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WOODY INVASIVE PLANT SPECIES OCCURRENCE AND ABUNDANCE AS

Jyoti Patnaik
Clemson University, jpatnai@clemson.edu

WOODY INVASIVE PLANT SPECIES OCCURRENCE AND ABUNDANCE AS RELATED TO DISTURBANCE, LANDSCAPE CLASSIFICATION VARIABLES AND HISTORICAL LAND USE IN THE SOUTHERN INNER PIEDMONT OF SOUTH CAROLINA

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by
Jyoti Rekha Patnaik
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Accepted by:
Dr. Victor B. Shelburne, Committee Chair
Dr. Patricia A. Layton
Dr. David C. Guynn

ABSTRACT

The spread of invasive plants is one of the most challenging ecological problems in the 21st century, causing a $35 billion loss per year to the economy in the United states alone. More than 85% of woody invasive species were introduced originally for ornamental and landscape use. As a result, over the last few decades, perennial woody invaders have appeared in fence rows, rights-of-way, old fields, understories, and the canopies of eastern forests of the United States. Besides the information about the geographical distribution, general biological characteristics, and response to herbicides, very little information is available on the occurrence and abundance of these invasive plants in relation to landscape variables, and historical land use. The objective of this study was to identify landscape variables that were correlated with occurrence and percent cover of woody invasive species. We examined the distribution and abundance of woody invasive plants in the Clemson Experimental Forest, situated in the Southern Inner Piedmont of South Carolina in relation to landscape variables and historical land use. GPS locations of woody invasive, slope gradient, landform index, aspect, overstory canopy cover, woody invasive species cover, and dominant tree vegetation were recorded for 175 invaded ON road plots and 175 paired 150 feet OFF road plots throughout the Clemson Experimental Forest. *Ligustrum sinense*, *Lonicera japonica*, and *Rosa multiflora* were the most frequent woody invasives. The Friedman Test and GLIMMIX procedure were used to identify factors predicting woody invasive presence. Slope gradient, overstory canopy, and near or ON road were significant factors associated with presence or absence of woody invasive species. Occurrence and abundance of invasive species were associated with low slope gradient, lower overstory canopy, and roadside habitats as compared with higher slope gradient and higher overstory canopy associated with the absence of invasive species. The land use history was studied from the aerial photographs of the area to determine if the change in land use caused the spread of the invasive species. Major land use changes, occurring on the area during the last several decades, furnished a favorable situation for the spread of invasive species. These results add to our understanding of factors promoting plant invasions. Because the control of woody invasive species in natural areas is a time- and resource-intensive task, this information may be used to direct conservation efforts by efficiently predicting and managing biological invasions.

DEDICATION

I dedicate this work to my husband and to my son Manish. Their encouragement and cooperation made this research possible.

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INTRODUCTION

Invasive Species:

Invasive or non-native plants have become a major threat to the integrity of plant communities and natural habitats around the world. These plants are a great problem because they are generally very efficient in exhibiting early maturation, profuse seed production, effective dispersal mechanisms, and high germination rates. Also many invasives can even propagate asexually by root or stem fragments (Gordon 1998, Monaco et al. 2002). The natural controls of such plants by herbivores or by pathogens are generally lacking. As a result, the invasive plants, which are spread by humans or other natural agents, have greater tolerance to a wide range of growing conditions than native plants. By definition, an invasive exotic species is an introduced species that has or is likely to cause harm to the economy, the environment or to human health (Monaco et al. 2002). The United States harbors more than 1500 species of invasive non-native plants (Vitousek et al. 1996). It is estimated that 100 million acres in the United States are already impacted by invasive plant species (South Carolina Exotic Plant Pest Council 2004). These new colonists are disrupting the dynamics of ecosystems, pushing native species towards extinction, shifting community dominance and competitive regimes, and are causing billions of dollars of direct damage to human enterprises (Cox 1999, Gordon 1998).

The vast majority of woody invasive plants were intentionally introduced for landscaping, erosion control, or plantations (Reichard and Hamilton 1997). As a result, over the last few decades, perennial woody invaders from all over the world have cropped up in fence rows, rights-of-way, old fields, understories, and the canopies of eastern forests of the United States. The population of invasive woody shrubs has become so dense in some forest understories that researchers have speculated that heavily invaded forests may succeed to shrub lands (Collier et al. 2002). For example, Kudzu (*Pueraria montana L.*) was introduced to reduce soil erosion and for grazing, but is now considered a significant nuisance on large areas of the Southern United States (Monaco et al. 2002). The concern over invasive plant species has moved to the forefront with federal and state agencies and practitioners involved with vegetation and natural resource management. Millions of acres of forest land in the Southeast are being occupied increasingly by non-indigenous harmful plants--exotic escapes. The actual infested acreage and spread rates of encroaching exotic plants are unknown, even though this information is essential for planning eradication and containment strategies (U.S. Congress Office of Technology Assessment 1993). Kudzu and Japanese honeysuckle (*Lonicera japonica* Thunb) alone occupy over 7 million acres each and their spread rates are increasing (Watson 1989, Craver 1982). Exotic plant bio-pollution threatens plant and animal biodiversity across the landscape and continues to capture our highly valued nature preserves and recreational lands. All federal park and forest lands in the Southeast have exotic infestations (Hamel and Shade 1985, Hester 1991).

The abundance, distribution and edge associations of six species of non-indigenous, harmful plants were surveyed throughout North Carolina. Those plants were Japanese honeysuckle (*Lonicera japonica),* multiflora rose *(Rosa multiflora* Thunb), kudzu, Chinese privet (*Ligustrum sinense* Lour), tree-of-heaven(*Ailanthus altissima* Mill), and oriental bittersweet (*Celastrus orbiculatus* Thunb) Their abundance was expressed as the percent of occurrence in the total length of measured transects. Japanese honeysuckle occupied an average of 25.9% of all edge types, highest in the piedmont. Chinese privet occupied an average of 7.5% of all edge types, highest along rivers and streams. Multiflora rose occupied an average of 4.8% of all edges, highest along rivers and streams of the mountainous western part of the state. Kudzu occupied 2.4% of all edges, fairly evenly distributed on edge types. Tree of heaven occupied 1.7% of edges, high along railroad rights-of-way of the piedmont. Oriental bittersweet occupied 0.6% of all edge types, highest along railroads of the mountains (Merriam 2003).

Landscape Classification in the Piedmont:

Jones (1988) described forest community types and associated soil and landform properties within the piedmont physiographic province of South Carolina. Using discriminant analysis procedures to detect relationships between community and environmental data, the steady state Piedmont forests were classified into five vegetation types: xeric, sub-xeric, intermediate, sub-mesic, and mesic. Vegetation patterns associated with the five vegetation types varied across an environmental gradient characterized by the interaction of slope position (as measured by landform index (McNab 1993)) , aspect, depth to clay or rock, and texture of subsurface horizon. This complex environmental gradient is essentially a soil moisture gradient.

On xeric sites, landscape positions were typically exposed ridge flats and upper slopes of any aspect. Soils had clayey texture within 30cm of the surface or bedrock within 60 to 90cm of the surface. Post oak (*Quercus stellata*) was restricted to these sites sharing overstory dominance with black oak (*Quercus velutina)*, white oak (*Quercus alba*) and scarlet oak (*Quercus coccinea).*

On sub-xeric sites, landscape positions included ridge flats, upper slopes of any aspect, or mid-slope positions with a southerly aspect where soils had clay or sandy clay subsurface horizons at a depth greater than 30cm but less than 60cm. This community type also occurred on less exposed mid-slopes with northerly or easterly aspects where soils had clayey textures within 30cm of the surface or rock within 60 to 90cm of the surface. The overstory was dominated by white oak in association with pignut hickory (*Carya glabra*), scarlet oak, and black oak.

Sites of mid-slope positions with northerly and easterly aspects or mid-lower slopes with more southerly aspects were interpreted as intermediate in terms of soil moisture status. Soils had sandy clay loam or clay loam subsurface horizons at 30 to 60cm depths. Canopy dominants were white oak and pignut hickory in association with northern red oak (*Quercus rubra)* and occasionally black oak.

Submesic sites were restricted to mid-lower slope positions with northerly to easterly aspects. Soils had sandy clay loam to clay loam subsurface horizons at 30 to 60cm depths. On some sites, the soil-water status is improved due to subsurface water flow (interflow). Overstory dominance was often shared among northern red oak, white oak, and pignut hickory with yellow-poplar (*Liriodendron tulipifera*) frequently occurring with canopy openings.

Mesic sites were on lower slopes with typically northerly and easterly aspects. Soils had sandy loam subsurface textures. The overstory ranged from pure American beech (*Fagus grandifolia*) to varying mixtures of American beech and northern red oak with occasional stems of white oak and pignut hickory.

Integrating Invasive Species and Landscape Classification:

For many invasive species, ecologists lack understanding of how invaders spread through native communities, although disturbance appears to play a major role (Bergelson et al., 1993). Quantitative ecological relationships are unavailable for assessment or management of many exotic species. McNab and Loftis (2002) modeled the probability of occurrence of oriental bittersweet in relation to environment, competition, and disturbance in stands of deciduous hardwoods in mountainous terrain. They found that bittersweet was significantly associated with (1) topographic variables associated with mesic environments, (2) density of midstory arborescent vegetation, (3) overstory canopy gaps, (4) past silvicultural harvests, (5) overstory canopy composition, and (6) scarification of the forest floor. The results of their study indicated that probability of oriental bittersweet occurrence in an area typical of the Southern Appalachian mountains is greater in mesic environments and where the overstory canopy and forest floor have been disturbed. Mesic habits are most susceptible to invasion. In open fields, Japanese honeysuckle can form mats, but it is even more productive if supports such as young trees are present (Schweitzer and Larson 1999).

Besides the information about the geographical distribution, general biological characteristics, and response to herbicide of these invasive woody plants, very little information is available on the occurrence and abundance of these invasive plants in relation to the site classification, disturbance and historical use. It would be valuable to both lay and professionals to know what type of sites and site variables are most commonly associated with the woody invasives. Recognition of these variables would aid in reducing invasion and help in the process of eradication. The objectives of this research are as follows

Objectives:

1. Relate occurrence and abundance of invasive woody plants to landscape variables.
2. Relate occurrence and abundance of invasive woody plants to historical use.
3. Relate abundance and occurrence of invasive woody plants to the existing stand structure and disturbance (open canopy, closed canopy, pine vs. hardwood canopy, etc.)

Questions for this research:

1. How do the various landscape variables (Slope, Aspect, and Landform Index) which describe the five major site units (xeric, sub-xeric, intermediate, sub-mesic, and mesic) affect the occurrence and abundance of invasive woody plants?
2. How does previous and present land use history influence the occurrence and abundance of invasive woody plants?
3. How does openess of the stand and the overstory composition (hardwood, pine or some combination) affect the occurrence and abundance of invasive woody plants?

Hypotheses:

1. Occurrence and abundance of invasive woody plants is NOT affected by the site unit variables on which they grow.
2. Occurrence and abundance of invasive woody plants is NOT affected by previous and present land use history.
3. Occurrence and abundance of invasive woody plants is NOT affected by openess of the stand and overstory composition.

CHAPTER TWO

LITERATURE REVIEW

Biological invasions by non-native species have become a major environmental problem and a focus of ecological research (Vitousek et al. 1996, Brock et al 1997, Luken & Thiret 1997, Dukes & Mooney 1999, Higgins et al. 1999). The spread of invasive plants is ranked second, behind habitat loss, as the greatest threat to biological diversity and ecosystem function in the United States (Brumback 1998, Pimentel et al.1999). The effect of invasive non-native species in natural system is generally regarded as one of the most critical issues confronting conservation science (Drake et al. 1989, Simberloff et al. 1997, Mack et al. 2000). The ecological effects of non-native species have been well documented at the population, community, and ecosystem levels (Vitousek 1986, Gordon 1998, Mack & D'Antonio 1998, Parker et al. 1999), as have the economic costs associated with environmental damage and control (Pimental et al. 2002).

Woody Invasive Species:

Invasion by woody species is of particular concern because they are important as wildlife habitat and for aesthetic purposes in a region that is primarily wooded. Shrubs and vines originally planted as hedgerows or wildlife plantings have invaded abandoned fields. Exotic species, including Chinese privet, multiflora rose, Asian honeysuckles, and thorney olive (*Elaeagnus pungens*) produce prolific amount of seed allowing them to spread quickly without natural diseases or insects pests to keep them in check (Richburg et al. 2002). Reichard and Campbell (1996) documented that 85% of the 235 invasive woody plants in the United States were originally introduced as ornamental plants, while an additional 14% were introduced as agricultural plants. Woody invasive plants are part of a much larger invasion of alien species of plants, insects, and disease that has fundamentally altered the composition and structure of eastern forests (Liebold et al. 1995, Britton et al. 2004). Woody invaders pose a variety of challenges for forest managers, from inhibiting and/or outcompeting regeneration of desires species to strangulation and overtopping of overstory trees (Webster et al. 2006).

Vines:

The twining growth habit, rapid growth, and shade tolerance of many introduced woody vines make them aggressive competitors with tree regeneration after silvicultural treatments or natural disturbance. Vines damage young trees by stem gridling, increasing the risk of ice damage, and, eventually, causing death by overtopping and shading (McNab and Meeker 1987).

Japanese Honeysuckle was first introduced to the United States during the mid-1800s as an ornamental and later was popularized for erosion control and wildlife forage (Schirenbeck 2004). Japanese honeysuckle is an evergreen to semi-evergreen, moderately shade tolerant, woody vine that uses both vegetative and sexual reproduction (Schirenbeck 2004). Japanese honeysuckle damages natural communities it invades by outcompeting native vegetation for both light (shoot competition Thomas 1980, Bruner 1967) and below ground resources (root competition Dillenburg et al. 1993a, 1993b, Whigham 1984), and by changing forest structure (Sasek and strain 1990, 1991).

Japanese honey suckle is considered an important species in the disruption of fire regimes throughout the eastern U.S. (Richburg et al. 2002) and survives all but the most severe fires by resprouting from below ground stems (Barden and Matthews, 1980, Faulkner et al. 1989).

Kudzu was originally introduced to the United States from Asia around 1876 which was planted throughout the southeast for erosion control and livestock forage between 1920 and 1950 (Mitich 2000). Since its introduction kudzu has spread over 3 million hectare of the eastern United States and is spreading 50,000 hactare per year (Blaustein, 2001), making it one of the most aggressive introduced vine in North America. In 1953, kudzu was removed from the list of approved plants for erosion control, in 1970, it was officially labeled a weed, and in 1997, it was placed on the federal obnoxious weed list. The ability of kudzu to overtop and shade forest trees, fix atmospheric nitrogen, and emit isoprene suggest that it may have substantial effects on native forest biodiversity, forest nitrogen cycles, watershed nitrogen saturation, freshwater eutrophication, and regional air quality (Forseth and Innis, 2004). Kudzu was the most commonly reported plant management problem in the Southern Appalachian region, likely because of its widespread distribution, its obvious impact on natural systems, and its difficult nature to control (Kuppinger 2000). It is a Rank 1, Severe Threat species (Tennessee Exotic Pest Plant Council 1996).

Shrubs:

The primary threat posed by woody invasive shrubs to forest management is their ability to form dense monocultures that inhibit native tree regeneration and depress forest herb populations. Many traits including rapid growth, tolerance of shade and drought, bird-disseminated seeds, and the ability to outcompete native plants made invasive shrubs ideal for harsh urban environments, wildlife habitat, and erosion control contributed to their success as invaders (Webster et al. 2006).

Chinese privet was introduced into the United States in 1852 from China and was traditionally planted as an ornamental (Dirr 1998, Merriam and Feil 2002, Morris et al. 2002). Privet forms dense stands in the understory of bottomland hardwood forests and exclude most native plants, drastically altering habitat and critical wetland functions (Brown and Pezeshki 2000, Merriam 2003, Harrington and Miller 2005). Vigorous sprouting from root suckers and the ability to produce huge amount of seeds that are dispersed by birds give privets their competitive advantage over native flora (Strong et al. 2005).

Multiflora rose was originally introduced to the East Coast from Japan in 1886 as an understock for ornamental roses (Wyman 1949). It grows best on deep, fertile, well-drained but moist uplands or bottomlands, but is capable of enduring a wide range of edaphic and environmental conditions (Wyman 1949, Stevenson 1946). In the 1930's, the U.S. Soil Conservation Service advocated the use of multiflora rose for soil erosion project and as a "living fence" to confine livestock (Albaugh et al. 1977). The plant is extremely prolific, however, and successfully invades pastures and other unplowed lands, crowding out existing vegetation and creating dense, impenetrable thickets, in some areas entire pasture have been taken over (Barbour and Meade 1980, Doudrick 1987). Multiflora rose was reported as a management problem by resource managers in the Southern Appalachians more often than Japanese honeysuckle and microstegium, perhaps because its upright and clumped growth form make it relatively apparent on landscape (Kuppinger 2000). It is classified as noxious weed in several of the United States and is ranked as a “Severe Threat” to natural ecosystem in Tennessee (Tennessee Exotic Pest Plant Council 1996).

Trees:

Invasive exotic trees are capable of competing directly with native canopy trees for growing space. Additionally, they often outcompete regeneration of native canopy species after canopy disturbance. Invasive trees are aggressive colonizer of disturbed sites and fast growing, some species are well adapted at colonizing relatively undisturbed forests. Consequently, if left unchecked, invasive trees have the potential to eventually replace commercially and ecologically important native canopy species (Webster et al. 2006).

Factors affecting invasive species occurrence and abundance:

Landuse, disturbance, and climate are driving factors of alien plant invasion (Londsdale 1999, Hobbs 2000). In temperate ecosystems, most alien species are invasive in human disturbed landscapes at low elevations (Hobbs 2000). Many factors affect the establishment and spread of non-native species, which include the interaction of multiple environmental variables, such as elevation, precipitation, and soil type, which constitute the species' fundamental niche (Hutchinson 1957, Pysek etal. 2003). Non-native species have also been associated with areas of disturbance, either natural (e.g. fire or flooding; Rajmanek 1989, Mack & D'Antonio 1998) or human related (Macdonald et al. 1988, Cowie & Werner 1993, Gerlach et al. 2003), and influenced by abiotic factors, such as historical land use and management (Mack et al. 2000).

Impact of historical land use on invasion:

Lundgren et al. (2004) found that historical land use appeared to have a stronger influence on the abundance of invasive species than present land use. They also found that. For both current and historical land uses, invasive species richness and cover were significantly lower in forested plots than in plots adjacent to field or residential land. Myster and Pickett (1990) reported that historical agricultural fields could develop strong positive association with invasive species. These species may persist in the seed bank, in some cases for centuries after abandonment, to later invade old fields. Vitousek et al. (1997) found that damming and impoundment of most of the rivers in U.S. have been correlated with the invasion of rivers, streambanks and floodplains by introduced species, and with rapid conversion of diverse, native riparian forests to low diversity stands of introduced species. The fragmentation of wildland habitat resulting from agricultural or urban development has also affected the spread of introduced species.

Impact of roads on invasion:

Roads represent the primary pathway for the introduction of alien plant species into protected areas, especially for generalist species with short life cycles and high reproductive rates (Spellerberg 1998, Parendes & Jones 2000, Trombulak & Frissell 2000). Tyser and Worley (1992) reported a correlation between non-native species and disturbance from roads and trails, and high visitations to reserves was positively correlated with high invasion rates (Macdonald et al.1989). Parendes et al. (2000) revealed that roads and streams apparently serve multiple functions that enhance exotic species invasion in this landscape, they act as corridors or agents for dispersal, provide suitable habitat, and contain reservoirs of propagules for future episodes of invasion. Bartuszevige et al. (2006) revealed that presence of amur honeysuckle (*L. maackii* Rupr.) was significantly explained only by distance from the nearest town; woodlots nearer town were more likely to be invaded. Density of amur honeysuckle was positively related to the amount of edge in the landscape and negatively related to total tree basal area and number of native woody species. Kudzu is a notorious invader of roadsides and power transmission line rights-of-way in the southeastern United States, but it is seldom found in adjacent, lessdisturbed habitata (Plant Conservation Alliance 1997).

Impact of landscape variables on invasive species

Identification of environmental factors that facilitate a particular species' invasion is necessary to assist early intervention (Silveri et al. 2001). Landscape-scale information on areas impacted by invasive species is particularly vital (Byers et al. 2002, Rudis 2005, Saura and Carballal 2004). Landscape-scale factors interact with more local biotic and abiotic factors which allow the exotic species to become abundant and persistent differentially within the landscape, and contribute to their potential nuisance or pest status (Rand et al. 2004, Knight and Reich 2005). Pande et al (2006) found that presence of oak, elevation, slope gradient, soil pH, soil texture, and distance to road were significant factors associated with presence or absence of oriental bittersweet. Probability of occurrence of oriental bittersweet was highest on gently sloping interfluves with successional forest canopy not dominated by oak, and less acidic mesic soil. Pauchard & Alaback (2004) reported that elevation and alien species richness along roadsides were significantly and negatively correlated. Higgins et al (1999) found that elevation and annual rainfall are the environmental variables that explained most of the variance in distribution of the six invasive plant species on the Cape Peninsula, where as slope, soil moisture, soil nutrient status, vegetation flammability, and radiation loads explained less of the variance in species response.

Effect of light on invasion:

Duggin & Gentle (1998) attributed the invasion of a forest by a shrub to increased light availability following removal of the forest overstory. Luken et al. (1997) concluded that an invasive shrub was more able to take advantage of high light than a related native shrub. Raghubanshi et al. (2005) reported that many alien invasives benefit from the reduced competition, as a direct relationship has been demonstrated between canopy opening due to disturbance and density of species such as lantana (*Lantana camera* L), jack in the bush (*Chromolaena odorata*). Morris et al. (2002) found that Chinese privet appears to possess a competitive advantage over swampprivet (*Forestiera ligustrina*) because of its greater ability to spatially and temporally capture light, a phenomenon that may lead to higher photosynthetic capacity and resource-use efficiency.

CHAPTER THREE

METHODS

Study area:

The study site is located in the Clemson Experimental Forest (Figure 3.1), which lies within the Piedmont Physiographic region of South Carolina and specifically in the Southern Inner Piedmont of South Carolina (Griffith et al. 2002). The forest covers approximately 7,100 hectares (ha) in Anderson, Oconee, and Pickens counties and is managed by Clemson University.

Elevation ranges from 200 to 300 meters above sea level and the area is characterized by gently rolling hills interspersed with deep gullies resulting from erosion. Most soils on the Clemson Experimental Forest are of the Cecil-Lloyd-Madison association. These are Ultisols with moderate to extremely severe erosion. Entisols and Inceptisols are present but not abundant. Entisols occur along streams and Inceptisols occur on steep slopes.

A wide variety of cover and site types can be found on the Clemson Experimental Forest. Almost all of the forest is in second- or third-growth timber resulting from reforestation programs during the Great Depression and harvesting since that time. Dominant species are loblolly pine (*Pinus taeda*) and shortleaf pine (*P. echinata*) with a mixture of oak and other hardwoods in the canopy and subcanopy. Study sites were selected along the roadsides as these areas serve as the primary pathway for introduction of invasive species.

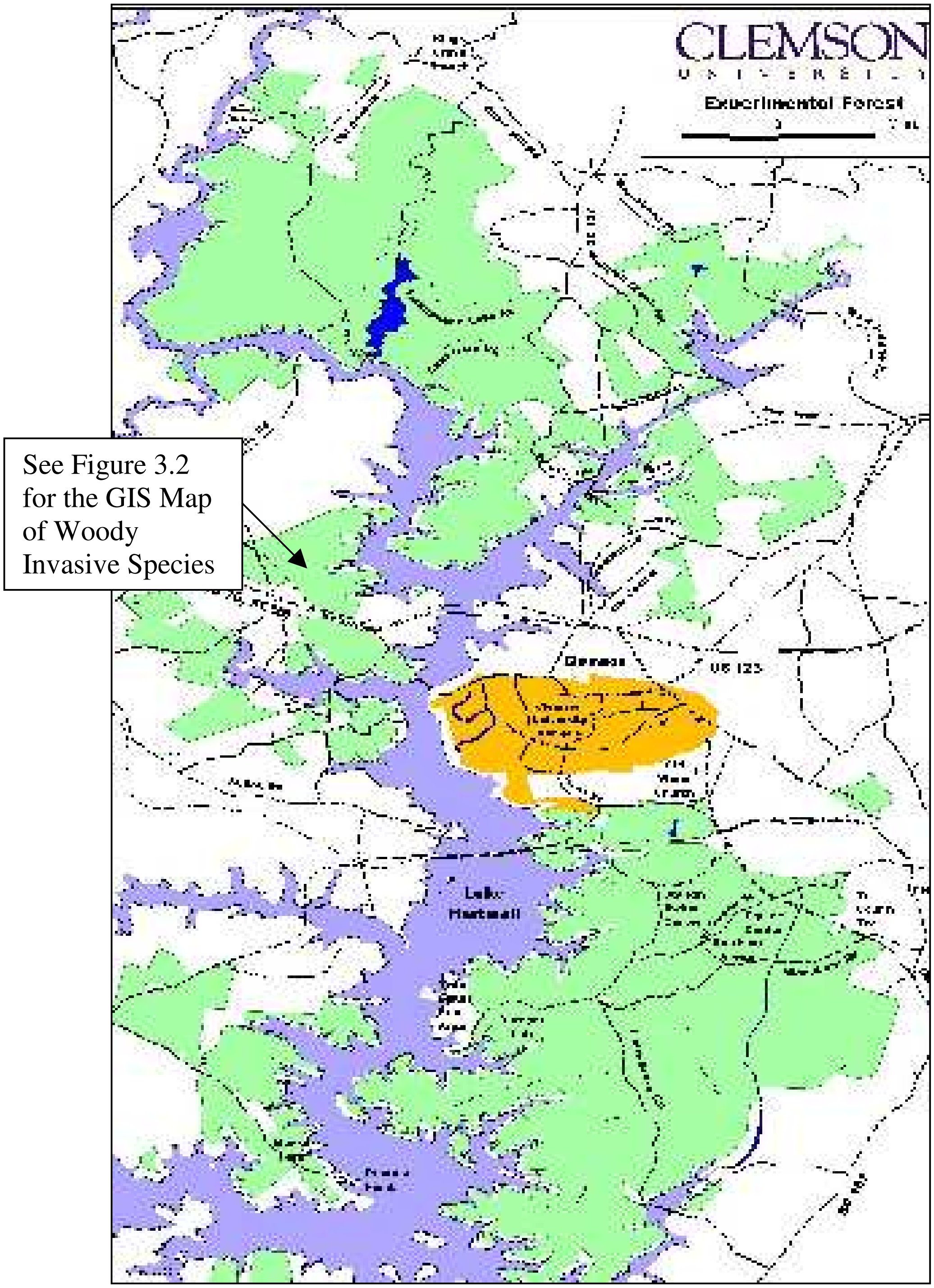

Figure 3.1. Study Area of Clemson Experimental Forest

Data collection:

1. A Preliminary survey of woody invasive plants along the roadsides of Clemson Experimental Forest was conducted with help of a handheld Garmin GPS. All woody invasive plants viz: Japanese honeysuckle, multiflora rose, kudzu, Chinese privet, tree of heaven , mimosa (*Albizia julibrissin*), China berry tree (*Melia azedarach*), silvetthorne, Chinese wisteria (*Wisteria sinensis*), shrubby lespedeza (*Lespedeza bicolor*) were systematically located along the roadsides and stored in GPS as waypoints during Summer 2006. A total of 1770 points were located along the roadsides of both the North and South Clemson Experimental Forest.
2. At every 10^{th} point of the 1770 points collected where invasive species were present the following landscape variables were collected during the summer of 2007: slope, aspect, and Landform Index (LFI).
3. Sample 0.025 acre circular plots were randomly established along the roadsides (ON road). The abundance of individual woody invasive species were observed in the sample plot and stored as cover classes according to the North Carolina Vegetation Survey methodology (Table 3.1). The cover classes were recorded according to the percentage of area covered by each invasive species within the sampled circular plot. Then the surrounding dominant tree vegetation inside the plot was recorded.

Table 3.1: Cover classes and percentage cover ranges

Cover class	Percentage cover range
1	Trace
2	0-1%
3	1-2%
4	2-5%
5	5-10%
6	10-25%
7	25-50%
8	50-75%
9	75-95%
10	>95%

4. For each sample plot, the landscape variables noted above were collected with the use of a Clinometer. Slope gradient was measured by averaging two clinometer measurements in percent in the dominant slope directions above and below plot center. Landform index was derived from the mean of eight measurements in percent scale taken with a clinometer at forty-five degree spacings from plot center to the surrounding horizons. Landform index quantifies the degree of site protection by landforms surrounding a plot, with high values of index (e.g., 40) occurring in coves and stream ravines where protection is high, and low values (e.g., 10) occurring on exposed sites such as ridgetops (McNab 1993). Aspect was measured with a compass.
5. The overstory canopy coverage was determined with a spherical densitometer. Four densitometer readings were taken at center of the plot while facing north, south, east, and west. These four readings were averaged. There are a total of 24 1/8" x 1/8" squares in the grids of densitometer. Each square represents an area of canopy opening or canopy cover. The number of canopy opening squares was

counted imagining four dots in each square. The canopy opening is determined by multiplying the number of dots by 1.04 and then this number is subtracted from 100% to find out overstory canopy coverage.

6. A comparision plot, 150 feet perpendicular to the road (which side of road was decided randomly with flip of a coin) was established (OFF road) and the same data collected.
7. The land use history was studied from the aerial photographs of the area to determine if the change in land use may have caused the spread of the invasive species.

Data Analysis:

The collected GPS information on woody invasive plants along roadsides was transferred into Mapsource software. With MapSource, we can: 1.Transfer saved waypoints, routes, and tracks from GPS and save them to PC; 2.Create, view, and edit waypoints, routes, and tracks; 3.Find items, addresses, and Points of Interest included in the map data; 4.Connect GPS to a portable PC for real-time tracking, and; 5.Transfer map data, waypoints, routes, and tracks to GPS. The data were stored as data base files (dbf) in Excel and converted to point shape files in Arc catalog. In Arc Map, aerial photographs of the Clemson Experimental Forest, the roads map layer, and the soil layer of the Clemson Experimental Forest were added. Then woody invasive plants point shape files were overlain on the road layers (Figure 3.2).

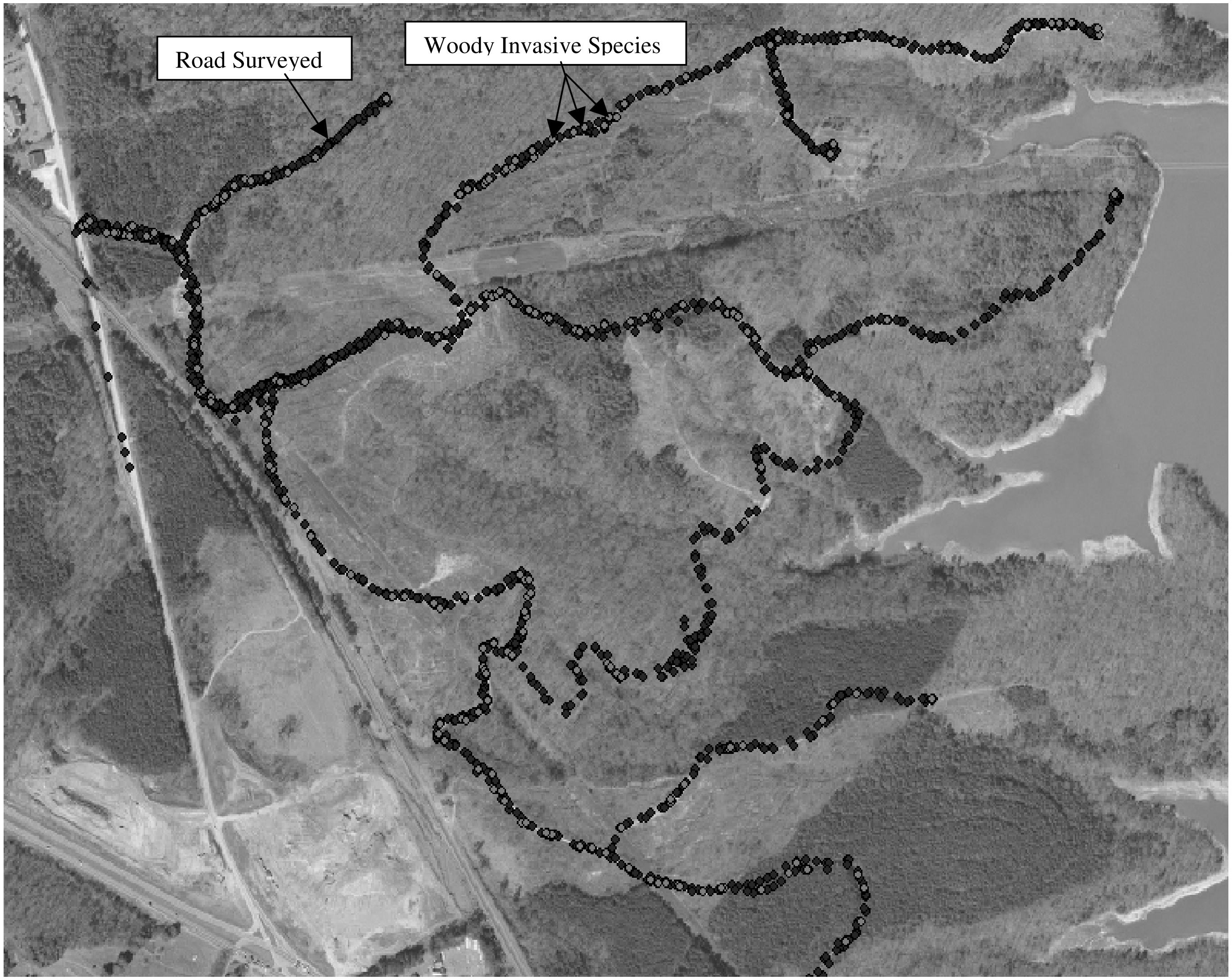

Figure 3.2. GIS Map of Woody Invasive Species on the Clemson Experimental Forest

The collected GPS information on woody invasive plants along roadsides was transferred from Mapsource software to a Garmin handheld GPS for the collection of the 2nd phase data at every 10th point. The collected data were stored in Excel and used for statistical analysis. Transformation of Aspect was done using the formula: Transformed Aspect (A') = Sin (A+45) +1 (Beers et al. 1966).

The data sheet was imported to SAS (9.1) and the following analyses were done. Analysis of correlation was done to determine the relationship between the following variables: Canopy, Aspect, Slope, LFI, and cover class.

Regression analysis was used to determine if there is multicolinearity among the variables. This is one of the difficulties related to the role of predictor variables in describing the response variable in the multiple linear regression model. When two or more independent variables are highly correlated this situation is known as multicolinearity.

Frequency analysis (Friedman Test--it is a non-parametric test for analyzing randomized complete block designs) was done to determine if there is difference in the variables viz: Canopy, Slope, Aspect, LFI, and cover class for ON road and OFF road, while controlling for sample site.

Frequency analysis was also done to determine if there is a difference in Canopy, Slope, Aspect, and LFI for Invasives presence and Invasives absence, blocking for sample site. This analysis was done for each of the most abundant individual species viz: Japanese honeysuckle, multiflora rose, Chinese privet, and shrubby lespedeza.

The Wilcoxon Rank Sum test was done to determine if there is a difference in slope and canopy for invasives presence and invasives absence in OFF road plots only.

A General Linear Mixed Model (GLMM) was developed to determine which variables viz: Canopy, Slope, Aspect, LFI, ON road (ROAD I), and their interaction variables were related to invasive species presence. The General Linear Mixed Model (GLMM) was used to correct for error nonconstant variability and non-normally distributed data.

Graphs were plotted in EXCEL to show the relationship between the Cover class of Invasives present ON Road vs. selected variables (Canopy, Slope, Aspect, and LFI). The graphs were also plotted for cover class of Invasives present OFF road (150 feet off road) vs. these same selected variables (Canopy, Slope, Aspect, and LFI).

CHAPTER FOUR

RESULTS

Out of total 1770 points of woody invasive plants collected during the first phase of data collection, Chinese privet occurred in the most number of points, followed by Japanese honeysuckle, multiflora rose, and shrubby lespedeza respectively (Figure 4.1).

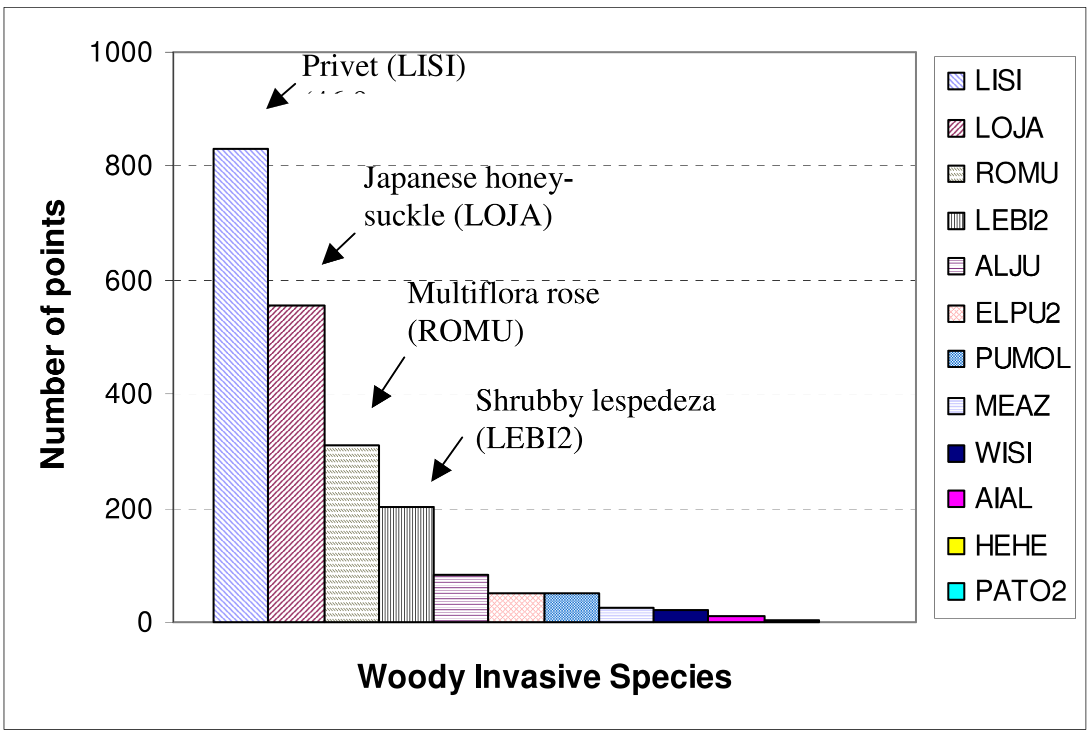

Figure 4.1. Abundance of Woody Invasive Species

Pueraria montana (PUMOL), *Ailanthus altissima* (AIAL), *Albizia julibrissin* (ALJU), *Melia azedarach* (MEAZ), *Elaeagnus pungens* (ELPU2), *Wisteria sinensis* (WISI), *Hedera helix* (HEHE), *Paulownia tomentosa* (PATO2)

During the second phase of data collection, 175 plots (every 10th plot of the original 1770 points) were sampled along the roadsides. Out of 175 plots along roadsides, Japanese honeysuckle was present in the most number of the points followed by Chinese privet, multiflora rose, and shrubby lespedeza respectively (Figure 4.2). Also, 175 paired 150 feet OFF road plots were sampled. Out of 175 paired 150 feet OFF road plots, Japanese honeysuckle was present in the most number of the points followed by Chinese privet, and shrubby lespedeza respectively (Figure 4.3). However there was a considable decrease in number of woody invasive species on OFF road plots compared with roadside plots.

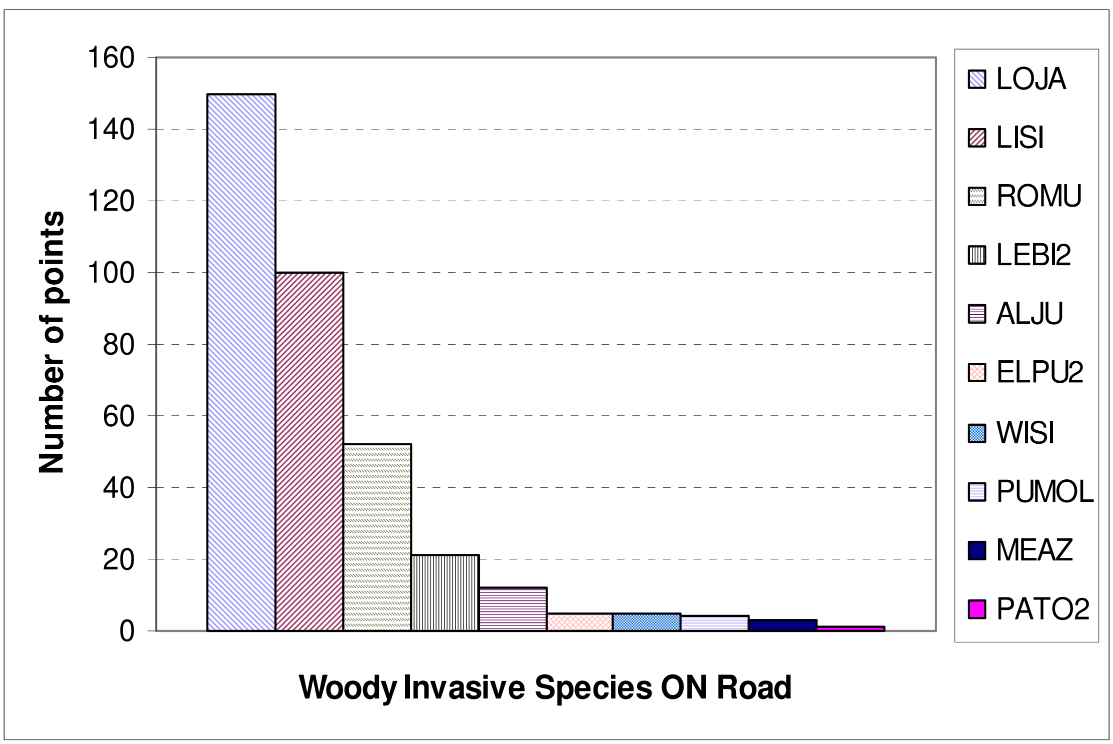

Figure 4.3. Abundance of Woody Invasive Species ON road.

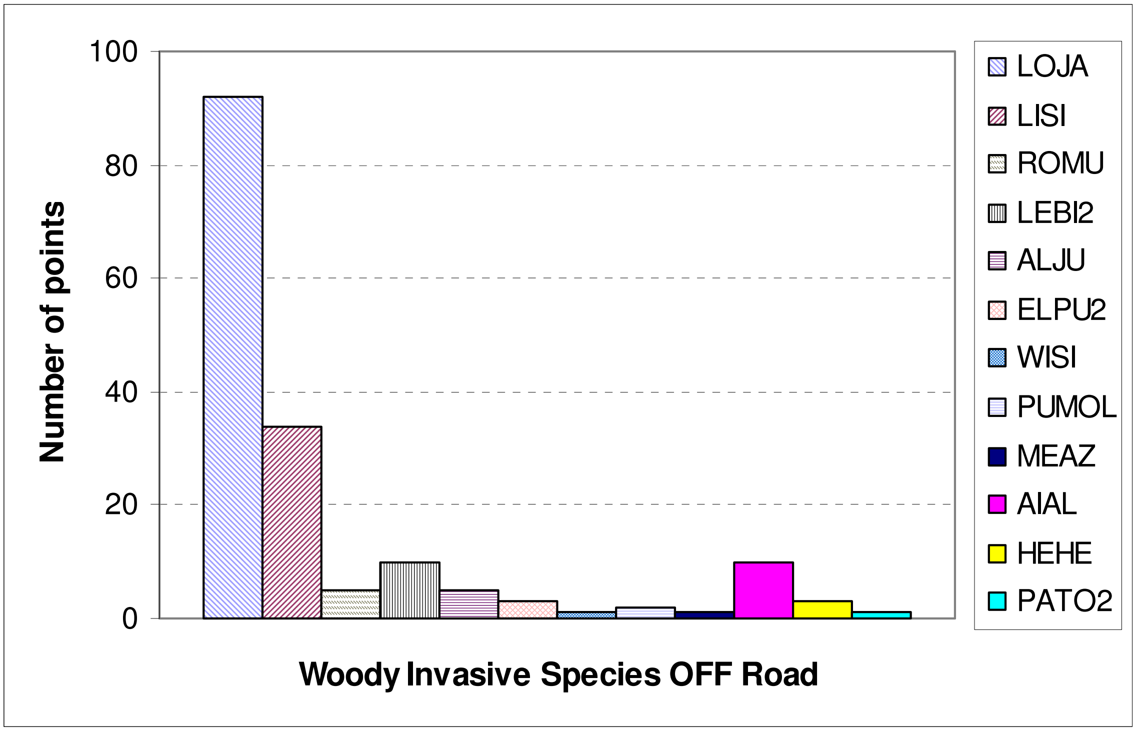

Figure 4.3. Abundance of Woody Invasive Species OFF road

Correlation analysis (Table 4.1) indicated that none of the variables was highly correlated. The variable overstory canopy was positively correlated with the variable Landform index ($r^2 = 0.401$, $p < .0001$) and slope ($r^2 = 0.209$, $p < .0001$) which indicated that high overstory canopy cover is associated with high landform index and high slope gradients.

The variables Canopy and Slope showed a highly significant negative relationship with the cover of invasives which indicated that high canopy cover and high slope gradient resulted in a lower abundance of the invasives.

Table 4.1. Correlation Analysis of Independent Variables.

	Canopy	Aspect	Slope	LFI	Privet cover	Japanese honeysuckle cover
Canopy	1	-0.028	0.20901	0.402	-0.1936	-0.29844
p-value		0.6049	<.0001	<.0001	0.025	<.0001
Number of plots	344	343	342	342	134	241
Aspect	-0.028	1	0.03759	0.034	-0.0532	0.0716
p-value	0.6049		0.4884	0.526	0.5417	0.2682
Number of plots	343	343	342	342	134	241
Slope	0.20901	0.03759	1	0.132	-0.2925	-0.31466
p-value	<.0001	0.4884		0.015	0.0006	<.0001
Number of plots	342	342	342	342	134	241
LFI	0.4018	0.03444	0.13204	1	0.10297	-0.31466
p-value	<.0001	0.5256	0.0145		0.2364	<.0001
Number of plots	342	342	342	342	134	241
Privet cover	-0.1936	-0.0532	-0.2925	0.103	1	
p-value	0.025	0.5417	0.0006	0.236		
Number of plots	134	134	134	134	134	
Japanese honeysuckle cover	-0.2984	0.0716	-0.3147	-0.31		1
p-value	<.0001	0.2682	<.0001	<.0001		
Number of plots	241	241	241	241		241

Regression analysis (Table 4.2) indicated that there was no multicolinearity among variables, since all the values of variance inflation (VIF, these factors are a measure of the multi-colinearity in a regression design matrix) are less than 10 (when VIF values are high for any of the independent variables, model fit is affected by multicolinearity). Thus, all the independent variables can be included in the model for predicting the response variable, presence of invasives.

Table 4.2. Testing for Multi Colinearity among Independent Variables

Variable	Label	DF	Estimate	Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	1.77123	0.09473	18.70	<.0001	0
ON road		1	-0.34150	0.05307	-6.44	<.0001	1.16251
Canopy	Canopy	1	-0.00030	0.00105	-0.32	0.7504	1.37181
Aspect	Aspect	1	-0.01980	0.03554	-0.56	0.5780	1.00995
Slope	Slope	1	0.00659	0.00274	2.40	0.0168	1.07066
LFI	LFI	1	-0.00110	0.00308	-0.37	0.7123	1.23672

Frequency analysis (Table 4.3) indicated that there was a significant difference in canopy, slope, and cover class of invasives for ON road vs. OFF road. Lower overstory canopy, low slope gradient, and high abundance of invasives were associated with ON road as compared with high overstory canopy, high slope gradient, and lower abundance of invasives found OFF road. However, the difference in Aspect and LFI were non-significant for ON road vs. OFF road.

Average cover class of Chinese privet was 5.56 ON road and 4.353 OFF road which indicated that this species covered approximately 5 to 10% of the sample plot area ON road where as it covered 2 to 5% of the sampled site OFF road. Also this species was found to occur on 100 of the sampled plots ON road but in OFF road plots, it occurred on only 34 plots. Similarly for Japanese honeysuckle, the average cover class in 150 sampled sites was 5.134 (covering 5 to 10% of sampled site) ON road and 3.848 in 92 sampled plots (covering 2 to 5% area) OFF road. However for multiflora rose and shrubby lespedeza, the occurrence in the number of sampled plots was much less in the OFF road (multiflora rose in 5 plots and shrubby lespedeza on 10 plots) as compared to their occurrence (52 plots for multiflora rose and 21 plots for shrubby lespedeza) ON road. The difference in occurrence and abundance of individual invasive species between ON road and OFF road may be mainly due to disturbances along roadsides, low canopy coverage by the dominant trees, and relatively flat areas.

Table 4.3. Average values of landscape variables and cover of invasive species for ON road and OFF road plots.

Variables	ON Road	OFF Road
Slope (%)	*9.4	12.7
Landform Index (%)	25.7	25.2
Canopy cover (%)	*55.588	71.476
Chinese privet average cover class	*5.56 (100 sites)	4.353 (34 sites)
Japanese honeysuckle average cover class	*5.134 (150 sites)	3.848 (92 sites)
Multiflora rose average cover class	*6.0 (52 sites)	4.8 (5 sites)
Shrubby lespedeza average cover class	5.56 (21 sites)	4.353 (10 sites)

* Significant at 0.05 level

Frequency analysis for all invasives (presence vs. absence) revealed that the differences in canopy and slope were significant. The mean slope gradient and mean canopy cover for all invasive species presence were lower than the mean slope gradient and mean canopy cover for invasives absence (Table 4.4). But for OFF road plots only, there was no significant difference in canopy cover and slope gradient for invasives presence and absence. This indicates that the significant differences in canopy and slope noted above were due to conditions on the ON ROAD plots only which implies more heterogeneity in these plots than the OFF ROAD plots. In other words, slope and canopy were not a factor in OFF ROAD invasives presence vs absence but were a factor in the ON ROAD plots. Also, there was no difference for aspect and LFI associated with all invasives presence and absence. Similar results were obtained when the frequency analysis was done for the individual invasive species viz: Japanese honeysuckle, Chinese privet, multiflora rose, and shrubby lespedeza.

Table 4.4. Average values of landscape variables for Invasives presence and absence.

Species	Slope%		LFI %		Canopy%		Aspect degrees	
	P	A	P	A	P	A	P	A
Invasives	*9.812	16.83	25.611	24.677	*62.071	71.098	0.89 (173.34)	0.90 (162.79)
Japanese honeysuckle	*9.231	15.24	25.748	24.75	*62.8	65.568	0.89 (175.16)	0.90 (162.96)
Chinese privet	*8.974	12.39	25.692	25.191	*60.23	65.3	0.94 (160.80)	0.87 (178.59)
Multiflora rose	*9.448	11.34	26.982	25.137	*64.053	63.315	0.92 (166.84)	0.89 (172.48)
Shrubby lespedeza	*10.6	11.06	19.07	26.06	*39.264	66.045	0.92 (144.06)	0.89 (174.16)

P- Invasive species presence, A- Invasive species absence

* Significant at 0.05 level

GLIMMIX analysis determined the variables responsible for invasives presence and the predicted probability of invasives presence on that particular site. For all invasive species present (Table 4.5), canopy, slope, and their interaction variables were significant which suggests that areas in the Clemson Experimental Forest with low canopy cover or more open canopy and relatively flat slope have a greater chance of invasion.

Table 4.5: Effect of independent variables and their interaction for woody invasive species presence

Effect	Numerator DF	Denominator DF	F Value	Pr > F
Canopy	1	153	1.16	0.2832
LFI	1	153	1.84	0.1769
Aspect	1	153	0.53	0.4698
Slope	1	153	1.14	0.288
CA	1	153	0.73	0.3941
CS	1	153	4.2	0.042
CL	1	153	1.8	0.1815
AS	1	153	0.98	0.3226
AL	1	153	1.95	0.1646
SL	1	153	1.74	0.1888
ROADI	1	153	1.59	0.2098
RC	1	153	0.03	0.8684
RA	1	153	0.38	0.5388
RS	1	153	0.2	0.6539
RL	1	153	0.32	0.572

canopy*aspect (CA), canopy*slope (CS), canopy*LFI (CL), aspect*slope (AS), aspect*LFI (AL), slope*LFI (SL),ONroad*canopy (RC), ONroad*aspect (RA), ONroad*slope (RS), and ONroad*LFI (RL)

For Chinese privet and Japanese honeysuckle presence (Tables 4.6 and 4.7), the variables slope, road, canopy, LFI, canopy*LFI, and road*LFI were significant. Presence of Chinese privet and Japanese honeysuckle were associated with lower slope, road habitat, and higher canopy opening but there was a canopy landform index and road landform index interaction found in the model. This indicated that these two species prefer roadside habitat with relatively gentle slopes where there is more propagule pressure due to flow from surrounding areas by different means (anthropogenic, mammals, birds). They were also present in higher canopy openings due to the availability of more sunlight (though Chinese privet is a shade tolerant plant, but it does well in sunlight). The interaction effect of the canopy landform index and road landform index indicated that geomorphic position of the landform may interact with road habitat and canopy openings of the dominant tree vegetation for occurrence and spread of invasive species.

Table 4.6: Effect of independent variables and their interaction for Chinese privet presence

Effect	Num DF	Den DF	F Value	Pr > F
Canopy	1	153	1.73	0.191
LFI	1	153	2.2	0.1397
Aspect	1	153	0.56	0.4557
Slope	1	153	7.62	0.0065
CA	1	153	0.01	0.9409
CS	1	153	1.05	0.307
CL	1	153	7.6	0.0065
AS	1	153	1.47	0.2266
AL	1	153	0.28	0.5956
SL	1	153	3.03	0.0835
ROADI	1	153	31.55	<.0001
RC	1	153	0.13	0.7182
RA	1	153	2.16	0.1437
RS	1	153	0.85	0.359
RL	1	153	6.55	0.0115

Table 4.7: Effect of independent variables and their interaction for Japanese honeysuckle presence

Effect	Num DF	Den DF	F Value	Pr > F
Canopy	1	153	0.83	0.3639
LFI	1	153	2.09	0.15
Aspect	1	153	0.02	0.9011
Slope	1	153	21.16	<.0001
CA	1	153	0.06	0.8049
CS	1	153	4.2	0.0422
CL	1	153	8.56	0.004
AS	1	153	0.33	0.5691
AL	1	153	5.15	0.0246
SL	1	153	1.09	0.2992
ROADI	1	153	20.66	<.0001
RC	1	153	1.96	0.1638
RA	1	153	0.33	0.566
RS	1	153	0.02	0.8869
RL	1	153	0.06	0.8057

For multiflora rose presence (Table 4.8) slope, road, canopy, LFI, aspect, canopy*LFI, canopy*slope, and aspect*slope were significant which indicated that all the landscape variables had a significant effect on the occurrence and abundance of multiflora rose. Roadsides with relatively flat slope and higher canopy opening areas were the suitable habitats for multiflora rose presence.

Table 4.8: Effect of independent variables and their interaction
For multiflora rose presence

Effect	Num DF	Den DF	F Value	Pr > F
Canopy	1	153	0.21	0.6436
LFI	1	153	0.62	0.4329
Aspect	1	153	3.12	0.0795
Slope	1	153	3.07	0.0815
CA	1	153	0.45	0.5017
CS	1	153	4.66	0.0324
CL	1	153	7.53	0.0068
AS	1	153	6.61	0.0111
AL	1	153	1.51	0.2215
SL	1	153	1.36	0.2447
ROADI	1	153	14.11	0.0002
RC	1	153	0.18	0.673
RA	1	153	2.82	0.0949
RS	1	153	0.07	0.7852
RL	1	153	0.57	0.4518

For shrubby lespedeza presence (Table 4.9) canopy cover was highly significant which revealed that shrubby lespedeza is mostly present in open areas with lower canopy cover.

Table 4.9: Effect of independent variables and their interaction
for shrubby lespedeza presence

Effect	Num DF	Den DF	F Value	Pr > F
Canopy	1	153	9.79	0.0021
LFI	1	153	3.31	0.0708
Aspect	1	153	0.01	0.907
Slope	1	153	0.56	0.456
CA	1	153	0	0.9736
CS	1	153	0.91	0.3411
CL	1	153	0	0.9884
AS	1	153	0.05	0.8156
AL	1	153	2.81	0.0959
SL	1	153	0.91	0.3411
ROADI	1	153	2.42	0.1219
RC	1	153	0.28	0.5996
RA	1	153	0	0.945
RS	1	153	0.17	0.6789
RL	1	153	0.03	0.8572

All the GLIMMIX analysis for individual species indicated that predicted probability of invasives presence was less in OFF road as compared to ON road (see Appendix B).

The plotted graphs between cover of invasives present ON Road vs. associated variables (canopy, slope, and LFI) ON road showed an inverse relationship (Figures 4.4, 4.5, and 4.6) i.e abundance of invasives decreases with increase of variables (canopy, slope, and LFI). But the graph plotted between cover of invasives present ON Road vs. corresponding transformed aspect had a direct relationship (Figure 4.7) i.e abundance of invasives increases with an increase of transformed aspect for ON road plots. The percentage cover of invasives in the sampled plots ON road was high irrespective of any aspect direction.

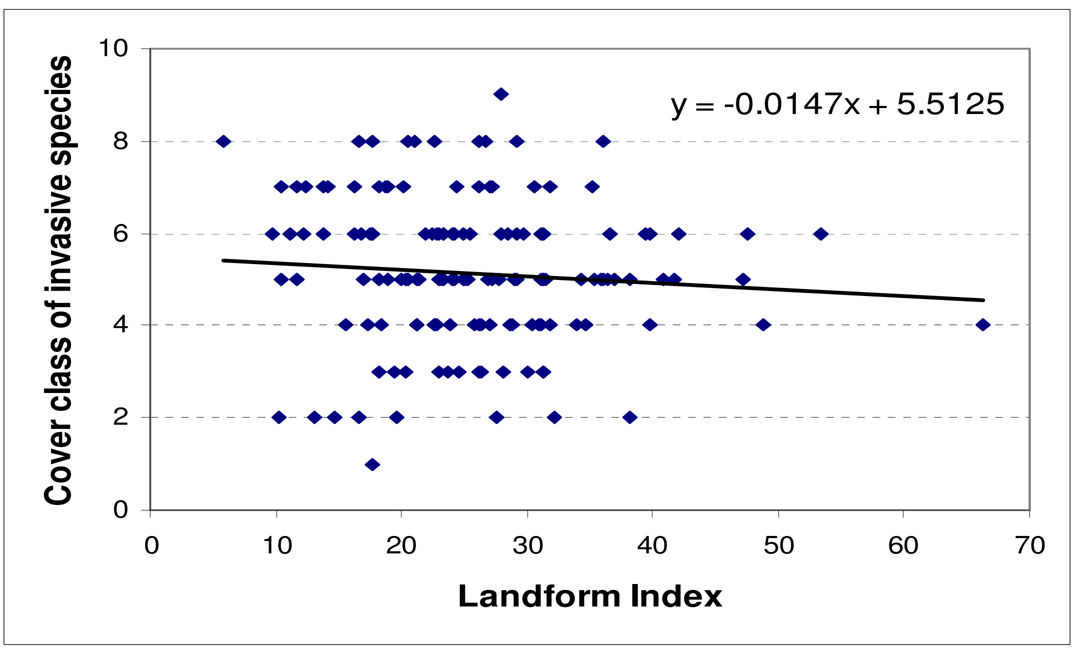

Figure 4.4. Nonsignificant Correlation of Landform Index and Abundance of Woody Invasive Species ON road

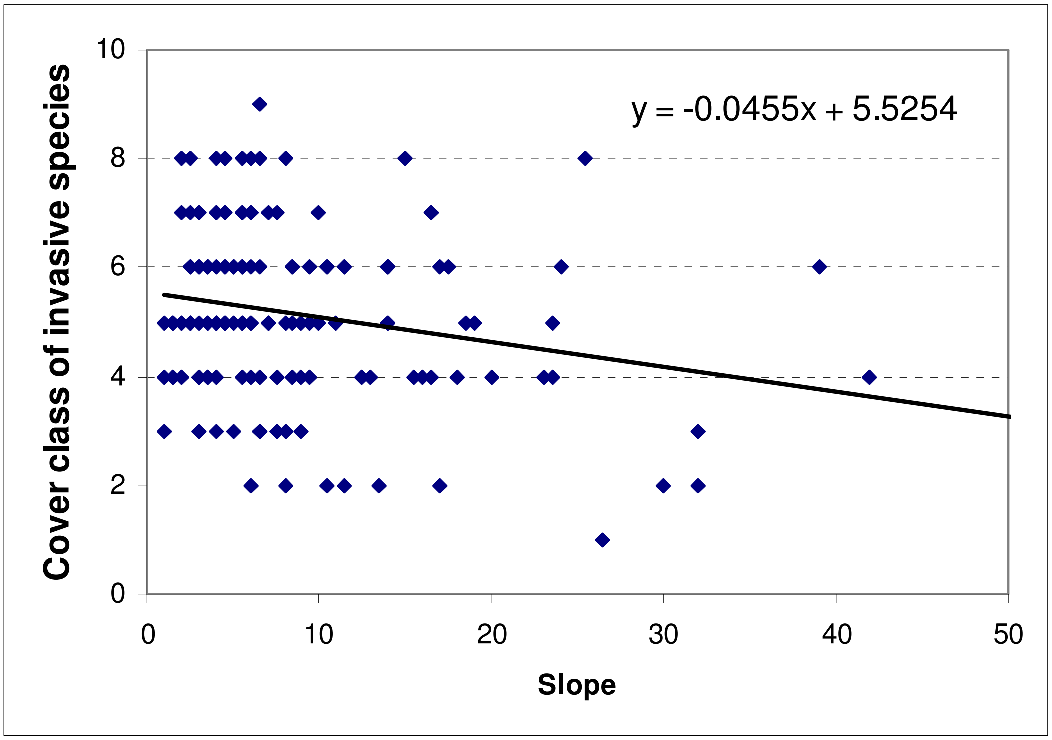

Figure 4.5. Significant Correlation of Slope and Abundance of Woody Invasive Species ON road

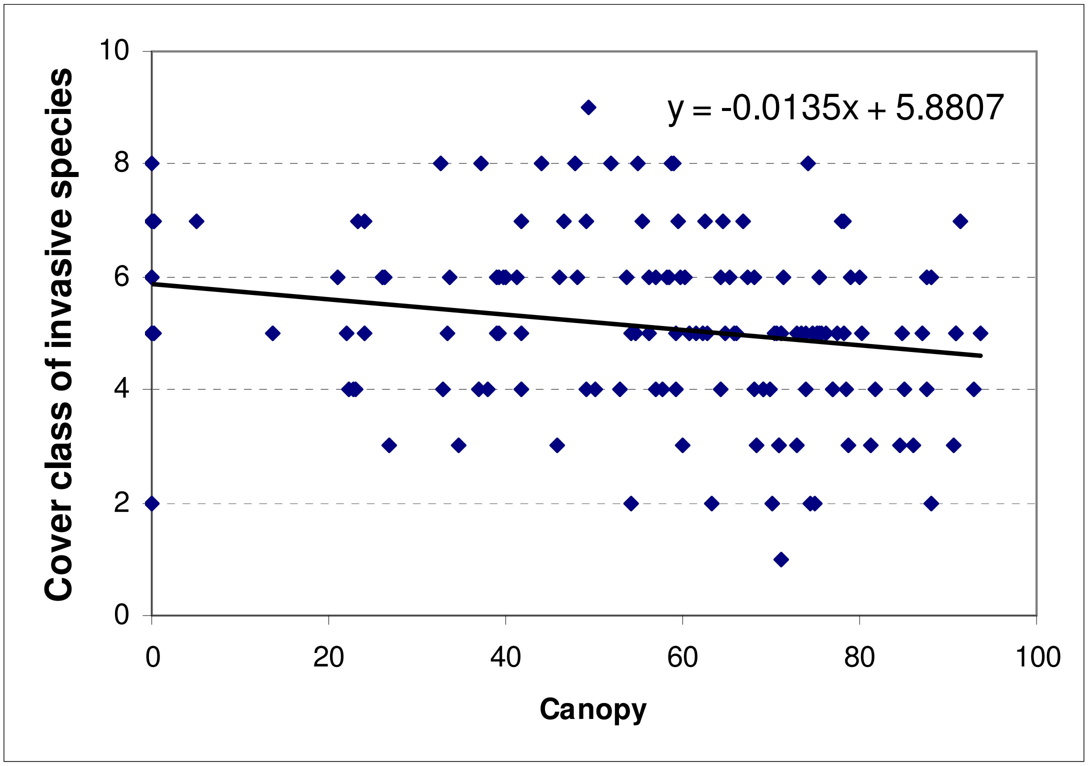

Figure 4.6. Significant Correlation of Canopy and Abundance of Woody Invasive Species ON road

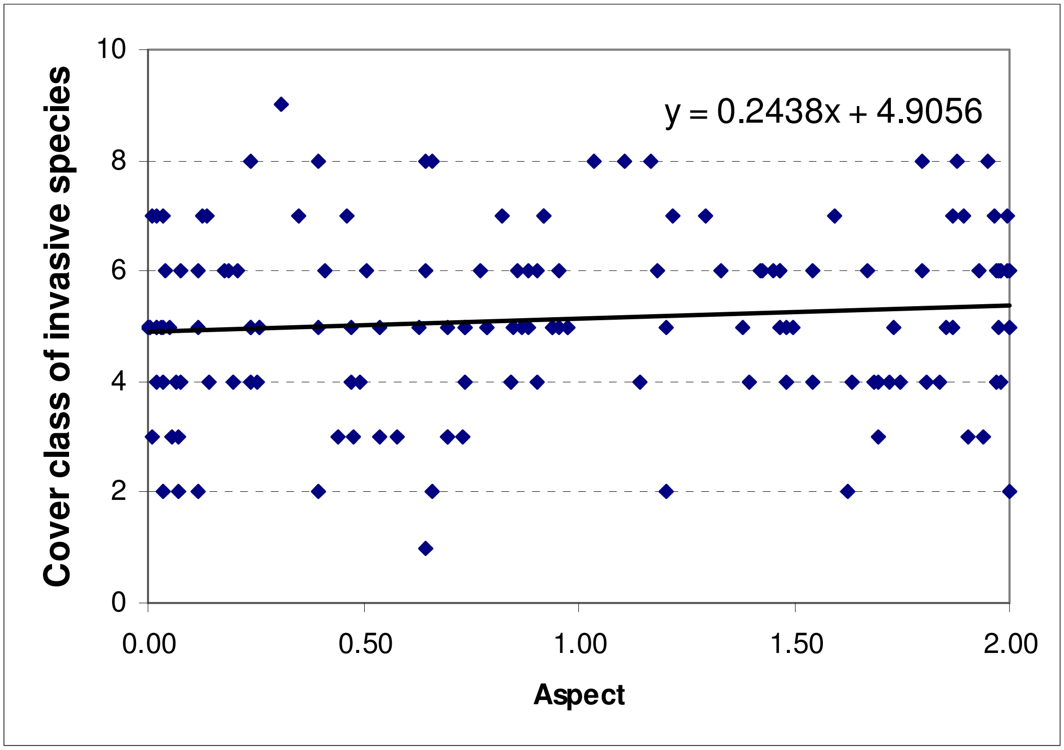

Figure 4.7. Nonsignificant Correlation of Aspect and Abundance of Woody Invasive Species ON road

Aspect value of 0.00 represents 225^0-230^0, 0.50 represents 165^0 and 285^0, 1.00 represents 135^0 and 315^0, 1.50 represents 105^0 and 345^0, and 2.00 represents 45^0.

Similar plots (Figure 4.8, 4.9, and 4.10) were obtained when the graphs were plotted between Cover of invasives present OFF Road vs. Associated Variables (Canopy, Slope, and LFI), however there was a negative relationship (Figure 4.11) shown between OFF road transformed aspect and cover of invasive (as opposed to a positive relationship for ON road). The percentage cover of invasives in the sampled plots OFF road was slightly higher in southerly aspect positions than northerly aspects but not significantly.

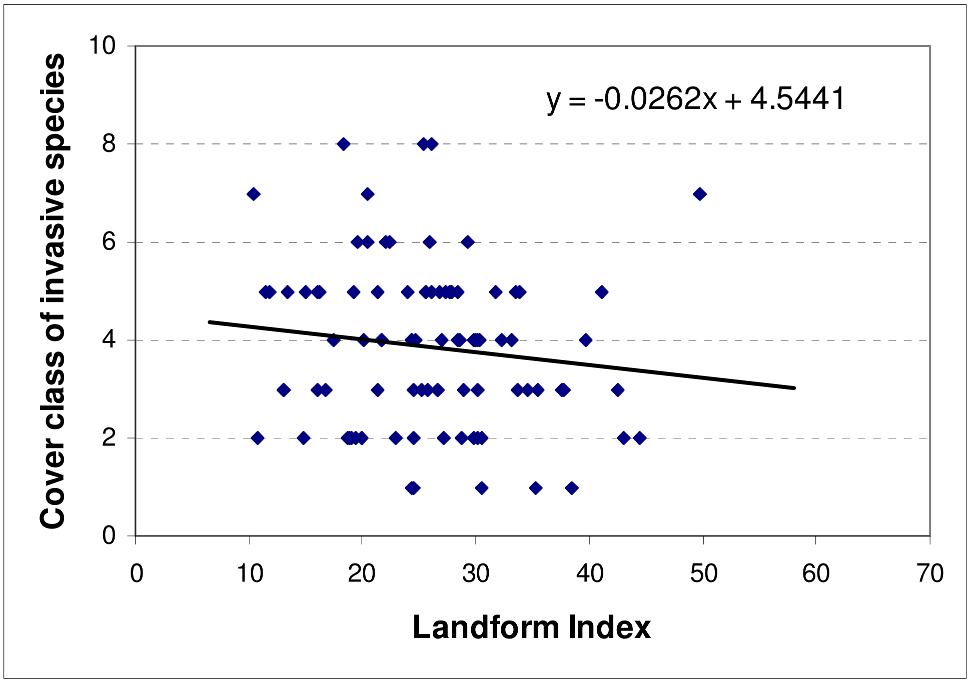

Figure 4.8. Nonsignificant Correlation of Landform Index and Abundance of Woody Invasive Species OFF road

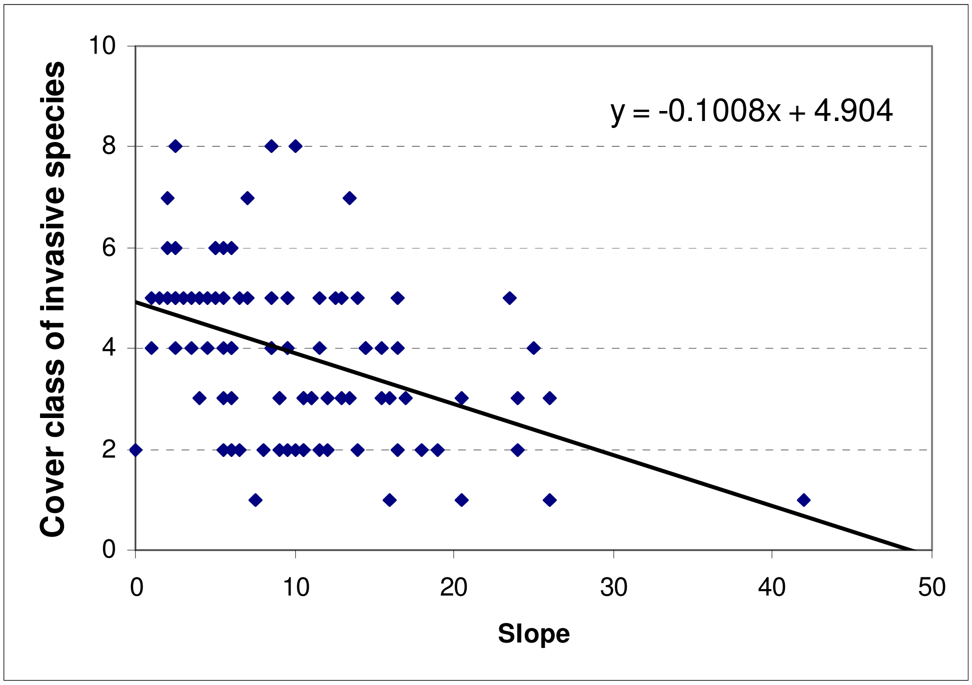

Figure 4.9. Significant Correlation of Slope and Abundance of Woody Invasive Species OFF road

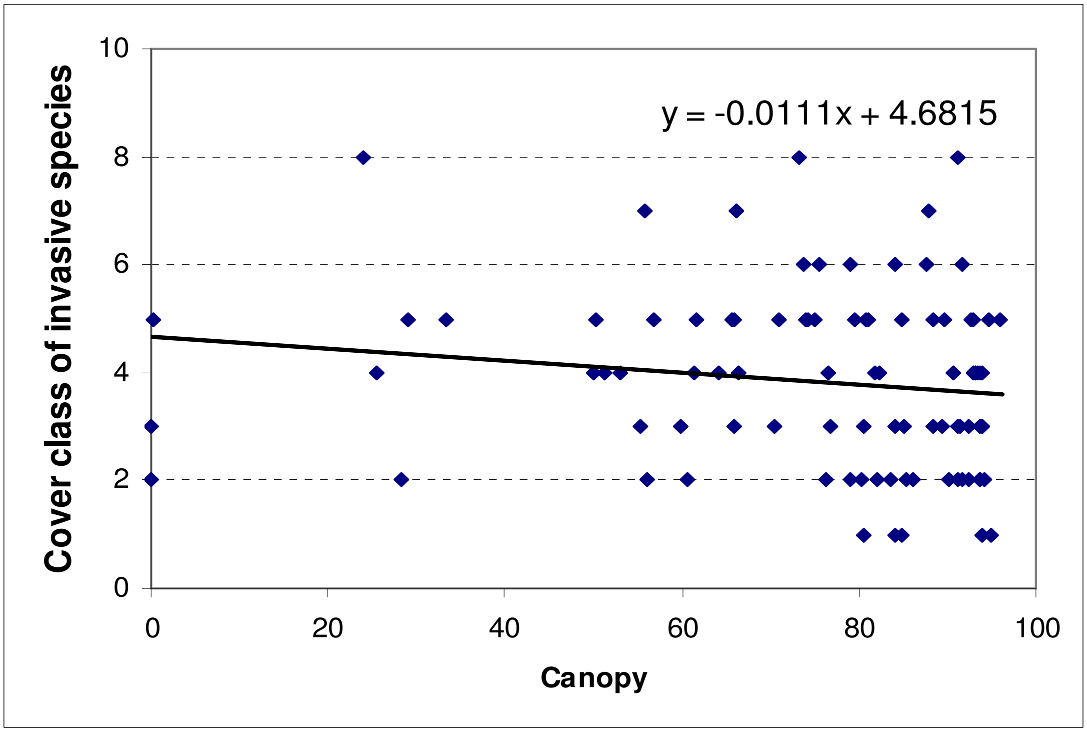

Figure 4.10. Significant Correlation of Canopy and Abundance of Woody Invasive Species OFF road

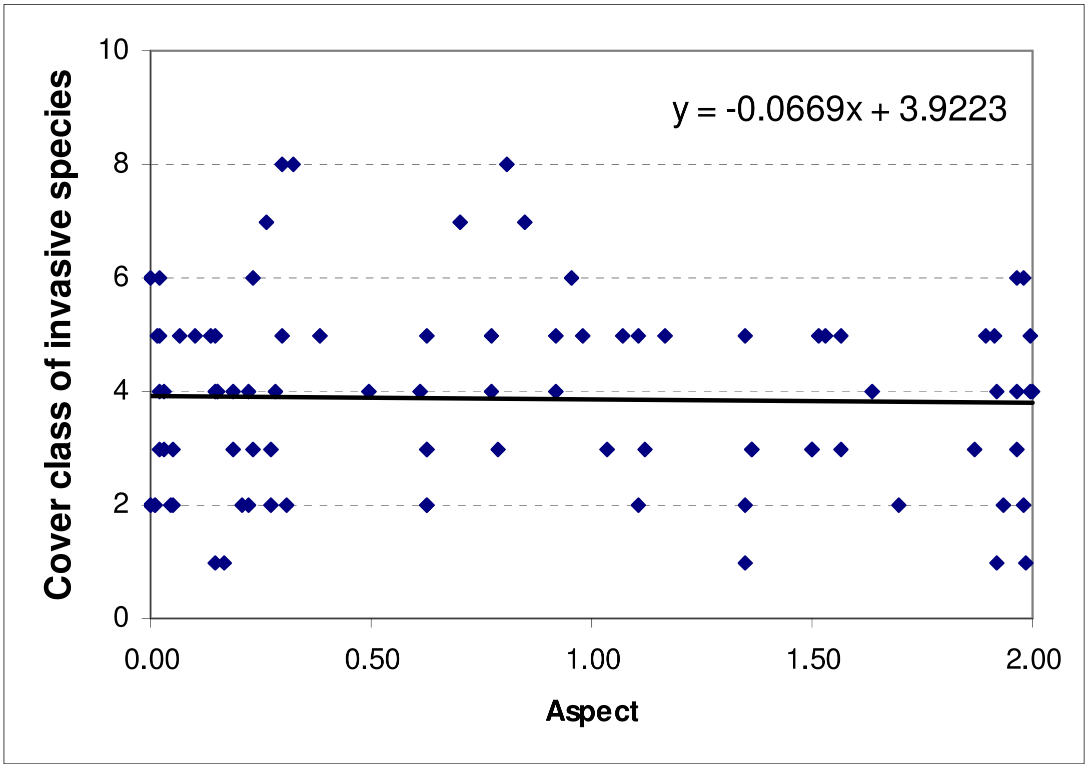

Figure 4.11. Nonsignificant Correlation of Aspect and Abundance of Woody Invasive Species OFF road

Aspect value of 0.00 represents 225^0-230^0, 0.50 represents 165^0 and 285^0, 1.00 represents 135^0 and 315^0, 1.50 represents 105^0 and 345^0, and 2.00 represents 45^0

Land use study from aerial photographs revealed that the study area was primarily submarginal farmland until the mid-1930. From 1935 until 1939, conservation projects were carried out on the major portion of the area which included construction of recreational areas, establishment of pine plantations, and enhancement of wildlife habitat. After the development of Lake Hartwell, the average size of stands on the forest was between five and ten acres. The climax forest of the region was an oak-hickory type, but intensive use of the land for agriculture and an absence of sound forestry practices (before the 1930’s) resulted in very few high quality timber areas in the climax type. Stands of mixed pine and hardwood occur on the study area. Land used for agriculture and residences was present on the area in addition to the land in forest use. In many cases, these uses were found in close association with the forest uses, causing delineation between the uses to be uncertain. For example, some areas were wooded but serve as shaded areas in an area of residential use. Also, old agricultural fields were abandoned for several years and were seeded by volunteer pine species. Significant land use changes were detected when past and current aerial photographic coverages were compared. A large decrease in agricultural land, a conversion of bottomland hardwoods to a lake, an increase in the amount of urban and built-up land, and an increase in pine plantation areas were detected. Major land use changes, occurring on the area during the last several decades, furnished a favorable situation for the spread of invasive species.

However, quantification of these changes in an aerial extent was difficult to determine and the actual ability to quantify these changes on the spread of invasives remains elusive.

CHAPTER FIVE

DISCUSSION

Woody invasive species were widespread, abundant, and diverse in the Clemson Experimental Forest, of South Carolina. Woody invasive species were found on all of the 175 sampled sites ON road. Some of these plots were subset of the 1770 pints where invasive were originally found. The woody invasive encountered were Japanese honeysuckle, multiflora rose, kudzu, Chinese privet, tree of heaven, mimosa, Chinaberry tree, silverthorne, Cinese wisteria, and shrubby lespedeza. These species were documented as invasive in 13 Southern States of the United States. The present study and the literature both suggested that woody invasive plants possess a suite of characteristics making them well adapted to invade forests with varying disturbance levels. These characteristics include: (a) wide distribution by avian and human vectors; (b) wide tolerance of edaphic conditions; (c) extensive powers of photosynthetic acclimation (Patterson 1975); (d) rapid extension growth; (e) ability to climb supports of varying sizes (Silveri et al. 2001).

Our results suggested that roadsides in Clemson Experimental Forest have more woody invasive species because of higher propagule flow from surrounding areas, frequent grazing, and higher sunlight due to open canopies (Wilson et al. 1992, Finckh & Thommas 1997, Milton & Dean 1998, Parendes & Jones 2000). The significantly greater occurrence of invasive species along roadsides than in the forest interior may result from various forms of human disturbance. McCarthy et al. (2001) in the central Appalachians and Parendes and Jones (2000) found that invasive plant species were almost completely restricted to roadsides, open fields, and recent clearcuts and almost entirely absent under mature or old growth forests.

Lower abundance of invasives found in OFF road forests may be caused by (1) higher slope gradient; (2) lower light availability due to a closer canopy; (3) a thick litter layer and a low proportion of bare soil, which limit the establishment of invasive species (Myster 1994, Finckh 1996, Parendes & Jones 2000, Mazia et al. 2001). This explained our findings regarding abundance of invasives in OFF road and associated landscape variables on that site. Cover of woody invasive species were higher ON road irrespective any aspect direction, but in OFF road sites, there was a higher abundance of invasives found in southerly aspects which means that woody invasives were adapted to relatively high solar radiation.

We found that the presence of woody invasive species was associated with low slope gradient as compared to the absence of woody invasive species, which was supported by the findings of Underwood et al. (2004). Slope gradient between 0 to 10% had higher abundance of woody invasives which indicated that these invasive species have tended to invade lower slope areas. However, the abundance of invasives drastically decreased above a 30% slope gradient.

Invasive species occurrence and abundance approaches maximum at landform index values of 10 to 30% (with low values (e.g., 10) occurring on exposed sites such as ridgetops) which implies more canopy opening and higher solar radiation but abundance reaches a minimum at landform index value above 40% (as high values of index (e.g., 40) occurring in coves and stream ravines where protection is high (McNab 1993).

Land use directly affects the invasion process because it modifies disturbance regimes and environmental condition. It can also affect the invasion process by creating sources of propagules in the landscape. Areas with high human intervention such as agricultural land, serves as sources for invasions into more pristine environments (Tyser & Worley 1992, Hobbs 2000, Parendes & Jones 2000). Previous work has shown that colonization rates of invasive species tends to increase near abandoned agricultural fields (Elmore et al. 2003).This supports our historical land use study in Clemson Experimental Forest. Propagule pressure from these sources appears the most influential mechanism by which land use affects the abundance and distribution of invasive species in roadsides (Pauchard & Alaback 2004).

The difference in slope gradient and canopy cover for invasives presence vs. absence were found statistically significant. But biological significance of this result is questionable. In many sampled plots, it has been noticed that the abundance of woody invasive species were higher even in higher slope gradient and high canopy cover. So further research is required for the validity of this research.

The cover class of woody invasive species were found high near water courses like roads near to creek and swampy areas, and areas near to the gate of the forest roads. The main reason for high abundance of invasives in these areas is due to high propagule flow by different means (water, vehicles, anthropological disturbances etc). So findings of this study can be used as base line data for further reseach like spread of invasives through water courses and near forest gates.

CHAPTER SIX

CONCLUSION

This study demonstrates the relationship between woody invasive species, landscape variables, and historical land use. Results of this study indicate the probability of occurrence and abundance of woody invasive species in the Clemson Experimental Forest, specifically in the Southern Inner Piedmont of South Carolina are greater along the roadsides with lower slope gradients i.e relatively flat areas and where the overstory canopy cover is low. The GIS map of woody invasive plants in Clemson Experimental Forest should be used primarily for locating these invasives and predicting the future risk to the forest ecosystem due to invasion. Although this study was conducted at the Clemson Experimental Forest in South Carolina, the general results regarding woody invasive species' habitat preferences may be applicable over a broader area of the Southern Inner piedmont of South Carolina. Additional validation of this study is desirable over a broader geographical area.

If forest managers need occurrence and abundance information on woody invasive species in general, the techniques of this study are applicable. The invasive species inventory developed in the study area can easily be adapted for larger, landscape-scale inventories that may include other invasive species that can occur in a forested environment.

The factors that constrain the distribution of woody invaders must be known to evaluate the threat of invasion or potential for restoration of a specific plant community (Parker et al. 1993). This study aids in the understanding of site and landscape variables that may encourage successful establishment of invasives on a particular site and increases the ability to predict areas of potential invasion. Because the control of woody invasive species in natural areas is a time- and resource-intensive task, this information may be used to direct conservation efforts by efficiently predicting and managing biological invasions.

APPENDICES

Appendix A

The FREQUENCY Procedure

Summary Statistics for Road by Canopy
Controlling for Site

Cochran-Mantel-Haenszel Statistics (Based on Rank Scores)

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	62.5828	<.0001
2	Row Mean Scores Differ	1	62.5828	<.0001

Effective Sample Size = 344
Frequency Missing = 6

The FREQ Procedure

Summary Statistics for Road by Aspect
Controlling for Site

Cochran-Mantel-Haenszel Statistics (Based on Rank Scores)

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	1.0120	0.3144
2	Row Mean Scores Differ	1	1.0120	0.3144

Effective Sample Size = 343
Frequency Missing = 7

The FREQ Procedure

Summary Statistics for Road by Slope
Controlling for Site

Cochran-Mantel-Haenszel Statistics (Based on Rank Scores)

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	23.4390	<.0001
2	Row Mean Scores Differ	1	23.4390	<.0001

Effective Sample Size = 342
Frequency Missing = 8

The FREQ Procedure

Summary Statistics for Road by LFI
Controlling for Site

Cochran-Mantel-Haenszel Statistics (Based on Rank Scores)

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	0.1515	0.6971
2	Row Mean Scores Differ	1	0.1515	0.6971

Effective Sample Size = 342
Frequency Missing = 8

The FREQ Procedure

Summary Statistics for Road by code
Controlling for Site

Cochran-Mantel-Haenszel Statistics (Based on Rank Scores)

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	7.7586	0.0053
2	Row Mean Scores Differ	1	7.7586	0.0053

Effective Sample Size = 134
Frequency Missing = 216

The FREQ Procedure

Summary Statistics for LISIC by Canopy
Controlling for Site

Cochran-Mantel-Haenszel Statistics (Based on Rank Scores)

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	15.5152	<.0001
2	Row Mean Scores Differ	1	15.5152	<.0001

Effective Sample Size = 344
Frequency Missing = 6

The FREQ Procedure

Summary Statistics for LISIC by Aspect
Controlling for Site

Cochran-Mantel-Haenszel Statistics (Based on Rank Scores)

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	1.5152	0.2184
2	Row Mean Scores Differ	1	1.5152	0.2184

Effective Sample Size = 343
Frequency Missing = 7

The FREQ Procedure

Summary Statistics for LISIC by Slope
Controlling for Site

Cochran-Mantel-Haenszel Statistics (Based on Rank Scores)

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	4.3134	0.0378
2	Row Mean Scores Differ	1	4.3134	0.0378

Effective Sample Size = 342
Frequency Missing = 8

The FREQ Procedure

Summary Statistics for LISIC by LFI
Controlling for Site

Cochran-Mantel-Haenszel Statistics (Based on Rank Scores)

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	0.0149	0.9028
2	Row Mean Scores Differ	1	0.0149	0.9028

Effective Sample Size = 342
Frequency Missing = 8

Appendix B

Table: Predicted probability of invasives on each sample site

Obs	Site	Road	Canopy	Aspect deg.	Aspect	Slope	LFI	PREDPROB	PREDPROB_PA
1	1	ON	91.42	40	0.82	5.5	19.00	0.99977	0.99976
2	1	OFF	92.46	48	0.05	0.0	19.88	0.88843	0.88678
3	2	ON	75.82	156	0.94	4.0	35.88	0.99989	0.99989
4	2	OFF	83.62	10	0.00	5.5	20.00	0.78617	0.78079
5	3	ON	60.22	320	1.54	5.0	42.13	0.99806	0.99803
6	3	OFF	75.04	276	1.53	3.0	16.25	0.88962	0.88797
7	4	ON	84.66	78	0.54	7.5	31.38	0.99997	0.99997
8	4	OFF	75.56	192	0.02	2.5	19.63	0.82493	0.82115
9	5	ON	0.00	86	0.19	11.5	17.50	0.99999	0.99999
10	5	OFF	0.00	292	0.25	21.0	17.75	0.85085	0.84802
11	6	ON	5.00	318	0.01	16.5	24.38	1.00000	1.00000
12	6	OFF	55.80	348	0.70	13.5	20.50	0.68094	0.67058
13	7	ON	38.90	24	0.89	5.5	24.25	0.99979	0.99977
14	7	OFF	74.00	354	0.98	23.5	19.25	0.48104	0.46187
15	8	ON	23.19	150	1.22	6.0	14.13	0.99784	0.99775
16	8	OFF	50.00	30	0.61	11.5	21.75	0.70881	0.69976
17	9	ON	71.14	147	0.65	26.5	17.75	0.99975	0.99976
18	9	OFF	88.56	186	0.00	32.5	16.88	0.07804	0.07887
19	10	ON	22.26	350	0.25	20.0	22.63	1.00000	1.00000
20	10	OFF	95.00	349	0.04	26.5	19.38	0.15517	0.15821
21	11	ON	0.00	321	2.00	11.5	9.75	0.94181	0.93876
22	11	OFF	66.20	248	0.26	7.0	10.38	0.69258	0.68092
23	12	ON	0.00	162	0.66	14.5	14.38	0.99994	0.99993
24	12	OFF	78.68	160	0.29	23.0	17.50	0.37178	0.35031
25	13	ON	0.00	58	1.62	11.5	10.25	0.98904	0.98831
26	13	OFF	0.00	42	0.18	2.5	11.88	0.56672	0.55049
27	14	ON	34.58	264	1.90	8.0	19.38	0.97445	0.97512
28	14	OFF	90.00	333	1.85	35.0	22.38	0.21222	0.21688
29	15	ON	78.42	147	0.65	19.5	22.75	0.99985	0.99986
30	15	OFF	80.76	147	0.65	21.5	27.38	0.51995	0.53913
31	16	ON	0.00	60	0.03	6.0	10.38	0.99998	0.99998
32	16	OFF	0.00	3	0.23	13.5	13.00	0.71272	0.70392
33	17	ON	64.38	94	1.70	9.5	28.88	0.99527	0.99513
34	17	OFF	80.50	140	1.35	7.5	24.38	0.80398	0.79925
35	18	ON	0.00	141	0.40	32.0	16.63	1.00000	1.00000
36	18	OFF	0.00		1.85	.	.	.	.
37	19	ON	0.00	189	2.00	11.5	5.88	0.93637	0.93250
38	19	OFF	0.00	161	0.03	10.5	8.25	0.63679	0.62204
39	20	ON	41.24	38	1.97	8.5	16.88	0.97301	0.97087
40	20	OFF	29.02	234	1.57	12.5	26.13	0.49776	0.47817
41	21	ON	75.04	111	0.12	10.5	13.00	0.99994	0.99994

Table: Predicted probability of invasives on each sample site

Obs	Site	Road	Canopy	Aspect deg.	Aspect	Slope	LFI	PREDPROB	PREDPROB_PA
42	21	OFF	87.52	86	0.19	23.0	13.00	0.20577	0.21080
43	22	ON	70.10	85	0.07	8.0	14.63	0.99997	0.99997
44	22	OFF	86.74	180	0.07	32.5	23.13	0.16480	0.16819
45	23	ON	70.88	324	0.01	8.0	28.13	1.00000	1.00000
46	23	OFF	84.14	243	0.14	42.0	30.50	0.20603	0.18745
47	24	ON	85.96	114	1.94	32.0	23.00	0.97161	0.97366
48	24	OFF	89.08	214	1.98	23.0	20.00	0.54831	0.56731
49	25	ON	74.52	106	1.20	6.0	38.13	0.99963	0.99966
50	25	OFF	89.08	156	0.94	13.5	36.88	0.68553	0.70699
51	26	ON	68.28	94	1.70	7.5	23.63	0.99382	0.99451
52	26	OFF	87.26	128	0.79	6.5	28.88	0.80441	0.82235
53	27	ON	71.14	226	1.73	10.0	20.00	0.99250	0.99318
54	27	OFF	83.62	180	0.07	16.0	28.63	0.65085	0.67219
55	28	ON	54.24	145	2.00	13.5	19.63	0.97531	0.97825
56	28	OFF	0.00	79	0.00	15.0	26.25	0.90047	0.91151
57	29	ON	18.10	127	1.71	8.0	20.63	0.98579	0.98669
58	29	OFF	0.00	36	0.37	1.5	8.88	0.45862	0.47501
59	30	ON	49.09	271	1.96	4.5	10.38	0.97051	0.97209
60	30	OFF	0.00	133	1.88	12.5	6.50	0.41289	0.42673
61	31	ON	77.38	137	0.79	19.0	27.75	0.99987	0.99987
62	31	OFF	71.14	136	0.06	24.0	15.88	0.31760	0.32788
63	32	ON	54.76	111	0.12	18.5	29.00	1.00000	1.00000
64	32	OFF	83.36	157	1.81	20.5	20.00	0.58392	0.60478
65	33	ON	69.31	47	0.22	9.0	22.00	0.99998	0.99998
66	33	OFF	77.64	162	0.66	14.5	15.50	0.58865	0.60959
67	34	ON	0.00	117	0.02	7.0	18.75	1.00000	1.00000
68	34	OFF	65.94	96	1.36	10.5	13.13	0.76423	0.75788
69	35	ON	56.84	22	0.14	3.0	22.75	0.99999	0.99999
70	35	OFF	44.88	118	0.65	17.5	21.88	0.64964	0.67122
71	36	ON	85.44	100	1.47	5.0	29.63	0.99853	0.99860
72	36	OFF	92.72	64	1.82	11.0	58.00	0.32752	0.33825
73	37	ON	26.16	203	1.18	17.0	28.00	0.99977	0.99976
74	37	OFF	85.18	217	0.05	16.0	26.63	0.64455	0.63238
75	38	ON	88.04	349	0.04	17.0	32.13	1.00000	1.00000
76	38	OFF	87.52	206	0.68	26.0	43.00	0.61187	0.59813
77	39	ON	70.88	338	0.73	5.0	18.25	0.99982	0.99981
78	39	OFF	65.90	127	1.71	9.0	18.25	0.76942	0.76330
79	40	ON	66.20	336	0.24	4.0	29.00	0.99999	0.99999
80	40	OFF	84.40	43	1.04	4.0	32.00	0.83455	0.83114
81	41	ON	76.86	349	0.04	7.5	30.38	1.00000	1.00000
82	41	OFF	88.82	76	2.00	33.5	35.25	0.21953	0.22515
83	42	ON	13.68	82	1.97	11.0	25.25	0.96990	0.96819
84	42	OFF	60.48	107	1.93	16.5	18.88	0.64569	0.63256
85	43	ON	75.56	208	1.99	14.0	22.38	0.98322	0.98291

Table: Predicted probability of invasives on each sample site

Obs	Site	Road	Canopy	Aspect deg.	Aspect	Slope	LFI	PREDPROB	PREDPROB_PA
86	43	OFF	86.74	85	0.07	2.5	30.75	0.88918	0.88731
87	44	ON	0.00	200	0.96	6.0	23.00	0.99962	0.99962
88	44	OFF	90.38	224	0.08	3.5	28.00	0.87089	0.86872
89	45	ON	0.00	265	1.85	7.0	27.25	0.96297	0.96499
90	45	OFF	31.88	125	1.35	1.0	29.38	0.43034	0.44468
91	46	ON	78.94	297	1.42	56.0	30.13	0.99809	0.99814
92	46	OFF	84.40	311	0.16	31.5	20.75	0.16822	0.17170
93	47	ON	63.34	162	0.66	30.0	27.63	0.99996	0.99996
94	47	OFF	87.52	31	1.57	49.5	19.75	0.04285	0.04311
95	48	ON	81.28	323	0.58	4.0	26.13	0.99995	0.99995
96	48	OFF	65.94	247	1.17	11.5	25.63	0.69942	0.68997
97	49	ON	41.74	199	0.14	16.5	35.13	1.00000	1.00000
98	49	OFF	91.68	211	0.00	24.0	43.00	0.74114	0.73371
99	50	ON	52.68	241	0.89	15.0	29.88	0.99991	0.99991
100	50	OFF	86.22	280	0.01	9.5	28.75	0.79264	0.78754
101	51	ON	77.12	247	1.17	18.5	36.25	0.99971	0.99973
102	51	OFF	88.82	233	2.00	26.5	27.88	0.38428	0.39783
103	52	ON	76.08	336	0.24	14.0	35.38	1.00000	1.00000
104	52	OFF	90.12	147	0.65	15.5	39.38	0.72927	0.72128
105	53	ON	74.00	260	0.74	5.5	31.13	0.99993	0.99993
106	53	OFF	84.92	257	1.40	10.5	26.25	0.73659	0.75721
107	54	ON	78.42	251	1.64	42.0	26.13	0.99329	0.99388
108	54	OFF	85.44	318	0.01	19.0	31.38	0.62932	0.65057
109	55	ON	73.48	285	0.87	9.5	37.00	0.99992	0.99993
110	55	OFF	92.40	267	0.17	4.5	40.50	0.88912	0.90145
111	56	ON	22.88	307	1.14	2.0	31.13	0.99920	0.99918
112	56	OFF	89.86	288	0.99	6.5	29.25	0.82958	0.82596
113	57	ON	60.74	191	0.63	1.5	41.75	0.99998	0.99998
114	57	OFF	93.76	263	1.12	15.5	37.63	0.65978	0.64838
115	58	ON	79.98	313	0.86	3.5	36.63	0.99993	0.99993
116	58	OFF	85.44	219	1.11	18.0	30.50	0.61556	0.60199
117	59	ON	61.24	197	0.90	30.0	29.63	0.99992	0.99993
118	59	OFF	88.56	203	1.18	37.0	18.38	0.11972	0.12160
119	60	ON	41.77	95	1.98	6.5	27.13	0.97072	0.96971
120	60	OFF	76.69	169	1.36	4.0	30.13	0.79242	0.78659
121	61	ON	75.82	24	0.89	13.0	34.00	0.99991	0.99991
122	61	OFF	84.14	203	1.18	3.0	27.75	0.85738	0.85477
123	62	ON	58.50	41	0.08	4.0	24.13	0.99999	0.99999
124	62	OFF	28.24	74	0.63	10.5	19.38	0.68018	0.66979
125	63	ON	72.96	15	0.70	6.5	26.25	0.99992	0.99992
126	63	OFF	94.02	74	0.63	10.5	33.63	0.78391	0.77844
127	64	ON	45.92	11	0.48	3.0	31.38	0.99998	0.99998

Table: Predicted probability of invasives on each sample site

Obs	Site	Road	Canopy	Aspect deg.	Aspect	Slope	LFI	PREDPROB	PREDPROB_PA
128	64	OFF	84.92	4	0.05	10.0	28.38	0.75682	0.77686
129	65	ON	77.64	155	0.13	10.0	21.63	0.99998	0.99998
130	65	OFF	85.70	187	0.54	15.5	28.13	0.63866	0.66020
131	66	ON	76.86	148	0.02	23.5	21.25	0.99998	0.99998
132	66	OFF	84.40	343	0.00	11.0	18.25	0.60727	0.62851
133	67	ON	41.76	213	1.38	2.0	31.25	0.99807	0.99793
134	67	OFF	52.94	271	1.96	2.5	29.75	0.52214	0.50438
135	68	ON	50.08	197	0.90	4.0	15.50	0.99946	0.99951
136	68	OFF	72.70	117	0.02	18.0	31.88	0.72970	0.75047
137	69	ON	62.82	157	1.81	1.0	27.25	0.99029	0.98987
138	69	OFF	84.92	74	0.63	13.0	27.88	0.71884	0.71005
139	70	ON	36.30	131	1.07	22.0	21.75	0.99977	0.99978
140	70	OFF	90.90	119	1.59	24.5	30.13	0.41304	0.42794
141	71	ON	78.68	9	0.44	9.0	31.38	0.99998	0.99998
142	71	OFF	91.94	282	1.27	10.0	33.00	0.73306	0.75377
143	72	ON	59.96	85	0.07	1.0	30.13	1.00000	1.00000
144	72	OFF	91.42	115	1.22	14.5	23.88	0.67196	0.69351
145	73	ON	60.18	49	0.75	4.0	17.38	0.99979	0.99978
146	73	OFF	61.52	131	1.07	16.5	21.38	0.63963	0.62723
147	74	ON	40.72	335	1.13	3.0	34.25	0.99955	0.99953
148	74	OFF	93.24	46	1.11	13.5	23.63	0.72116	0.71276
149	75	ON	72.96	124	0.40	5.5	34.38	0.99999	0.99999
150	75	OFF	62.56	158	1.93	6.5	32.00	0.53107	0.55061
151	76	ON	87.52	260	0.74	5.5	28.63	0.99991	0.99992
152	76	OFF	92.46	185	0.38	30.5	31.25	0.29266	0.30172
153	77	ON	89.86	165	1.47	37.0	36.38	0.99803	0.99817
154	77	OFF	87.52	120	2.00	12.0	39.00	0.52705	0.54639
155	78	ON	52.94	227	1.97	15.5	48.75	0.99243	0.99213
156	78	OFF	91.16	204	0.27	20.5	42.50	0.73970	0.73199
157	79	ON	39.16	147	0.65	14.0	22.88	0.99995	0.99995
158	79	OFF	64.12	179	0.19	14.5	28.50	0.76346	0.75707
159	80	ON	90.38	186	0.00	13.0	37.50	1.00000	1.00000
160	80	OFF	90.90	271	1.96	61.5	28.00	0.01701	0.01706
161	81	ON	56.32	144	1.48	9.0	27.25	0.99756	0.99780
162	81	OFF	56.58	167	0.00	10.5	21.50	0.71742	0.73839
163	82	ON	26.94	173	0.06	6.5	20.38	0.99999	0.99999
164	82	OFF	80.24	261	0.05	12.0	19.00	0.64070	0.62836
165	83	ON	38.90	120	2.00	4.5	11.75	0.96004	0.95753
166	83	OFF	0.00	193	0.31	12.0	7.75	0.61131	0.59612
167	84	ON	39.16	106	1.20	7.0	21.13	0.99896	0.99891
168	84	OFF	84.92	7	1.99	16.0	24.50	0.68951	0.67955
169	85	ON	21.91	177	1.87	4.0	20.50	0.95743	0.96094
170	85	OFF	89.08	77	1.50	14.0	31.38	0.64715	0.66733
171	86	ON	33.70	183	1.97	5.5	23.38	0.96194	0.96071
172	86	OFF	80.76	80	0.38	7.0	27.75	0.81585	0.81085

Obs	Site	Road	Canopy	Aspect deg.	Aspect	Slope	LFI	PREDPROB	PREDPROB_PA
174	87	OFF	59.96	234	1.57	13.0	26.63	0.62534	0.61187
175	88	ON	69.06	210	0.49	13.0	17.38	0.99990	0.99990
176	88	OFF	55.28	188	1.50	9.0	16.13	0.72522	0.71703
177	89	ON	53.72	223	0.18	6.5	17.63	0.99998	0.99998
178	89	OFF	93.24	243	0.14	15.5	33.13	0.71064	0.70174
179	90	ON	60.74	330	0.09	4.0	22.13	0.99999	0.99999
180	90	OFF	66.46	187	0.54	8.5	12.13	0.68055	0.70206
181	91	ON	55.54	325	0.35	10.0	31.88	0.99999	0.99999
182	91	OFF	70.88	125	1.35	5.0	28.38	0.76401	0.75765
183	92	ON	33.44	15	0.70	4.5	31.25	0.99994	0.99995
184	92	OFF	85.18	101	2.00	11.5	35.25	0.58446	0.60532
185	93	ON	0.00	247	1.17	15.0	5.75	0.99848	0.99847
186	93	OFF	0.00		.	.	.	.	.
187	94	ON	67.24	166	0.51	4.5	21.88	0.99994	0.99994
188	94	OFF	50.34	219	1.11	9.5	13.38	0.69954	0.69010
189	95	ON	47.74	162	0.66	6.5	22.63	0.99991	0.99991
190	95	OFF	73.22	149	0.30	10.0	25.38	0.76227	0.75583
191	96	ON	46.18	197	0.90	5.5	39.75	0.99993	0.99993
192	96	OFF	61.26	210	0.49	9.5	30.00	0.78158	0.77600
193	97	ON	48.00	111	0.12	8.5	31.13	1.00000	1.00000
194	97	OFF	90.64	76	2.00	8.5	32.25	0.75299	0.74612
195	98	ON	.		.	.	.	.	.
196	98	OFF	.		.	.	.	.	.
197	99	ON	20.96	100	1.47	10.5	28.50	0.99807	0.99798
198	99	OFF	55.02	98	0.00	10.0	18.00	0.70815	0.69907
199	100	ON	39.16	110	0.13	9.0	20.75	0.99999	0.99999
200	100	OFF	56.06	171	1.70	19.0	18.63	0.60244	0.58825
201	101	ON	64.12	235	0.61	8.0	24.25	0.99994	0.99993
202	101	OFF	92.46	179	0.19	26.0	21.25	0.24847	0.22826
203	102	ON	37.86	135	0.20	16.0	22.63	0.99999	0.99999
204	102	OFF	25.38	172	0.77	16.5	24.25	0.71572	0.70707
205	103	ON	69.06	108	1.81	16.5	66.38	0.99835	0.99849
206	103	OFF	93.76	93	0.77	24.5	48.88	0.59384	0.61482
207	104	ON	90.90	277	2.00	23.5	47.13	0.99101	0.99050
208	104	OFF	94.02	267	0.17	20.5	35.25	0.62917	0.61595
209	105	ON	37.08	320	1.54	12.5	34.63	0.99837	0.99830
210	105	OFF	89.34	188	1.50	12.0	35.38	0.68582	0.67565
211	106	ON	39.68	91	0.21	39.0	53.38	1.00000	1.00000
212	106	OFF	.		.	.	.	.	.
213	107	ON	85.18	19	1.92	31.0	44.63	0.99489	0.99436
214	107	OFF	95.06	19	1.92	26.0	38.50	0.34371	0.32196
215	108	ON	71.14	78	0.54	8.0	36.00	0.99998	0.99998

Table: Predicted probability of invasives on each sample site

Obs	Site	Road	Canopy	Aspect deg.	Aspect	Slope	LFI	PREDPROB	PREDPROB_PA
216	108	OFF	79.46	242	0.10	8.5	27.38	0.79964	0.79484
217	109	ON	32.92	121	1.48	9.0	31.00	0.99804	0.99786
218	109	OFF	27.46	228	1.31	4.5	33.88	0.43513	0.41461
219	110	ON	32.66	46	1.11	8.0	26.75	0.99955	0.99955
220	110	OFF	74.26	101	2.00	2.0	15.00	0.92307	0.92225
221	111	ON	64.64	349	0.04	5.5	13.75	0.99997	0.99997
222	111	OFF	56.84	149	0.30	2.5	11.38	0.75409	0.74727
223	112	ON	59.70	97	0.41	3.5	12.25	0.99989	0.99989
224	112	OFF	0.16	81	1.33	6.0	7.00	0.39020	0.40403
225	113	ON	62.56	177	1.87	2.5	11.75	0.98694	0.98672
226	113	OFF	87.52	271	1.96	5.0	22.13	0.89780	0.89623
227	114	ON	74.78	200	0.96	8.5	24.25	0.99968	0.99972
228	114	OFF	79.20	129	0.06	7.0	16.88	0.70380	0.72506
229	115	ON	0.16	164	2.00	3.0	16.25	0.86032	0.85249
230	115	OFF	24.08	237	0.32	8.5	18.25	0.70959	0.69628
231	116	ON	46.70	119	1.59	2.0	20.13	0.99322	0.99302
232	116	OFF	66.46	160	0.29	6.0	27.00	0.81376	0.80938
233	117	ON	59.44	110	0.13	3.0	18.13	0.99998	0.99998
234	117	OFF	82.06	318	0.01	14.0	24.50	0.66766	0.65664
235	118	ON	78.94	95	1.98	3.0	11.13	0.98943	0.98900
236	118	OFF	76.34	193	0.31	6.0	10.75	0.73969	0.73188
237	119	ON	56.32	202	1.93	5.0	16.25	0.97880	0.98065
238	119	OFF	82.32	17	0.26	9.0	13.13	0.64906	0.66995
239	120	ON	37.34	141	0.40	4.5	21.00	0.99996	0.99996
240	120	OFF	78.94	95	1.98	9.0	14.88	0.87861	0.87668
241	121	ON	24.08	298	0.46	4.0	12.38	0.99988	0.99988
242	121	OFF	33.44	22	0.14	4.5	11.75	0.66992	0.65901
243	122	ON	66.72	153	0.92	6.0	26.13	0.99979	0.99979
244	122	OFF	91.16	181	0.81	2.5	26.13	0.88830	0.88665
245	123	ON	55.02	113	1.80	6.0	20.50	0.98867	0.98865
246	123	OFF	.		.	.	.	.	.
247	124	ON	71.40	165	1.47	4.5	17.63	0.99712	0.99744
248	124	OFF	76.60	201	1.82	3.5	25.50	0.80065	0.81884
249	125	ON	68.02	215	1.68	8.5	22.63	0.99469	0.99461
250	125	OFF	80.50	271	1.96	5.5	16.75	0.90555	0.90428
251	126	ON	68.02	95	1.98	3.0	13.75	0.98406	0.98385
252	126	OFF	84.14	170	1.98	2.0	20.50	0.92311	0.92213
253	127	ON	58.92	43	1.04	2.5	17.63	0.99932	0.99936
254	127	OFF	0.16	27	1.25	7.5	8.38	0.41015	0.42491
255	128	ON	54.24	329	0.85	1.0	20.25	0.99972	0.99971
256	128	OFF	51.38	153	0.92	1.0	20.13	0.75933	0.75274
257	129	ON	78.16	21	0.97	7.0	25.00	0.99973	0.99972
258	129	OFF	91.42	191	0.63	6.0	28.88	0.84221	0.83907

Table: Predicted probability of invasives on each sample site

Obs	Site	Road	Canopy	Aspect deg.	Aspect	Slope	LFI	PREDPROB	PREDPROB_PA
259	130	ON	74.26	336	0.24	25.5	29.13	0.99999	0.99999
260	130	OFF	91.94	263	1.12	31.0	27.00	0.24815	0.25507
261	131	ON	0.16	272	1.30	4.5	27.13	0.99781	0.99763
262	131	OFF	94.02	19	1.92	25.0	24.75	0.47531	0.45589
263	132	ON	88.04	209	1.45	24.0	29.25	0.99787	0.99771
264	132	OFF	94.02	177	1.87	24.0	25.25	0.49514	0.47638
265	133	ON	56.84	293	0.04	9.5	25.00	1.00000	1.00000
266	133	OFF	70.36	205	0.03	9.0	24.50	0.77619	0.77038
267	134	ON	26.42	172	0.77	14.0	25.50	0.99994	0.99995
268	134	OFF	86.22	133	1.88	17.0	23.38	0.64869	0.67026
269	135	ON	80.24	244	0.97	2.5	31.50	0.99981	0.99983
270	135	OFF	0.16	179	0.19	5.0	21.63	0.67713	0.69866
271	136	ON	85.18	270	1.75	1.0	21.13	0.99585	0.99602
272	136	OFF	0.16	190	1.58	7.0	17.38	0.29011	0.29891
273	137	ON	59.18	224	0.08	23.0	25.75	1.00000	1.00000
274	137	OFF	0.16	105	0.29	3.0	16.63	0.56314	0.58355
275	138	ON	61.52	192	0.02	3.5	36.50	1.00000	1.00000
276	138	OFF	88.30	148	0.02	11.0	34.50	0.81979	0.81581
277	139	ON	70.36	217	0.05	5.5	38.25	1.00000	1.00000
278	139	OFF	94.80	129	0.06	4.0	26.88	0.86266	0.86023
279	140	ON	74.00	257	1.40	3.5	34.00	0.99890	0.99894
280	140	OFF	96.10	342	0.45	27.5	28.38	0.28375	0.29234
281	141	ON	39.94	113	1.80	5.0	39.50	0.98836	0.98808
282	141	OFF	94.28	125	1.35	8.0	23.00	0.85231	0.84931
283	142	ON	58.66	118	0.65	5.5	36.00	0.99997	0.99997
284	142	OFF	.		.	.	.	.	.
285	143	ON	75.56	248	0.26	3.5	17.00	0.99996	0.99996
286	143	OFF	93.50	197	0.90	9.5	16.50	0.77536	0.79473
287	144	ON	64.90	241	0.89	2.5	23.25	0.99977	0.99977
288	144	OFF	95.84	199	0.14	6.5	27.63	0.82980	0.82620
289	145	ON	46.18	120	2.00	3.0	22.00	0.96047	0.96389
290	145	OFF	66.72	157	1.81	6.5	26.75	0.67374	0.69405
291	146	ON	59.18	109	0.94	2.5	19.00	0.99955	0.99959
292	146	OFF	67.50	166	0.51	11.0	20.50	0.68367	0.70514
293	147	ON	64.38	297	1.42	10.5	47.50	0.99941	0.99947
294	147	OFF	94.54	273	0.36	9.5	19.25	0.70168	0.72296
295	148	ON	44.10	239	1.95	4.0	16.63	0.97080	0.96936
296	148	OFF	88.30	153	0.92	14.0	25.63	0.69500	0.68440
297	149	ON	87.00	260	0.74	4.0	24.00	0.99987	0.99989
298	149	OFF	89.86	236	0.01	9.5	28.75	0.76281	0.78264
299	150	ON	77.90	220	1.89	7.5	27.25	0.99083	0.99042
300	150	OFF	92.98	205	0.03	9.5	21.75	0.71369	0.70466

Table: Predicted probability of invasives on each sample site

Obs	Site	Road	Canopy	Aspect deg.	Aspect	Slope	LFI	PREDPROB	PREDPROB_PA
301	151	ON	62.82	137	0.79	2.0	23.13	0.99983	0.99984
302	151	OFF	52.94	51	1.98	16.0	29.50	0.44521	0.46155
303	152	ON	51.90	133	1.88	2.0	26.13	0.98164	0.98115
304	152	OFF	78.94	3	0.23	6.0	29.25	0.83720	0.83351
305	153	ON	49.30	72	0.31	6.5	27.88	0.99999	0.99999
306	153	OFF	89.60	172	0.77	3.5	33.50	0.86424	0.86186
307	154	ON	81.80	83	1.72	6.0	21.25	0.99528	0.99514
308	154	OFF	76.60	287	0.15	3.5	17.50	0.80708	0.80248
309	155	ON	87.52	83	1.72	4.0	22.13	0.99631	0.99610
310	155	OFF	84.14	137	0.79	17.0	25.75	0.62725	0.61412
311	156	ON	87.52	81	1.33	2.5	31.38	0.99933	0.99931
312	156	OFF	92.72	352	1.92	5.5	33.88	0.79497	0.78996
313	157	ON	90.64	15	0.70	6.5	24.50	0.99990	0.99990
314	157	OFF	91.68	65	0.96	5.0	26.00	0.86231	0.85986
315	158	ON	93.76	344	0.47	14.0	25.13	0.99993	0.99993
316	158	OFF	93.24	47	0.22	4.5	30.38	0.86950	0.86729
317	159	ON	75.56	345	1.43	17.5	29.75	0.99868	0.99861
318	159	OFF	93.76	13	1.99	14.5	30.13	0.68638	0.67625
319	160	ON	90.90	73	0.02	4.0	23.00	0.99999	0.99999
320	160	OFF	92.98	33	1.51	1.5	31.75	0.88106	0.87920
321	161	ON	70.62	77	1.50	4.5	18.13	0.99723	0.99714
322	161	OFF	73.74	299	0.00	5.5	22.38	0.80140	0.79661
323	162	ON	62.30	123	0.00	2.5	24.13	0.99999	0.99999
324	162	OFF	81.02	192	0.02	9.5	24.00	0.75196	0.74504
325	163	ON	65.42	82	1.97	3.5	23.38	0.98261	0.98214
326	163	OFF	91.16	191	0.63	6.5	30.13	0.83624	0.83253
327	164	ON	84.92	35	0.01	5.0	40.75	1.00000	1.00000
328	164	OFF	94.02	222	1.04	11.0	37.75	0.74954	0.74251
329	165	ON	58.14	259	1.67	2.5	31.25	0.99470	0.99426
330	165	OFF	65.68	220	1.89	1.0	41.00	0.46050	0.44052
331	166	ON	0.16	248	0.26	1.5	21.38	0.99998	0.99998
332	166	OFF	93.76	47	0.22	11.5	27.13	0.73056	0.72263
333	167	ON	24.08	249	0.03	1.5	20.50	0.99999	0.99999
334	167	OFF	87.78	329	0.85	2.0	49.75	0.83364	0.83019
335	168	ON	23.04	336	0.24	3.5	23.88	0.99999	0.99999
336	168	OFF	82.32	355	0.15	6.0	24.25	0.81317	0.80892
337	169	ON	49.04	129	0.06	1.5	26.38	1.00000	0.99999
338	169	OFF	31.62	240	1.77	4.0	18.63	0.51931	0.50151
339	170	ON	69.84	269	0.84	3.0	39.75	0.99994	0.99994
340	170	OFF	90.12	204	0.27	10.0	29.88	0.78567	0.78028

Table: Predicted probability of invasives on each sample site

Obs	Site	Road	Canopy	Aspect deg.	Aspect	Slope	LFI	PREDPROB	PREDPROB_PA
341	171	ON	0.16	48	0.05	6.5	13.38	0.99999	0.99999
342	171	OFF	0.16	29	0.01	2.5	16.00	0.65087	0.63903
343	172	ON	75.30	54	0.00	6.0	29.25	1.00000	1.00000
344	172	OFF	93.50	73	0.02	8.5	39.63	0.87727	0.87530
345	173	ON	65.94	165	1.47	3.0	26.88	0.99794	0.99788
346	173	OFF	81.80	251	1.64	5.5	28.38	0.80372	0.79904
347	174	ON	78.16	153	0.92	4.0	30.50	0.99985	0.99985
348	174	OFF	.	.	.	.	.	.	
349	175	ON	92.98	344	0.47	1.5	31.88	0.99998	0.99998
350	175	OFF	93.76	91	0.21	10.5	44.38	0.86732	0.86504

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