *A. altissima*. As seen in Figure 3.5, it is noted that these circles are not in the interior of this plot.

Table 4.1 Gallaher Road stand density at sample circle level.

Sample Circle	All Species (stems ha ⁻¹)	<i>A. altissima</i> (stems ha ⁻¹)	Sample Circle <i>A. altissima</i> (%)
A	955	828	87
B	669	414	62
C	701	478	68
D	1083	924	85
E	860	446	52
F	892	382	43
G	446	223	50
H	350	96	27
J	892	732	82
K	350	159	45
Sample Circle Average	720	46	60

4.1.2 Route 273 plot

As seen in Figure 4.2 below, *A. altissima* is the most abundant species in the entire plot, while only being in two of the nine plots. The two plots that contain *A. altissima* are located in the eastern portion of the plot as indicated by Figure 3.4.

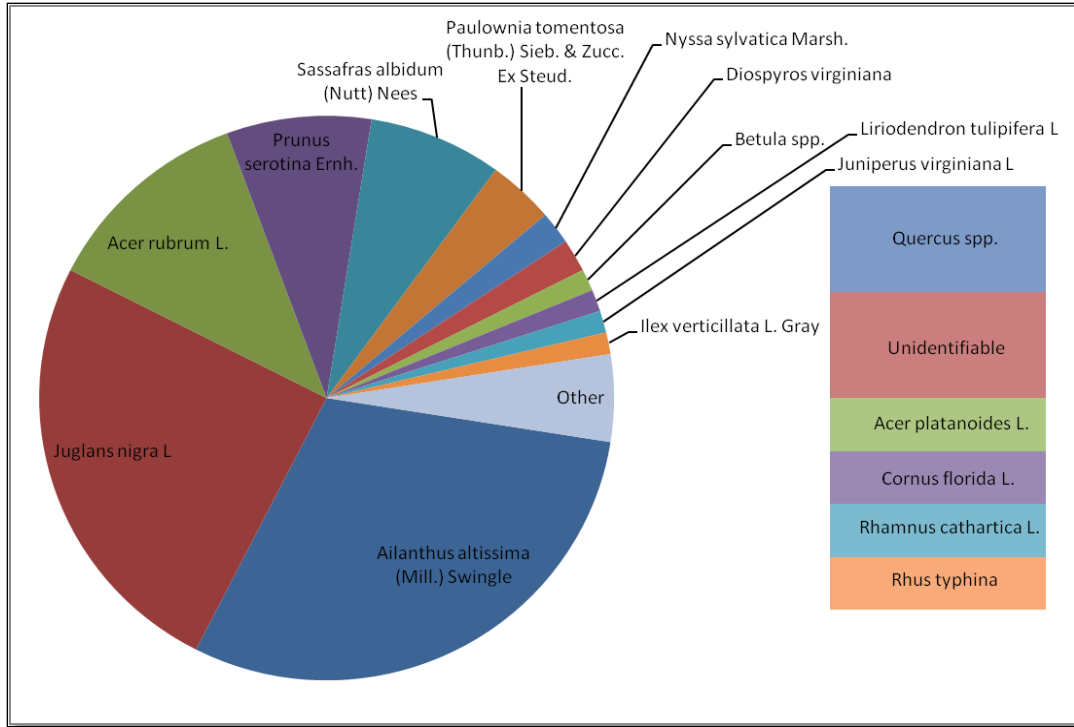


Figure 4.2 Route 273 stand composition.

In Table 4.2 the stand densities of all species and the stand densities of *A. altissima* is seen for R273 plot. Of the nine sample circles in this plot, only two contain *A. altissima*. However only in these two circles does the species have the greatest prevalence. In circle 8, the species makes up 67% of the total amount of species sampled and in circle 9, 94% of all the sampled trees were *A. altissima*. When comparing these percentage values to GALRD plot, circle 9 ranks as having the greatest percentage of *A. altissima*, while circle 8 ranks sixth in overall percentage of *A. altissima*.

Table 4.2 Route 273 stand density at sample circle level.

Sample Circle	All Species (stems ha ⁻¹)	<i>A. altissima</i> (stems ha ⁻¹)	Sample Circle <i>A. altissima</i> (%)
8	764	510	67%
9	1083	1019	94%
Sample Circle Average	923.5	764.5	80%

Figure 4.3 is a visual display of the data listed in Table 4.1 and Table 4.2. The top of the figure displays the stand density of R273 plot with each pie chart depicting a sample circle's composition as either *A. altissima* or other species. Pie charts with an area containing a greater amount of white are sample circles that contain more of *A. altissima*. The red numbers indicate the identifier of each sample circle. The background image display is the 2005 NAIP image as noted in Table 3.1.

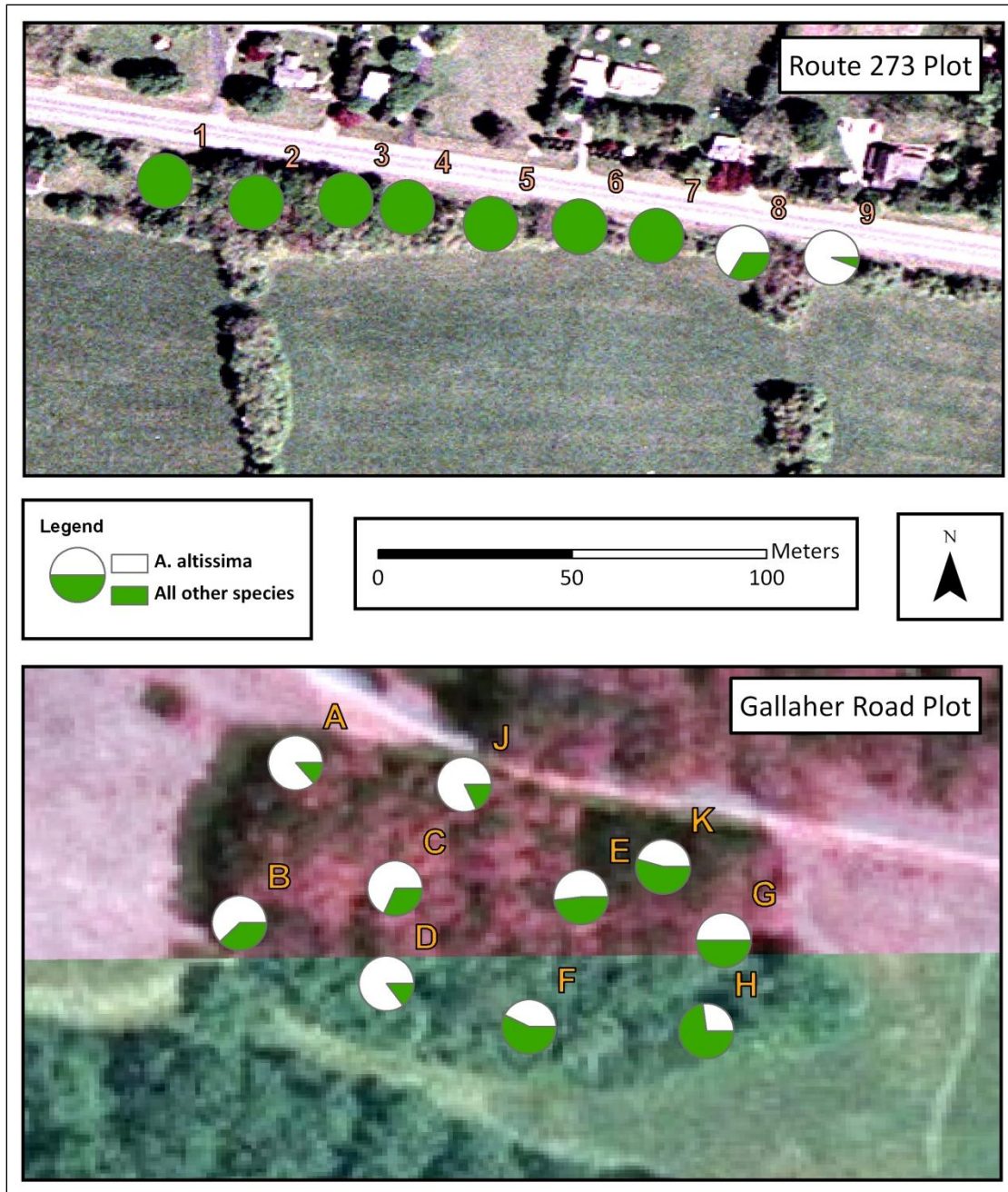


Figure 4.3 *Ailanthus altissima* composition of whole.

The diversity of both plots was analyzed by the Simpson's diversity index for trees and the Shannon index of biodiversity. The results are displayed in Figure 4.4. The higher the value of the index, the more diverse the sample circle. Circles H, E and 1 are

the most diverse, while circles 9, A and D have the least diversity. When using the indices to analyze each plot, plot R273 has a more diverse population, while GALRD ranks as having about 30% less diversity.

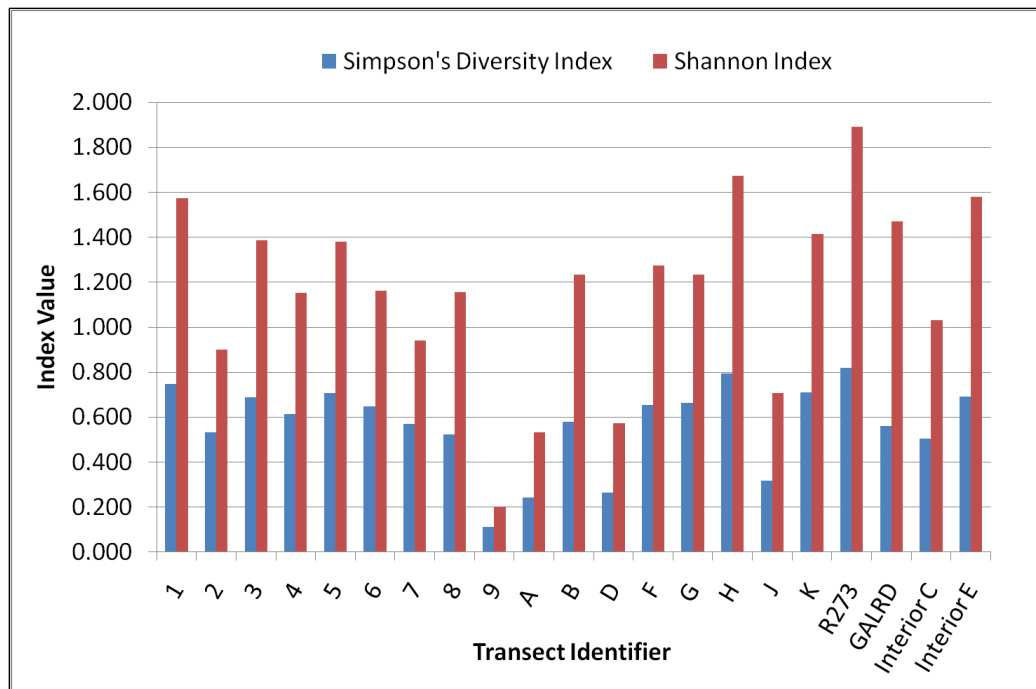


Figure 4.4 Diversity index values for FHNRM.

Figure 4.5 displays the same information seen in Figure 4.4, but adds a geographical component not seen in the chart display. Each of the circle's diversity index was mapped as a color indicating whether the circle was high, intermediate or low in tree diversity. Circles with low diversity index values as seen in Figure 4.4, will appear closer to red in Figure 4.5. Circles that have a higher diversity will appear green and the intermediate values will appear closer to yellow. This analysis will show which areas of the forested plot have more tree species diversity.

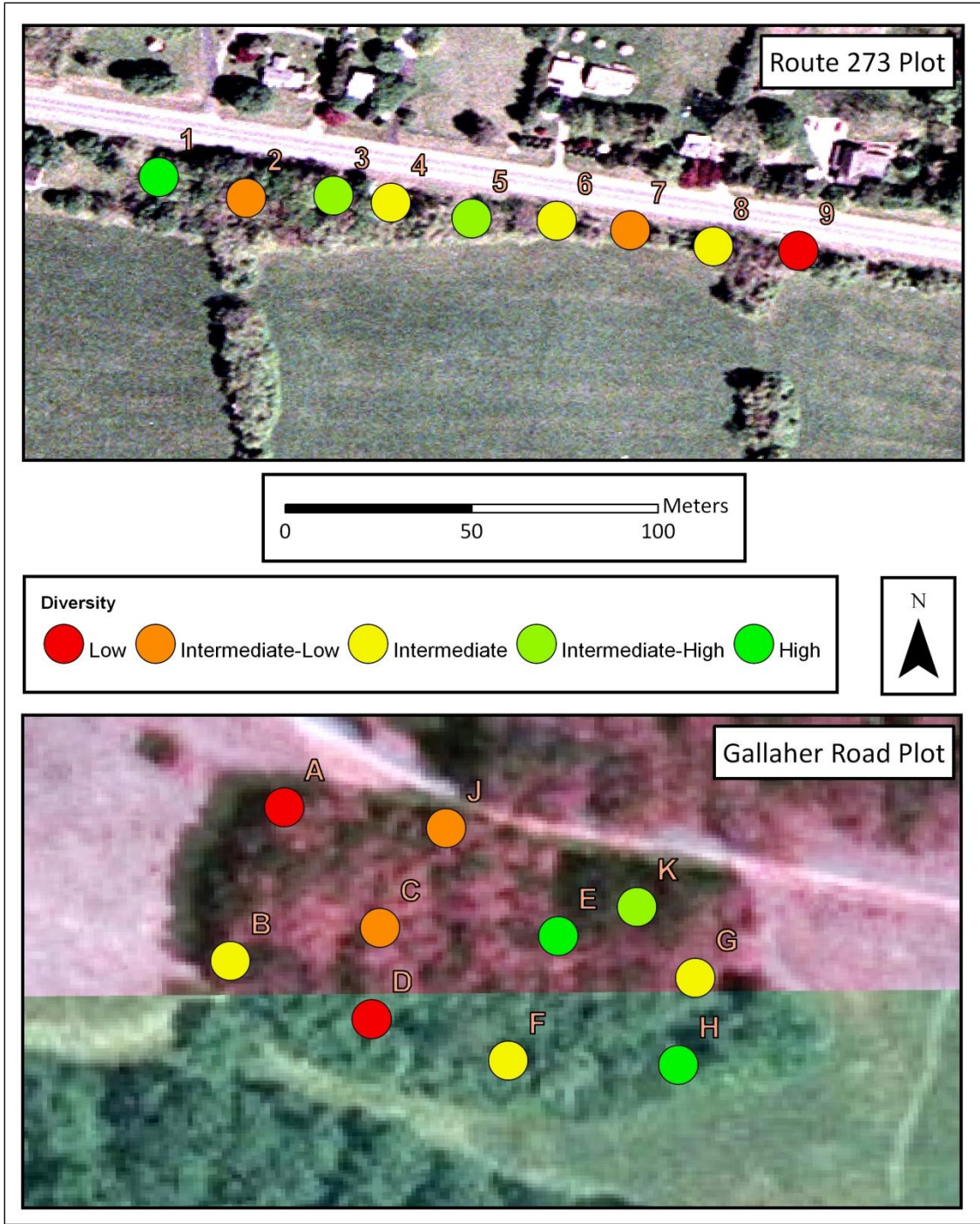


Figure 4.5 Diversity Index Maps of Study Plots in FHNRMA.

4.2 Tree ring analysis

Analysis of tree rings allows for an examination of tree age, although the method does involve the use of destructive sampling. Tree rings are yearly growth rings the tree experiences and are affected by the amount of precipitation, available sunlight, and weather the tree experiences. A few *A. ailanthus* from each plot area were cut or chosen from the forest floor and at the dbh level, these species were cut. A corer sampler was not available for the study. The tree rings were then examined in order to find the age. Representative sample data were gathered at the two FHNRMA sites, GALRD and R273, and this data were compared to data gathered during Yale study at Saltonstall Ridge, CT (Siccama, 1999). Table 4.3 illustrates the data for the three sites. Each tree was given a number and at the dbh level, its age was recorded. At both FHNRMA sites the age of the tree at the dbh level was recorded, however, at the Saltonstall Ridge location the age of the tree was taken at its base.

Table 4.3 Site, tree age at dbh (FHNRMA) or tree age at base (Saltonstall).

Site	Tree	dbh (cm)	Age (yrs)
Gallaher Road	1	3.3	8
	2	3.6	11
	3	5.0	11
	4	4.2	11
	5	5.2	10
	6	9.3	25
	7	18.3	43
Route 273	1	5.6	19
	2	2.3	7
	3	2.3	7
	4	4.6	11
	5	3.5	4
Saltonstall Location	1	10.9	12
	2	3.5	5
	3	12.9	22
	4	1.3	3
	5	22	22
	6	7.9	12

Each tree age and dbh value was then displayed in graphic form, which is displayed in Figure 4.6. The figure displays the age in years along the y -axis and the dbh in cm along the x -axis. A linear trend line was added to each data set. The equation for each trend line as well as the Pearson's R^2 value is displayed along the right of the figure. The Saltonstall site experiences the quickest growth of *A. altissima*, and the equation from that site is:

$$y=0.995x + 2.9661$$

The equation has an R^2 value of 0.832 which shows not a very good relationship between the data points.

An intermediate growth rate is seen at the GALRD site as it has an equation of:

$$y = 2.35x - 0.6024$$

The GALRD site equation had an R^2 value of 0.979 which shows a near perfect relationship between tree age and dbh.

The growth rate of R273 is slower than both the Saltonstall and GALRD locations with an equation of :

$$y = 3.287x - 2.431$$

The R273 site had an R^2 value of 0.669 which shows a modest relationship between these two variables.

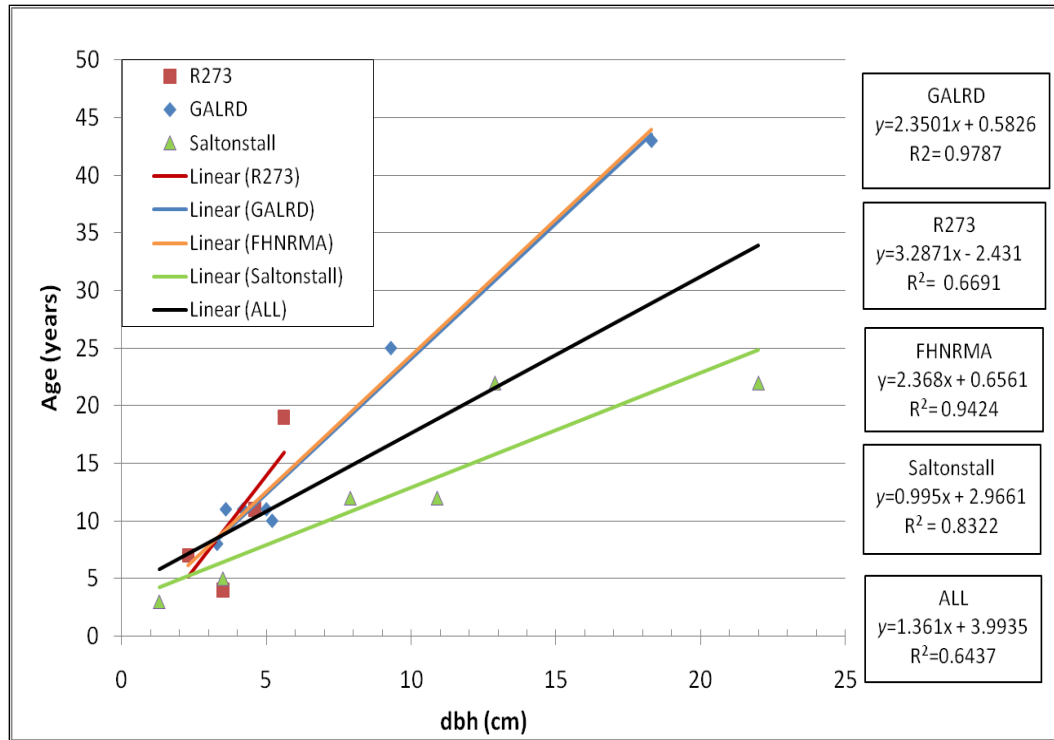


Figure 4.6 Tree age vs. dbh-Saltonstall and FHRMA locations.

Table 4.4 shows each trend line for each site as well as two composition trend lines. A trend line marked as “Fairhill Trendline” in Table 4.4 is the composition of both FHRMA data sets. The trend line marked as “ALL” is the trend line equated from all three site locations.

Table 4.4 Tree age trend line equations.

Trend line	Equation	R ²
ALL	$y=1.361x + 3.9935$	0.644
Fairhill Trendline	$y=2.368x + 0.6561$	0.942
Saltonstall Trendline	$y=0.995x + 2.9661$	0.832
Gallaher Road Trendline	$y=2.35x + 0.5826$	0.979
Route 273 Trendline	$y=3.287x - 2.431$	0.669

From the plot inventories that were taken, each circle's *A. altissima* trees were grouped and their dbh value was put into each of the five equations to give an estimate of the age of the tree. The results gained indicate which circles have experienced *A. altissima*'s intrusion first and which circles have experienced the intrusion of the invasive species much later. The last column, titled "Average age of circle based on all 5 equations," is an average of all the five trend line equations. From the results, the circle that has experienced *A. altissima*'s growth the longest is circle C, located in the interior of the GALRD plot area. The plot which has the experienced the least amount of years with *A. altissima* intrusion is circle H in the GALRD plot area.

Table 4.5 Average age in years of *A. altissima* tree in circle based on 5 trendline equations.

Plot Area	Circle	All	R273	GALRD	FHNRMA	Saltonstall	Average age of tree based on 5 trendline equations
GALRD	A	22.94	43.28	33.29	33.62	16.81	29.99
GALRD	B	24.54	47.14	36.05	36.40	17.98	32.42
GALRD	C	32.78	67.04	50.27	50.73	23.99	44.96
GALRD	D	23.66	45.01	34.52	34.86	17.33	31.08
GALRD	E	19.30	34.48	27.00	27.27	14.15	24.44
GALRD	F	21.50	39.79	30.80	31.10	15.76	27.79
GALRD	G	27.78	54.95	41.63	42.02	20.34	37.35
GALRD	H	18.44	32.41	25.52	25.78	13.53	23.14
GALRD	J	27.40	54.05	40.99	41.37	20.07	36.78
GALRD	K	22.36	41.88	32.29	32.60	16.39	29.10
R273	8	21.74	40.38	31.22	31.52	15.94	28.16
R273	9	21.37	39.48	30.58	30.88	15.66	27.59

Figure 4.7 geographically depicts the information listed in Table 4.5. A color scale visually depicts the average age of *A. altissima* based on the inputs of the five trendline equations. Green circles indicate areas where introduction of the *A. altissima* had not occurred or the circle contained *A. altissima* which were less than 5cm dbh. Green-Yellow and yellow visual colors circles where younger *A. altissima* are situated. Orange and red indicate areas where the oldest *A. altissima* are located and their average age indicate intrusion over 30 years ago. The circle with the oldest average age for *A. altissima* is circle C, where an average age of 45 years based on 15 readings.

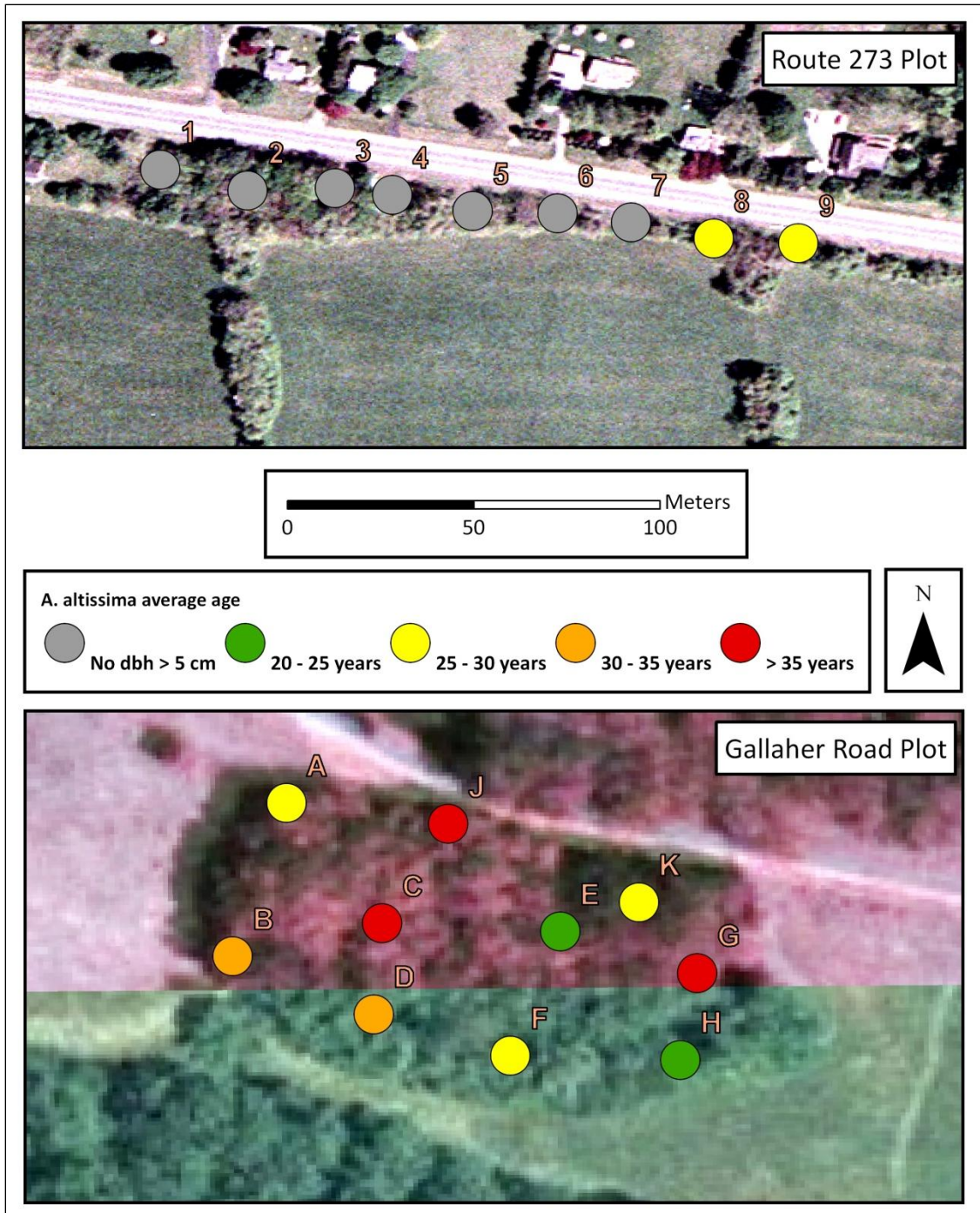


Figure 4.7 Average age of *A. altissima* in circle.

4.3 Historical image analysis/GIS layer production.

The historical aerial images were analyzed for forest plot growth by creating GIS layers to display the growth in size during the time period of 1937 to 2007. The layers were then used to calculate the area and perimeter of the forest block, as well as the shape index. Forest blocks with the most compact shapes give values close to 1, while distended shaped forests give values much higher than 1. Distended forest shapes will have a larger perimeter, thus having a greater perimeter for entry of invasive species. The shape index value is computed for the years when aerial photography was available and is give in Table 4.6. Listed in Table 4.6, an increase of area can be seen in each year for both plots.

Table 4.6 Area and perimeter of forest per year.

Year	Gallaher Rd			Route 273		
	Area (m ²)	Perimeter (m)	Shape Index	Area (m ²)	Perimeter (m)	Shape Index
1938	191.93	77.58	1.58	49.33	48.82	1.96
1952	1311.7	349.5	2.73	554.24	296.44	3.56
1958	3728.11	448.73	2.08	1230.7	489.27	3.94
1964	3960.7	418.53	1.88	1929.41	338.7	2.18
1972	5293.5	448.54	1.74	3169.28	449.6	2.26
1980	5759.45	424.19	1.58	4393.73	473.38	2.02
1988	6746.42	383.1	1.32	5976.12	677.67	2.48
1995	7032.42	378.21	1.27	6630.13	696.24	2.42
2002	7100.32	364.14	1.22	6965.15	718.14	2.43
2005	7916.21	362.27	1.15	7912.61	695.94	2.21

Figure 4.8 presents the data geographically that is found in Table 4.6.

Increases in total area in both plots over the entire time period can be seen. The time period from 1952 to 1958 shows the greatest increase in total area for the GALRD plot, while the greatest increase in total area of the R273 plot occurs during the time period between 1980 and 1988. As of 2005, both plot areas were about the same size in total area (GALRD 7916.21 m², R273 7912.61 m²). However, the plots differed in perimeter size, with GALRD being 362.27m and R273 being 695.94m. The perimeter size differences may be an indication in the amount of *A. altissima* present, as plots with greater perimeters could have greater invasive species counts due to edge-effects.

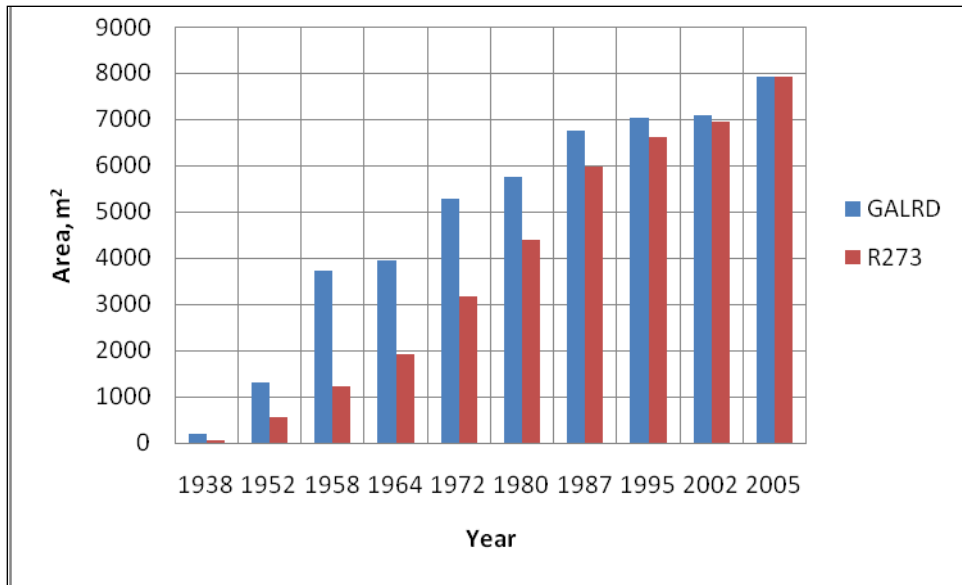


Figure 4.8 Area of forest per year.

Figure 4.9 shows a map of the forest change of the GALRD plot since 1938 with the 2005 NAIP image acts as the background display. Each of the images listed in Table 3.1 had a shapefile of the forest drawn.

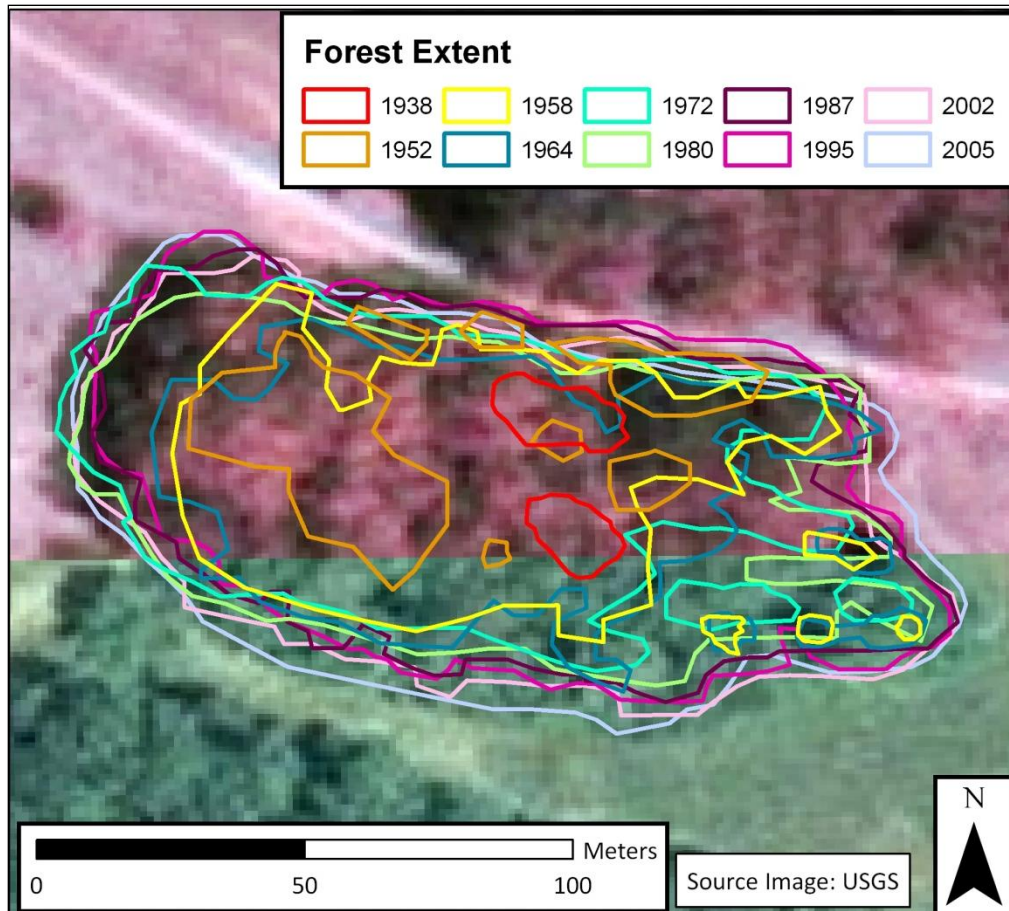


Figure 4.9 Gallaher Road Plot forest change composite 1938 to 2005.

Figure 4.10 displays the historic forest structure acquired from the historic images listed in Table 3.1. Similar to Figure 4.9, an outward progression in forest structure is found. The most recent GIS layer (2005) is shown in periwinkle and has the largest area as recorded in Table 4.6.

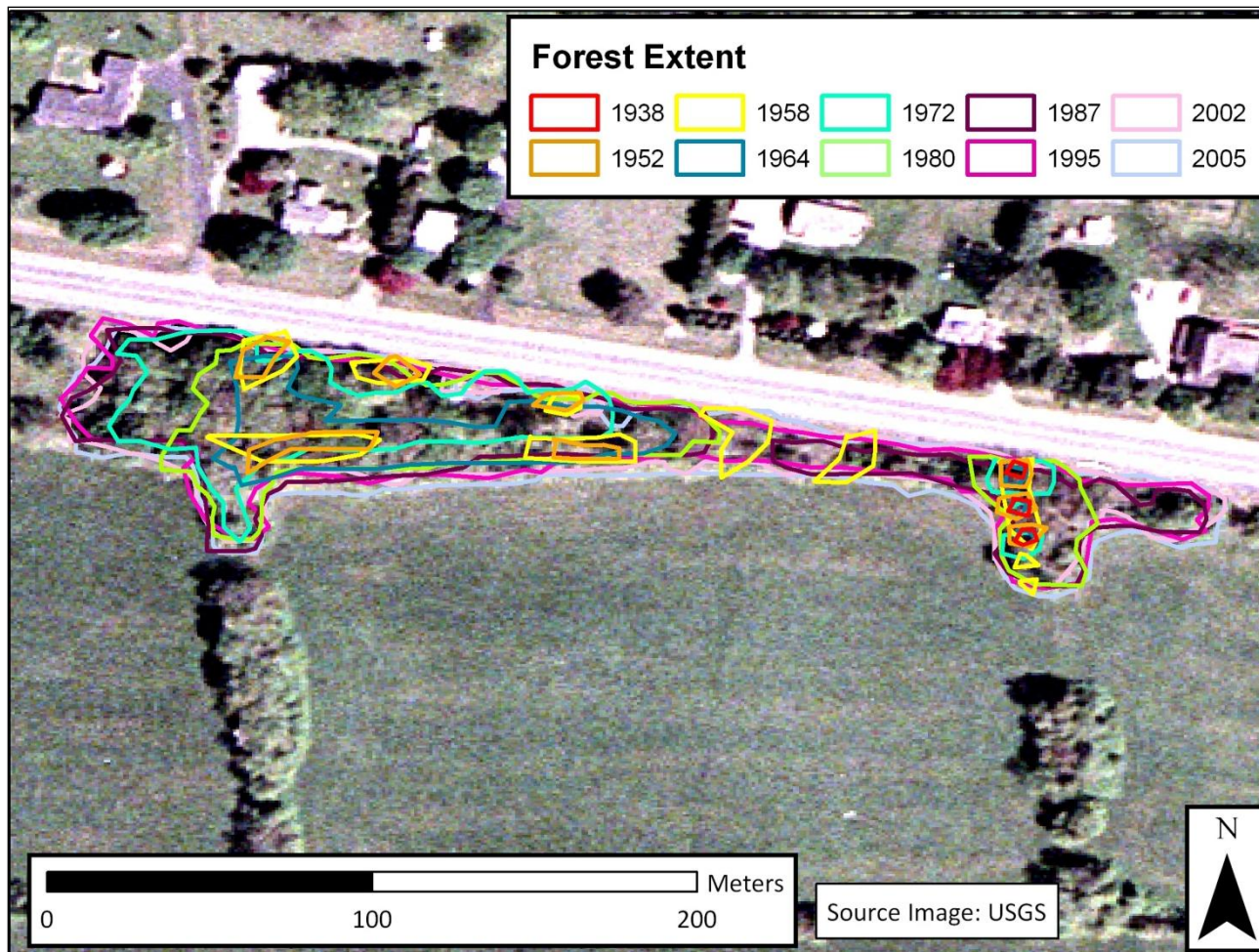


Figure 4.10 Route 273 plot forest change composite 1938-2005.

4.4 Application of results to hypotheses

Ailanthus altissima is an invasive alien species known to cause a loss of biodiversity in habitats in which it has been introduced. Primarily a species associated with urban and disturbed habitats, it has been increasingly found in suburban habitats and in forest interiors. The FHNAMA (2272 ha) is a resource area located in a suburban environment which has seen increasing numbers of invasive species, with *A. altissima* being of major concern. The two plot areas in this study are of particular concern as both areas contain significant amounts of *A. altissima* which is atypical of other forested regions in FHNAMA. The hypotheses in this study will attempt to answer questions about the diversity of these two study plots.

4.4.1 Presence of *A. altissima* and lowered biodiversity (Hypothesis 1)

Due to the effects of *A. altissima* and its ability to form monocultures, areas where the species is present should have values that indicate levels of lower biodiversity compared to areas where the species is not present (Hypothesis 1 (H1)). Of the total 19 circles surveyed between GALRD and R273 plots, 12 contained *A. altissima*, with all of the circles in GALRD containing the species. On the plot level, *A. altissima* is the majority of the species. About 5/8 of plot GALRD (Figure 4.1) is *A. altissima* while just over a quarter is *A. altissima* in plot R273. Diversity indices of all circles are viewed in Figure 4.4 and geographically in Figure 4.5. Circle identifiers 1-9 refer to plot R273 and A through K (no circle I) plot GALRD. Of all the circles in the R273 plot, circles 1, 3, and 5 have the highest diversity. In this plot, circles 1-7 do not contain *A. altissima* greater than 5cm dbh. Circle 8 does contain *A. altissima* and ranks as having intermediate diversity. In circle 8, 67% of the stand density is *A. altissima*. There were a total of 24 trees studied in the circle and 16 of the trees were *A. altissima*. Of the

remaining eight trees, five were trees of differing species. Comparing the diversity results of this circle with the circles of lower diversity in this plot (excluding circle 9), these circles have lower diversity levels due to having less total species in the circle. Circle 2 contains 8 trees comprised of 3 species and circle 7 contains 11 trees, comprised of 4 species. The circle with the lowest diversity is circle 9 which contains 94% of the stand density as *A. altissima*. A possible reason why circles 8 and 9 contain much greater *A. altissima* counts is that between circles 7 and 8, a very dense thicket of *Smilax glauca* Walter (greenbrier) is present. The presence of these briars could act as a barrier for *A. altissima* spread into circles 7 and beyond. All of the circles in GALRD contain *A. altissima*. The circles with the highest diversity based off of Figure 4.4 are H, E, and K. These circles contain lower percentages of *A. altissima* than the circle average of 60%. Circle F has lower percentage of *A. altissima* than E and K, but lesser diversity due to high numbers of single species other than *A. altissima*. Only three circles (H, F, K) contain less than 50 % of the circle as *A. altissima* that indicates the presence of the species has truly affected the diversity of circles in this plot.

Hypothesis 1 describes how *A. altissima* affects the diversity of surrounding areas. Based on the results of this study, it is found that plot R273 does not have *A. altissima* as the majority of the species, but in the circles that the species is present, a lack of diversity has occurred. For GALRD plot, *A. altissima* is the major species and in seven out of the ten circles, it is also the major species. Of the 12 circles studied that contained *A. altissima*, nine of the circles had a majority of the species as *A. altissima*. By the fact that *A. altissima*'s presence has caused monoculture-like habitat in some circles, thus affecting diversity, H1 is supported.

4.4.2 Edge-effects and *A. altissima* (Hypothesis 2)

Hypothesis two (H2) examines edge effects acting on forest block by suggesting there will be greater stand densities and dbhs of *A. altissima* of the circles at the edge compared to circles in the interior. Due to edge-effects, the outside boundary of the forest experiences different biotic factors than the interior of the forest, where would suggest that circles at the edge will usually experience a higher invasive species count and greater size than interior circles. When examining the two interior circles of GALRD, circles C and E, the size and numbers of the *A. altissima* in these circles does not support H2. However, when examining each interior circle individually, circle E does support H2 but circle C does not. Circle C contains 68% of the total species as *A. altissima*, which is greater than the plot average of 60% *A. altissima* per circle. Comparing circle E to this plot average percentage, circle E contains 52% of the species as *A. altissima*.

The second part of H2 states that exterior circles of forest plots should have greater size in tree dbh (older tree age) as forest boundary areas are the entry places for invasive species. As these areas are the first places colonized by invasive species, they should have the greatest sized species. When examining interior and exterior circles, there is not a clear distinction between which type of circle (exterior or interior) contains larger *A. altissima* species. The exterior circle H has trees with the smallest dbhs which gives an average age of 23 years based on the average of all trend line equations in Table 4.4. Exterior circles A, F, and K, contain *A. altissima* trees with intermediate dbhs giving the average age of these circles between 25 and 30 years. The interior circles C and E, have large dbh and small dbh values, giving average age of the circles as 45 and 24 years, respectively. With interior circle C having the greatest dbh/age and exterior circles described above having lower values than this circle, H2 fails. After examination of GALRD plot, other forest growth dynamics are supported by this plot in comparison to

the edge-effects hypothesis. This is seen with the examination of forest growth in H4 in which outgrowth of a forest has occurred from the interior areas.

4.4.3 Dendrochronology and presence of *A. altissima* (Hypothesis 3)

Tree ring data coupled with historic aerial imagery allowed an estimate of the age of each *A. altissima* sampled to determine when FHNRMMA experienced introduction of the species. The hypothesis proposes that the sale from private ownership to state ownership in 1975 ushered in the species if the date of introduction was within a few years after 1975 (Hypothesis 3 (H3)). Trees sampled from both plot areas examined dbh and age via an analysis of tree rings. The results from FHNRMMA were compared to a Yale study from Saltonstall, CT.

Analysis of *A. altissima* age in plot R273 was only applicable for the two most easterly circles (circles 8 and 9) as these plots were the only two that contained the invasive species greater than 5cm dbh. It was found that the average age of *A. altissima* in these circles was 25-30 years. Given that this study was conducted in 2007, the year of introduction of these trees is estimated around the 1980 which could support an introduction of the species due to criterion of H3. There is record that private ownership of FHNRMMA had fostered farming and very frequent hunting activities which may have lead to the tending or clearing of forested regions. With the sale of FHNRMMA to public ownership, regions which may have been tended in the past may have been reverted back to forest fostering the growth of invasive species. The fact that these species became prevalent several years following the transition of ownership could confirm H3 if a similar trend is seen in the GALRD plot. If species are older than the transition of ownership, the sale of FHNRMMA may not be a factor in the spread of *A. altissima*.

Ailanthus altissima ages in GALRD show more variance than the results found in R273 that include two circles (E and H) fall within the 20-25 year grouping,

three circles (A, F, and K) represent the 25-30 year grouping, two circles (D and B) represent the 30-35 year grouping, and three circles (C, G, and J) represent the 35-45 year grouping. The oldest circles (C, G, and J), contain the largest and oldest *A. altissima* trees and are estimated to have been introduced around the year 1970. By examination of the oldest circle (C) and considering its geographic position, it resides in an area of forest that became established prior to 1952 based on aerial imagery. This circle is one of the oldest areas of this forest and contains the oldest and largest *A. altissima* species. Most of the ages of these trees predate the transfer of ownership and fails to support the criteria set by H3. From the data obtained in either plot, it looks like the transfer of ownership of FHNRMMA did not affect the introduction of *A. altissima* in GALRD as the trees were already established in this area, but in plot R273 the transfer may have affected the introduction. However, it remains unclear whether the sale transfer did affect the introduction of *A. altissima* in R273.

4.4.4 Historic imagery and forest shape (Hypothesis 4)

Hypothesis 4 examined the historic forest structure to determine if higher shape indices identified the introduction of *A. altissima*. This hypothesis analyzed the interior circles of GALRD through the time period of historic aerial photographs determining forest shape change of the oldest parts of the forest blocks. The historic imagery enabled an analysis of the area and perimeter of these digitally captured GIS layers of forest blocks. A large change in area and perimeter could indicate colonization of *A. altissima*, especially if the perimeter to area ratio is greater (higher shape index) as this would make the forest block at the mercy of edge effects. Validation of H4 looks at forest position and shape indices along with *A. altissima* ages of the circles through historic imagery analysis, to verify if higher shape indices led to introduction of *A. altissima*.

Looking at both plots through the historic imagery datasets, it is found that both forest plots experienced a large growth in the time period from 1938 to 2007. In 1938, the area of GALRD was estimated at 191.93 m² and for R273 the area was estimated at 49.33 m². The change of forest area between the two plots differed among the years. For GALRD, the change of area experienced large bursts (gain in 500 m² or more) during numerous time periods, with the six year time period of 1952 to 1958 having the greatest increase. This pattern seems to have bursts between certain years, while looking at the change in area of R273, there is only one time frame (1995-2002) that did not experience a change greater than 500 m². This pattern of growth seems to be steadier than compared to GALRD.

This shape index is calculated from the perimeter and area for each year, and shape index values that are closer to 1 form more compact shapes. The shape index of forest plots for each year is unstable. For GALRD, the overall shape index value trend was from values that represent more distended shapes to values that represent more compact shapes. The values are closer to 1 than R273 and the compactness (forest shapes more circular than R273) of the forest shapes can be seen in Table 4.6. For R273, the shape index value trend is not as pronounced as GALRD. An increase of shape index value is seen from 1938 to 1958, a decrease in 1964, an increase in 1972, a decrease in 1980, an increase in 1988, a decrease in 1995, an increase in 2002, and a decrease in 2005. However, a general trend of decreasing values is seen from 1958 to 2005. By looking at some of the relative maximums during the time period and comparing these values to the ages of *A. altissima*, the years with the greatest shape indices could have seen introduction of the species.

As seen in Figure 4.9, the GALRD forest started as two small forest blocks in 1938 but these are not present in the 1952 imagery. In 1938 and 1952, a house and shed can be seen on this property which may explain why the forested areas disappeared as

man could have interacted with growth of these two areas. After 1952, the forest expanded outward, with the exception of three small forest blocks located adjacent to the path at the northern part of GALRD (orange polygon line in 1952). The three forest blocks were not seen in the next image set (1964). Through the imagery it is seen that the oldest part of the forest block are the areas in the center and western part, while areas to the east are newer regions. In 1980, the forest block became an intact forest as seen by the filling in of the “islands” seen in the 1972 plot. The southeast portion of the forest block may be the newest, which is in accord with the *A. altissima* average ages in circles E, F, and H being three of the younger circles. However, circle G, located in the eastern portion of the plot, has one of the oldest average ages of *A. altissima* at 37 years of age. In examining Figure 4.9, circle G is situated in an “island” region at the east of the plot which can be seen first in 1958 and 1964.

When looking at the growth of the GALRD and comparing this to the shape index, the values decrease over time indicating *A. altissima* would have favorable shape structure in past years with less favorable conditions in more recent years. The ages and positioning of the two oldest circles with respect to *A. altissima* age are circle C (covered by forest before 1952) and circle G (covered by forest prior to 1958). For the years 1952 and 1958, the shape indices were 2.73 and 2.08 respectively. These values are two of the highest indices for GALRD which indicates years from 1952 to 1958 were favorable years of *A. altissima* colonization. These circles are two of the oldest circles in the plot based on forest cover prior to 1958 and with shape indices in future years being less than these two years, the growth and spread of *A. altissima* in this plot could be traced to first colonization of these circles. These two circles could indicate the historic forest start points for *A. altissima* colonization in this plot and further growth in the forest of *A. altissima* would have relied on circles C and G to be the seed origin of the species. The visual observations of nearby forest blocks adjacent to GALRD and that *A. altissima* is

not present in significant numbers or significant size indicate the growth of *A. altissima* in GALRD relied on species introduction to this plot. With the position in the forest and these circles having the oldest *A. altissima* species in the plot, higher shape indices did indicate entry of the invasive species which validates H4.

The forest stands in Plot R273 first appeared as three small circular shapes in the eastern portion of the plot in 1938 (red color). In 1938 and 1952 the plot is covered by a field and a few buildings, as well as a visible driveway seen to the right of the three forest stands colored red. The three forest stands seen in 1938 and 1952 could have been *Juniperus virginiana* L. (Eastern Redcedar) as some were seen in that region of the forest during the plot inventories. The positioning of these trees adjacent to a driveway means that these species were ornamental trees placed at the edge of the driveway. After 1958, these forest stands expand as well as other sections of the forest indicated by the yellow color. After 1958, the structures seen adjacent to the forest plot seem to become overgrown. The driveway located by the edge of the three shapes seen in 1938 and 1952 also seems to become overgrown in the 1958 image. From 1958 onward it looks like man did not tend this forest area and it became overgrown.

Shape indices for R273 were very high in the early years with the highest value in 1958 at 3.9. After 1958, shape indices hovered in the low twos. The decrease from 1958 to 1964 is a result of the forest left for filling in portions not previously tended by man. Since these shape index values are a sum of each individual shape, years with many small shapes give higher shape indices. However, when the forest growth occurs in the portions between the shapes, the following years will give a lower shape index as in 1964. The years after 1964 see a filling out of the forest to a shape index of 2.2 by 2005.

A detailed look at the imagery shows that forest stands in the east do date back to 1938, but these positions are localized until 1980 (light green color). Portions in the west of this forest plot date back to 1952 and from that year growth occurs outward

from these positions. In 1972, an intact forest block occurs in the west, with the areas seen in previous years becoming absorbed into one shape, possibly due to habitat and light restrictions of the adjacent forest blocks. Circles 8 and 9 (only two circles containing *A. altissima*) are seen as forested in 1980. Circle 8 is present west of the three forest shapes seen from 1938 to 1952 and circle 9 is seen to the east of circle 8 and the three forest shapes described above. Circle 9 is present at a location where some trees were present in 1980 where others did not appear until 1988. The shape index in the years that circle 8 and 9 contained forest is 2.02 for 1980. The value 2.02 is the lowest seen among values of R273. When comparing this value to the ages of the *A. altissima* species in this plot, age estimates for species introduction are around 1978 for both circles, with the average age of circle 8 and 9 being 28 years. The shape index for 1972 was relatively high (higher index than in 1980) which could have been an important indicator or conducive for species introduction. The position of circle 8 was seen as forested in 1980 which is in accord with age estimates of the species being present. The relatively higher forest index in 1972 validates H4 as the higher shape index is more conducive to the colonization of *A. altissima*. While 1980 was a year which experienced a low shape index of 2.02, the introduction of species to this circle was prior to 1980 and the trees in the circle grew outward to the 1988 GIS layer. This circle experienced introduction of *A. altissima* prior to 1980, when a higher shape index was experienced in 1972, which also validates H4.

5 CONCLUDING DISCUSSION

The invasive species *A. altissima* has been regarded widely as invasive species that causes great loss in biodiversity for introduced areas. The state of Maryland has declared this species as “the most serious invader to affect Maryland habitats” as *A. altissima* causes great loss in Maryland habitat diversity (Mcknight, 2004). The species is found in numerous types of habitats, from vacant city lots to forested areas, roadsides, and utility right-of-ways. It is most associated with areas that have been disturbed by human involvement, and as man settles in areas previously undisturbed, the species will soon follow. It is important to gain further knowledge of the growth patterns of this species in order to thwart the spread into previously unaffected areas. Past studies have analyzed the growth patterns of *A. altissima* and have found the species growing in gaps in the forest interior and other areas not associated with human involvement (Espenschied-Reilly, 2008; Knapp, 2000; Landenberger, 2007). This thesis objective is to gain knowledge of growth patterns of the *A. altissima* species by using historic aerial images and plot surveys to explain how historic growth affected the forest and how the biodiversity was affected by the presence of the species.

This study involved two forested plot regions in FHNRMA in northeastern Maryland. Tree counts and dbh measurements were collected of trees greater than 5cm dbh in 314m² area circles. The focus of this study was to examine a highly invasive exotic species and determine its effects on these two areas. The two plots that were examined, R273 (located off Maryland route 273) and GALRD (located 1km east of Gallaher Road), differed in shape and situation. Plot R273 was an elongated shape forest plot which contained primarily pioneer forest tree species with *A. altissima* contained in two circle areas. Gallaher road was situated on a farm path 1km east of Gallaher road and contained *A. altissima* in all sampled circles.

On first glance, one would expect that R273 plot would contain greater amounts of the invasive species as it is next to a heavy traveled road which would act as a vector for invasive species introduction, but the plot 1 km east of the minor road, Gallaher Road, contains greater amounts of *A. altissima*. This plot is almost entirely *A. altissima* and interestingly enough, the GALRD plot is far from major travel routes which act as vectors for spread of the species. Based on the historic aerial imagery analysis, it was found that this plot was bare in 1937 and was situated on and around an old structure and next to a road. In following years, the plot expanded with a majority of the species as *A. altissima*. In 2007, the plot had a very minor gravel horse path although this same road was traveled greater in previous years based on recognition of numerous residences that no longer exist. Anthropogenic involvement may have led to the prevalence of *A. altissima* in the young forest situated at GALRD, as young forests are more welcoming of exotic species (Flory, 2009). Also, when comparing this plot to R273, the size of GALRD was much greater in previous years, which could have been the species *A. altissima*.

Several hypotheses formulated in this study helped to examine how the species diversity and when and where *A. altissima* was likely introduced. Diversity of circles was examined in Hypothesis 1 (H1). Plots where *A. altissima* were present were predicted to have less diversity than plots where the species was not present. There were 19 circles sampled and of those 19 circles, 12 contained *A. altissima* and of these 12, nine contained 50% or more of the circle species as *A. altissima*. With a majority of the circles containing *A. altissima* (in an amount more than 50%) H1 is confirmed, emphasizing that the presence of *A. altissima* has caused diversity to be less in circles where present. These findings are in accord with previous findings that have indicated that *A. altissima* had decreased diversity among native flora (Vila, 2006, Landenberger 2007; Espenschied-Reilly, 2008). Interior circle diversity and edge-effects were examined in Hypothesis 2 (H2). This hypothesis proposed that due to edge-effects happening on the forest exterior,

interior circles should have greater diversity and smaller counts of *A. altissima*. Analysis of H2 only applied to circles C and E of GALRD plot as these were the only interior circles. It was found that H2 was not true for circle C but was confirmed for circle E. Circle C was found to have some of the oldest and highest numbers of *A. altissima* and was later found to have been an area which was first covered by forest based on the analysis of historic aerial imagery. Hypothesis 3 (H3) examined tree rings of *A. altissima* and hypothesized whether the introduction of the species was due to the transfer of ownership from privately-owned area to state-owned in 1975. Based on the findings of plot R273, H3 is confirmed as the two circles with *A. altissima*, (circles 8 and 9) see introduction around the years post-dating the sale. For the GALRD plot, however, introduction of *A. altissima* predated the sale and therefore fails the criteria set by H3. The final hypothesis, Hypothesis 4 (H4), investigates the shape index by analysis of historical aerial imagery and sample circle age. Hypothesis 4 suggests that *A. altissima* introduction should be introduced when shape indices are favorable for introduction (higher shape indices). Both GALRD and R273 saw introduction of *A. altissima* when shape indices were higher which validates H4.

These hypotheses were chosen in order to cover numerous aspects of growth of *A. altissima* in FHNRMMA and to build off of previous knowledge in diversity studies. Diversity indexes are a common statistical method to determine population diversity and this study used the Simpson index and the Shannon index of diversity (Shannon, 1948; Simpson, 1949; Soo, 2009; Top, 2009). Edge-effects, a phenomenon which causes outer areas of forest to experience environmental differences than interior portions was looked at within H2. This phenomenon is usually examined when invasive species are concerned. Tree ring data for *A. altissima* is very limited so establishing more data points for the species is important. This data were used in analysis of H3, which examined sale of property and ages of *A. altissima*. A final tool used in diversity studies which was

utilized in this study was the development of forest structure map layers derived from historic aerial imagery. The use of GIS has become a valuable tool to examine change over time by looking at historic aerial imagery and developing map layers to study forest shape and size.

All the hypotheses utilized common study methods in biodiversity studies. By using similar methods, it is easier to compare results and work towards understanding fully why this species is so successful in invading habitats.

As seen in the results of this study, *A. altissima* has affected to some degree, the diversity of the forests contained in GALRD and R273. To increase the diversity of these plots and to maintain the diversity of non-invaded forests, management at FHNRMMA may wish to develop a plan of action to control this specific invasive species, as MDDNR management has already stated that eliminating exotic species is a main stewardship goal. An herbicidal regimen could prove to be effective in both plots and even if other species are targeted, these forested plots contain numerous invasive species and eradicating other species could prove beneficial for the entirety of FHNRMMA. Also, to stop the spread of *A. altissima* better prevention methods could be taken. As FHNRMMA is used for numerous recreational activities, many people from other areas could be vectors for species spread as seeds could be transported to FHNRMMA within tire treads, horse apparatus or boots. Washing stations at parking lot areas could be installed as this would control invasive species spread into the park. A log sheet where visitors draw on a map places they have visited could be filled out when they exit the park. This effort could improve monitoring as park employees could periodically check routes traveled for any invasive species proliferation.

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6.5 Chapter 5

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