Exotic Invasive Plants on Private Woodlands of Virginia: Effects on forest composition, structure, and wildlife habitat

by

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(ABSTRACT)

Exotic invasive plants have become a significant issue in the Southeastern United States for private landowners. These plants possess characteristics that allow for rapid growth and easy adaptation to many growing conditions, often outcompeting native vegetation and altering wildlife habitat, especially in disturbed areas. Disturbance, including access roads, trails, harvest sites, powerline corridors, and fence rows, is common on private land. Private landowners are often left to combat these problems without many monetary or expertise resources that are available to federal lands. Three field sites, each in a different physiographic province in Virginia, were surveyed for exotic invasive populations and sampled with nested overstory, understory, and regeneration plots and wildlife point intercept transects using paired plots during the summers of 2006 and 2007. Species richness of the overstory and understory did differ, but native percent understory cover and sapling density remained unchanged. Tree density and forest basal area were reduced with presence of exotic invasive plants. Regeneration diversity and density decreased in areas of exotic plant invasion. Eastern cottontail habitat suitability increased with the presence of exotic invasive plants. Suitability of habitat for the gray squirrel, downy woodpecker food, black-capped chickadee reproduction, and eastern wild turkey cover declined with the occurrence of exotic invasive plants. Twenty three of thirty seven total invasive plots were within twenty feet of a disturbance area. Continual assessment of impacts will help provide a better understanding of the nature of exotic invasive plants to landowners and may help them to manage and prevent plant invasions.

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Introduction and Justification

Exotic invasive plants have become a significant issue in the Southeastern United States for private landowners. An exotic invasive plant is a plant introduced to an area where it does not naturally occur and which threatens natural communities, native plants, and ecosystem processes (Heffernan 1998). These plants possess characteristics that allow for rapid growth and easy adaptation to a multitude of growing conditions, often outcompeting native vegetation, especially in disturbed areas. During the invasion process, many changes may take place to ecosystems including alterations of wildlife habitat and plant community structure. As a consequence, areas of reduced ecological quality and economic value develop. Additionally, private landowners are often left to combat these problems with few monetary or expertise resources.

In the United States, fifty eight percent (423.8 million acres) of forestland is held by nonindustrial private forest (NIPF) owners (Belin et al. 2005). Seventy seven percent of timberland in Virginia is under NIPF ownership (USDA Forest Service 2006). In Virginia, NIPF owners hold 12 million acres collectively, with an average private landowner holding size of 29 acres (Birch et al. 1998). Private landowners in Virginia share some similar characteristics. Generally, these landowners have small properties with a high proportion of disturbed land. Disturbance often is a result of the establishment of roads and trails for recreation or travel within the property. This disturbance enables exotic invasive plants to quickly overrun an area, often causing several ecosystem changes.

The effects of exotic invasive plants on forestland and wildlife are recognized, but largely unquantified and not well understood. Some effects of these exotic invasive plants are loss of biodiversity, changes in nesting and foraging habitat for wildlife, and decreased regeneration of native vegetation. Quantifying these effects will help provide a better understanding of the nature of exotic invasive plants to landowners and may help them to manage and prevent plant invasions. This pilot study will help to inventory selected forestlands for exotic invasive trees, shrubs, and vines. It will also provide preliminary results to landowners about the potential impacts of these plants on the native flora and fauna on their properties.

Objectives

There are three major objectives for the proposed research.

1) Assess the extent of exotic invasive species on NIPF properties in 3 physiographic provinces of Virginia.
2) Compare native plant species composition, structure, and regeneration in areas with exotic invasive populations to areas without exotic invasive populations.
3) Compare habitat quality for several wildlife species in areas with exotic invasive populations to areas without exotic invasive populations.

Literature Review

Ecological Role

History

An invasive plant is one that threatens natural communities, native plants, and ecosystem processes (Heffernan 1998). It may be native, naturally occurring in the area, or exotic, not naturally occur in the area. Exotic invasive plants have been introduced either accidentally or intentionally. Globalization of society, international trade, and easier, increased movement of people has contributed to the spread of exotic invasive plants. Many of these introductions have occurred intentionally as a result of the plant being beneficial for agricultural or horticultural purposes. Other species have been introduced to new areas through unintentional seed dispersal by ships, planes, trucks, packing material, and unprocessed logs (McNeeley 1999). Heffernan (1998) found half of serious exotic invasive plants were originally introduced for horticultural uses. It is widely recognized that only 1% of exotic plants that become established in a new territory become pests. This may seem to be an insignificant amount, but these new plants and their progeny can spread rapidly and add up quickly. This has happened in New Zealand, which now has as many exotic plants as native ones (Mooney and Cleland 2001). Additionally, exotic invasive plants now occupy more than 100 million acres across the United States (Heffernan 1998). Williams (1997) suggests most plants have been introduced purposefully for landscaping, wildlife food and cover, erosion control, and wood and fiber production. These uses make many of the introduced plants highly valued commodities. Many exotic species have been recommended by government agencies as good species to aid in regeneration or provide ground cover. These species often become invasive as they outcompete native vegetation and proliferate rapidly due to lack of natural pests and herbivores. Whether intentional or unintentional, introduction of exotic plants can be detrimental.

Kudzu (*Pueraria montana L.*) is one example of how an exotic plant has been introduced and become invasive. Kudzu, a native of Asia, was extensively sold in the United States as an inexpensive forage for livestock and was then used as erosion control on agricultural lands by the Soil Conservation Service during the 1930s. It quickly spread throughout the South and soon covered millions of acres, growing up to 12 inches each day (Blaustein 2001). The Soil Conservation Service recognized the problem and many long term negative impacts that would be a result of this characteristic fast growth. Consequently, they immediately stopped using the plant for erosion control and forage. Kudzu was then listed as a common weed by the United States Department of Agriculture (USDA) in 1972 (Blaustein 2001), followed by federal noxious weed listing by Congress in 1997 (Harrington et al. 2003). However, these measures could not stop the spread of kudzu, which had already spread beyond control. It still covers large expanses of land and multiple structures today. Kudzu continues to be a significant structural, environmental, and economic problem. Despite the trouble with this species, it has developed as a part of southern culture. References to kudzu can be found today in folklore, music, literature, advertising, crafts, and recipes.

Biology

Dispersal, competition for resources, and evolutionary adaptation are three processes that need to take place for plant invasion to occur (National Academy Press and National Research Council 2002). Environmental and biological traits interact during these processes to change species composition and succession. These processes are usually characterized by rapid exponential increase of the invasive plant, but are often preceded by a lag phase during which the plant does not appear to be invasive. For example, the Brazilian pepper (*Schinus terebinthifolius* Raddi), introduced during the 19th century in Florida, was not extensively noticed until the 1960s, a lag period of more than 60 years. However, now more than 692,000 acres in south Florida are covered with dense stands of this plant that prevent growth of other vegetation (Mack et al. 2000).

Dispersal and spread of exotic invasive plants can be accomplished by insects, wind, water, birds, mammals, humans, or asexual reproduction. Each of these dispersal methods has different factors that influence distribution. Wind dispersal is affected by height of the plant, air turbulence (topographic/climatic conditions), and wind speed. For example, tree-of-heaven [*Ailanthus altissima* (Mill.) Swingle] produces lightweight winged seeds that move very easily with the wind. By contrast, autumn olive (*Elaeagnus umbellata* Thunb.) and multiflora rose (*Rosa multiflora* Thunb.) have fruit that is dispersed largely by birds (Cox 1999). If not dispersed by birds or other wildlife, these heavy fruits do not move far from the parent plant. The extent of spread is influenced by the life history, morphology, and behavioral traits of the invasive plant (Hastings 1996), as well as environmental heterogeneity. Environmental heterogeneity is the distribution of favorable and unfavorable potential seed establishment patches in the surrounding environment. The spread rate is different for each species and each situation, making a species invasive in one area at one point in time but not in another area. The amount of movement an exotic invasive plant can achieve is dependent on method of dispersal, length of fruiting period, interval between large seed crops, existing available growing space, and landscape uniformity. It is also dependent on the invasive plant species and the environmental conditions. According to a simple diffusion model, an invasive plant will spread from the origin and competition will slow its rate of spread as the carrying capacity is reached, so spread of the plant will then occur more at the edges and in adjacent areas (National Academy Press and National Research Council 2002).

Competition for resources is common in any ecological system. Invasive plants, however, have the ability to outcompete many native plants by taking over resources in a new range, using resources more efficiently, or altering the resources. Native plants that lose the competition for resources may be replaced by invasive plants. Many invasive plants have a good ability to sequester light, as light competition in most forests is very high. There are also some that have a fast initial growth rate, allowing them to establish in the canopy before slower growing native species. Some invasive plants have root systems that are better developed or more efficient, allowing them to get more water, such as the deep taproot established by tree-of-heaven seedlings. These characteristics may in turn have a domino effect enabling the production of more abundant fruit, attraction of more pollinators, and greater seed production (National Academy Press and National Research Council 2002). There is also competition for pollination between native and invasive plant species. Pollination and seed set can be disrupted by invasive plants in wind and animal pollinated native plants. Brown and Mitchell (2001) found invasive purple loosestrife (*Lythrum salicaria* L.) to decrease seed set of the native winged loosestrife (*Lythrum alatum* Pursh). Invasive trees or shrubs can also change the population in most, if not all, lower stature species or seedlings of other trees and shrubs. This has the potential to significantly inhibit tree regeneration (Woods 1997). Several

Asian bush honeysuckles, such as the Amur honeysuckle [*Lonicera maackii* (Rupr.) Herder], the Tartarian honeysuckle (*Lonicera tatarica* L.), and Morrow's honeysuckle (*Lonicera morrowii* Gray) have the potential to grow so dense that the forest floor is shaded and tree regeneration is halted. Some of the bush honeysuckles and tree-of-heaven also release chemicals that inhibit growth of other plants in nearby soil, a characteristic known as allelopathy (Invasive Plant Species Assessment Working Group 2004).

Evolutionary adaptation of exotic species will help ensure the success of their invasion. If hybridization occurs, the genetic diversity may support rapid evolution of local races. These hybrids may be more adapted to doing well in several environmental situations. In addition, their behavior may be harder to predict and cause innocuous or naturalized species to become invasive (National Academy Press and National Research Council 2002). The hybrid of the native North American cordgrass (*Spartina foliosa* Trin.) and the exotic cordgrass, *S. alterniflora* Loisel., in San Francisco Bay is extremely invasive. It took only a few years to invade marshes and cause the local extinction of native genotypes (Grosholz 2002). Hybridization can threaten native population numbers when fewer offspring occur each generation due to crossbreeding. The native species may also eventually become extinct if the hybrid succeeds or produces a new invasive species. *Spartina anglica* C.E. Hubbard is a successful hybird of the British native cordgrass [S. *maritima* (M.A. Curtis) Fern.] with the invasive North American cordgrass (*S. alterniflora* Loisel.) that is highly fertile and highly invasive (Mack et al. 2000).

The type of reproduction is also an important factor in establishment and spread of a species. Invasive species are generally characterized by early and consistent reproduction with a short juvenile period, a short interval between large seed crops, and a small mean seed mass. A short juvenile period may be related to fast growth, which may cause high leaf area ratio (LAR) and more photosynthesis (Rejmanek 1999). A small mean seed mass may imply a large number of seeds produced with better dispersal and shorter dormancy period. For example, oriental bittersweet (*Celastrus orbiculatus* Thunb.) produces large numbers of small berry seeds that are widely dispersed by several species of birds. High initial germination rate is also a common reproductive characteristic of invasive plants that helps to rapidly spread the species.

Some species may possess structural and physiological characteristics that allow them to be successful invaders in certain habitats. These characteristics include shade tolerance, rapid root growth, browse resistance, and stem photosynthesis. In California, the rapid root growth of yellow starthistle (*Centaurea solstitialis* L.) extends the flowering and fruiting period of the plant, which allows the growing season for this plant to be much longer than native species (Rejmanek 1999). The shade tolerance of Japanese honeysuckle (*Lonicera japonica* Thunb.) allows it to grow in the understory for long periods of time, spreading even in high shade conditions and then taking advantage of any canopy opening that may occur.

Plant invasions can have an effect on many parts of the floral community, including altering the competition, composition, diversity, structure, disturbance regime, and succession. Disturbance alters the availability and use of resources for many species and may encourage plant invasions. Areas with regular disturbance, such as edges of roadways, footpaths, and pastures have very common occurrences of invasive species. Also more susceptible to invasion are communities modified by human or exogenous natural events (National Academy Press and National Research Council 2002), successionally advanced communities that have become fragmented, areas with slow recovery rate, and eutrophic areas (Rejmanek 1999). The rate of recovery of the canopy after natural disturbance has also been shown to be altered when exotic vines such as honeysuckle (*Lonicera spp.*) are present (Gordon 1998). Diversity of an ecosystem is important in the invasion process with highly varied and mixed environments usually being less susceptible. The more diverse an area, the less susceptible it is to invasive species because more species often means less open space for invaders. In addition, as more invasive species appear, the more vulnerable that area is for additional invasion (Grosholz 2002). The disturbance regime can also be significantly altered, changing fire timing or intensity. Asian cogongrass [*Imperata cylindrica* (L.) Beauv.] has changed the fire dependent sandhill ecosystems in Florida due to the larger fuel load provided by this grass which produces larger, hotter fires. This often kills the longleaf pine seedlings while the deep rhizomes of the grass are protected, resulting in areas that are dominated by cogongrass (Cox 1999).

The movement of soil can introduce numerous, small, persistent seeds that are pre-adapted for transport to other places. Soil movement can be accomplished by something as common as mud on the tires of vehicles. In Australia, buses and tourist cars were found to be transporting seeds of many weed species to many areas in which these species did not previously exist (Huenneke 1997). Once an exotic plant becomes established in new soil, it may become invasive. The invasion of salt cedar (*Tamarisk spp.*) along the Green River in Canyonlands National Park changed a commonly flooded area with transient sandbars into terraces and permanent islands. Small stream channels were completely removed and the average channel width decreased by 27% during this process. Extreme environments are generally less favorable for invasion by exotic species. Xeric areas are too dry and undisturbed wet areas have extremely high biomass without available open space. Open water habitat is the most susceptible to invasion, but in terrestrial ecosystems, mesic environments are the most susceptible (Rejamanek 1999). Disturbed wet areas are also susceptible to invasion, such as the mountain slopes in Hawaii that are saturated for long periods of time. This saturation causes landslides that open areas of disturbance which then become home to broomsedge (*Andropogon virginicus* L.), a plant native to the southeastern United States (Cox 1999).

Invasive plants can play another important role in disturbance ecology. Invasive plants may aid recovery after disturbances or act as a substitute for native species that are lost. Use of exotic plants is common in reclamation projects and other badly degraded sites where native plant species may not survive (D'Antonio and Meyerson 2002). In these areas, where fast growing plants are needed to prevent erosion of soil, sterile exotic grasses have been established. These sterile grasses allow establishment and ultimate recovery of native species and do not seed. Invasive plants can also restore an area by facilitating successional change with the creation of a microclimate. Wildlife habitat can also be enhanced during this ecological change (Williams 1997). Whelan and Dilger (1992) found a preference by many bird species for exotic species of plants as a replacement for nesting cover of absent native plants. This type of plant substitution by wildlife often serves as an equal, if not better, component of habitat than native plants.

Landowner Concerns

Lack of Knowledge and Expertise

Private landowners have special concerns when it comes to exotic invasive species. Belin et al. (2005) found that NIPF owners are generally well educated, older, financially well off, and hold small tracts of land. NIPF owners were also shown to own land for residence, privacy, and conservation. Other primary reasons for ownership are recreation and stewardship (Ungrodt 2006). While these owners are not against timber sale, it is generally not a main reason for owning their land (Belin et al 2005). Birch (1997) found half of forest landowners in Virginia have not and do not intend to harvest timber.

While NIPF owners are well educated, there is often a gap in knowledge about invasive plants. A West Virginia study found landowners often base the determination of an undesirable plant on past experiences rather than facts they had read about or heard from family, friends, or forestry professionals (Steele et al. 2006). In doing this, landowners may inadvertently misidentify species or overlook several other species that may be negatively impacting the ecosystem.

It is common for people to repeatedly sell, advocate, or trade exotic invasive plants without realizing it. Websites have been developed that often tell the great things people have experienced with plants, while ignoring the potential negative side effects. A similar impact is seen involving nurseries, greenhouses, and community events. Community events, such as plant swaps, are a gathering of citizens who trade or give away plants from cuttings from their own gardens or plants they do not want anymore. These give aways or trades occur out of personal vehicles (Figure 1). Without thinking twice or knowing what the plant is, people freely exchange plants that may be harmful. Tree-of-heaven was given away at one of these events as a hickory tree (personal observation).

Figure 1. Tree-of-heaven given away at a plant swap in Maryland.

In Pierce County, Wisconsin, private landowner Greg Erickson found himself cutting buckthorn (*Rhamnus cathartica* L.) from areas of his 200 acres (Ungrodt 2006). Cattle grazing, timber harvest activities, and suppressed fire regimes in this area left excellent conditions for incursion by buckthorn, honeysuckle, and other exotic invasive species and poor conditions for regeneration of oak (*Quercus spp.*), hickory (*Carya spp.*), and white pine (*Pinus strobus* L.). Erickson originally had a management plan that involved a mandatory timber harvest, which he soon realized would encourage the growth of large amounts of buckthorn. He then had timber harvest plans redesigned to minimize potential movement of exotic invasive plants. Similar to Erickson, NIPF owners often conduct timber harvests and other activities that open areas for invasion by exotic species without realizing the implications. Therefore, a need exists for more knowledge in the field of invasive species, both with identification of more species and education of subsequent impacts.

Lack of Funding

Public lands have money from the government to use for studying, management, and control of invasive species. Invasive plant species alone cost more than $138 billion, including $24 billion in damage and losses each year and more than $9 billion for control each year in the US (Pimentel 2000). Golden Gate National Recreation Area and Point Reyes National Seashore spend over 60% of their Resources Management budget to control exotic species (D'Antonio and Meyerson 2002). Control costs and forage losses due to purple loosestrife in the United States, which now occurs in 48 states, amounts to $45 million (Henderson et al. 2006, Pimentel et al. 2005). Exotic aquatic weed control each year in the United States totals $100 million (Pimentel et al. 2005). Specifically, in Florida, $14.5 million is spent each year to control hydrilla. In addition, $10 million in annual recreational use loss in 2 lakes in Florida have occurred as a result.

While public lands have monetary support, a lack of funding exists for NIPF owners. Invasive plants impact agricultural expenses, including reduced land values, interference with grazing, reduced hay yields, and toxicity to livestock. Twenty four billion dollars each year is accounted for farmer crop losses caused by nonnative plants, with another $3 billion each year spent on the use of herbicides to control these introduced invasive plants (Henderson et al. 2006). Forage loss due to nonnative plants is estimated at $1 billion each year (Pimentel et al. 2005). In addition, five billion dollars is spent each year by ranchers in the US to control exotic invasive plants in an attempt to reduce grazing losses. Losses to management and productivity expenses in lawns, gardens, pastures, and rangelands accounts for $7.5 billion spent each year (Henderson et al. 2006). Specifically, $500 million each year is spent on exotic plant control in residential areas and $1 billion each year is spent for this control on golf courses (Pimentel et al. 2005).

Economic returns are compromised and landowners are often left at a monetary disadvantage when combating invasive plants. Invasive brush generally has low wood quality, which can significantly change management goals. Cutting and disposal costs for this vegetation are too high for most landowners if a local market does not exist for utilization (Ungrodt 2006). Among landowners surveyed in West Virginia, 88% tried to manage one or more undesirable (as determined by the landowner) species. Of these landowners, 81% stated they could not eliminate the species and 23% stated it required more time and expense than they could afford themselves (Steele et al. 2006). Bill Booker, owner of Cedar Grove Farm in Farnham, Virginia, has spent $3037.62 on 36 acres in 1996 for scotchbroom (*Cytisus scoparius* L.) control (personal communication). A separate application in the late 1990's for two areas, both 47 acres, totaled $7320.00 for each area. When a prescribed burn was not conducted post-harvest, immediately planted loblolly pine (*Pinus taeda* L.) did well. Scotchbroom was an interfering factor for pine regeneration growth and success when burning was conducted. No one else in this county (Richmond) or Westmoreland County has spent money on this type of treatment because economic constraints for landowners in this region are a problem. The same may hold true for landowners across the US.

Threat of Invasive Species

Ecosystem Function

The Virginia Native Plant Society and the Virginia Department of Conservation's Natural Heritage Program have identified 115 exotic invasive plant species in Virginia (Heffernan 1998). Some of these plants of special concern are Autumn olive, honeysuckles, Chinese privet (*Ligustrum sinense* Lour.), garlic mustard [*Alliaria petiolata* (M. Bieb.) Cavara & Grande], kudzu, multiflora rose, oriental bittersweet (*Celastrus orbiculatus* Thunb.), and tree-of-heaven. The life history of invasive plants can determine whether or not a species will compete with native plants of a similar life history. The life history of a plant includes how it reproduces and when it germinates, flowers, and produces seed (Heffernan 1998). The habitat requirements for a species can also help determine the potential extent of infestation. The extent of infestation is largely dependent on the amount of disturbance, with repeatedly disturbed areas being more vulnerable due to more available growing space.

Disturbance is often human induced, but can be caused by other things, often at a smaller scale. Human disturbance frequently involves agricultural or forestry practices and road or trail building. Animals can also cause areas of disturbance. Soil disturbance can be caused by burrowing, rooting, or trampling by gophers (*Geomyidae Cratogeomys spp.*), hogs (*Suidae Sus spp.*), or other ungulates. Foliar disturbance can be accomplished by grazing or herbivory. In Ireland, exotic sika deer (*Cervus nippon* Temminck) have eliminated the understory of oak forests, reducing holly (*Ilex aquifolium* L.) and other native shrubs. This has in turn removed safe establishment sites for oaks and has allowed the exotic invasive pontic rhododendron or common rhododendron (*Rhododendron ponticum*) to flourish (Hobbs and Huenneke 1992). Some invasive plants are better developed to withstand this potential herbivory than native species (Schiffman 1997). These types of disturbance make it much easier for invasive species to expand their range.

Invasive species of plants can alter species diversity, productivity, interactions between species, stability, and rates and pathways of successional recovery of native communities (Walker and Smith 1997). Native species diversity often declines when better adapted exotic species win the competition with native species for light, water, and resources. The success of exotic species in novel environments may be a result of the inclination of exotic plants to be taller, more vigorous, and have a higher seed production compared to those in the native range of the plant. *Chrysanthemoides monilifera* (L.)T. Nord. (tickberry) and *Acacia longifolia* (Andr.) Willd. (Sydney golden wattle) had higher seed production in areas where they were considered exotic than in their native ranges (Blossey and Notzold 1995). Productivity of the ecosystem changes with variation in structure, composition, growth, and diversity of exotics versus native vegetation. The coastal prairies on the Gulf Coast of Texas have been invaded by Chinese tallowtree [*Triadica sebifera* (L.) Small], which have proven to have doubled the net primary production of the native coastal prairies. This is accomplished by the tallowtree moving large concentrations of nutrients such as iron, phosphorous, potassium, zinc, nitrate nitrogen, and manganese from deep soil layers to the surface where it can be more readily used (Cox 1999).

Stand structure and regeneration are also impacted by invasive plant species. Twining vines such as Japanese honeysuckle and kudzu alter the vertical structure and increase the chance of collapse of supporting plants. These vines have also been shown to reduce native species recruitment and bend, constrict, and topple saplings. The growing season of Japanese honeysuckle is also extended beyond native species because of its low light compensation point. Several areas with invasive plant species such as tropical hammocks in Dade County, Florida have been found to have reduced density, mean height, and basal area of trees (Gordon 1998). The stability of the ecosystem can also be disrupted when invasive plants replace native plants. The Australian paperbark tree [*Melaleuca quinquenervia* (Cav.) Blake] in south Florida forms dense stands that prohibit most other vegetation growth. This tree uses large amounts of water due to increased evapotranspiration, which reduces the water table, accelerates groundwater loss, and helps to cause a strengthened fire regime by different drying patterns on the landscape (Mack et al. 2000, Webster et al. 2006). Salt cedar in the US southwest and the African crystalline ice plant (*Mesembryanthemum crystallium* L.) in California make salt concentrations in the soil extremely high. Native vegetation often cannot handle these high salt concentrations and eventually die out (Simberloff and Von Holle 1999).

Interactions with wildlife may change in several ways for many different species. Several avian species in the US have experienced changes due to exotic invasive species. In the eastern deciduous forest, the branch structure of exotic invasive shrubs (Amur honeysuckle [*Lonicera maackii* (Rupr.) Herder] and buckthorn) have provided numerous alternative nesting areas for many native species of birds, such as the gray catbird [*Dumetella carolinensis* (Linnaeus)], northern cardinal [*Cardinalis cardinalis*

(Linnaeus)], American robin [*Turdus migratorius* (Linnaeus)], and wood thrush [*Hylocichla mustelina* (J.F. Gmelin)]. Exotic hydrilla [*Hydrilla verticillata* (L.f.) Royle] in a Texas lake has increased waterfowl such as the American coot [*Fulica Americana* (J.F. Gmelin)] and the pied-billed grebe [*Podilymbus podiceps* (Linnaeus)] by providing more forage and horizontal cover than was previously available. In the northeastern US, the northern mockingbird [*Mimus polyglottos* (Linnaeus)] has been expanding its range due to increased availability of food by exotic multiflora rose (Schiffman 1997). However, not all of these interactions are positive for the wildlife involved. Native waterbirds were eliminated in northern Australia when *Mimosa pigra* L. (black mimosa) turned tropical wetlands into repetitive, unvaried shrubland (Mack et al. 2000).

Proximity to Disturbance Areas

The small holdings that NIPF landowners in Virginia generally own are often more susceptible to exotic invasive species than large land holdings. This is commonly due to many entry points, such as roads and trails that fragment the property. However, powerline corridors, farm fields, fence rows, and harvested areas may also serve as fragmentation sources. Fragmentation of landscapes creates more edges which increases the perimeter on which invasions can occur (Huenneke 1997). Roads outside the property, often rural paved roads that border the property, can also create points of entry by converting interior communities to roadside plant communities and serving as corridors of transport for invasive plants (Gelbard and Belnap 2003). In the year 2005 in Virginia, there were 50,475 miles of rural roads. Of these, 33,069 miles were local roadways. Across the US, there were 2,988,904 miles of rural roads, 2,042,242 miles of which were local (US Department of Transportation 2005).

Disturbance areas can also be the result of natural events, such as ice storms and hurricanes. These events can open small patches that may be left susceptible to invasion of exotic plants. In fact, past hurricanes have been found to contribute to the movement of exotic Cheesewood (*Pittosporum undulatum*) in the Blue Mountains of Jamaica (Hurricane Gilbert in 1988) and Asian soybean rust (*Phakopsora pachyrhizi*) spores from South America to Louisiana (Hurricane Ivan 2004) (Snitzer et al. 2005). Whether the disturbance is natural or man-made, more light and space resources are made available. Exotic plant percent cover increased 4.8% in non-gap areas with low light levels, 4.2% in forest with little damage, and 47.8% in canopy gaps with high light conditions as a result of moderate storm level Hurricane Isabel remnants. Japanese honeysuckle was present in disturbed patches before Hurricane Isabel and subsequently increased (Snitzer et al. 2005).

Invasive plants are opportunistic invaders that take advantage of openings and edges. Tree-of-heaven and Japanese honeysuckle are just two examples of this type of species. They may first enter along pathways and roads and then gradually move into the surrounding forest, remaining relatively hidden until a disturbance causes a population boom due to release from overstory shade. In Georgia, forest edge was found to be a more likely site for invasion than areas within the forest. Kudzu invasion was seven times more likely, Japanese honeysuckle was two times more likely, and privet was three times more likely to invade forest edge rather than interior forest areas (Rudis et al. 2004). Likewise, oriental bittersweet was found more plentiful in logged stands than in those stands without any management, with the largest amount being found on roads used previously for logging (Webster et al. 2006). Property boundaries may also serve as sources of fragmentation or even regions of management dispute. If one landowner is interested in controlling invasive plants and the adjacent landowner is not, then the landowner trying to resolve a potential problem may not get far in invasive control efforts.

Several other sources of disturbance exist, including streams and suburban areas. Streams can be transport channels for invasive plant seeds or areas of small openings that allow initial infestation of an invasive plant to begin. However, Pyle (1995) suggests these riparian areas may improve hardiness of native plants by requiring native plants to become adapted to more frequent disturbances, such as more frequent flooding regimes, providing greater resistance of native plants to exotic plants in this situation. Results from Pyle (1995) showed species richness and occurrence of exotic plants declined with an increase in flood frequency. Wildland/urban interfaces are also possible sources of invasion due to suburban gardens, refuse dumping, trail construction, soil erosion and damage, and aethestically pleasing vegetation management (Alston and Richardson 2006). While there are many different types of disturbance, disturbance types do not equally encourage or discourage invasion by exotic plants. However, fragmentation of forests, recreational use, and residential use of forests has promoted exotic species invasion as compared to undisturbed forest (Pyle 1995).

Impacts to Resources

Effects on Forests

Exotic invasive plants may alter native species composition, structure, competition, and regeneration in forests (Woods 1997). Invasibility of plant communities is dependent on the availability of resources (Gilbert and Lechowicz 2005), so areas with fewer resource openings should have fewer problems with invasion. Conversely, areas that have windfall damage or other resource openings will have a greater chance for invasion to occur. However, some species have better adaptations that allow them to do well in extremely limited environments which other plants may not be able to endure.

Norway maple (*Acer platanoides* L.) has invaded the Drew Forest in New Jersey and represents a good example of composition change and a decline in regeneration of native species (Cox 1999). Beneath a canopy of native American beech (*Fagus grandifolia* Ehrh.) and sugar maple (*Acer saccharum* Marsh.), exotic Norway maple seedlings and saplings are more plentiful than the native beech and sugar maple. This is the opposite of previous years when American beech and sugar maple had more regenerating seedlings and saplings in the understory, as well as established trees in the overstory. Norway maple now represents 25 % of 1 inch or greater diameter stems and the third highest total basal area. This suggests Norway maple is taking over this stand and pushing out the native sugar maple and American beech. Norway maple is capable of doing this because it is more efficient at using light, water, and nutrients than the native sugar maple. It is also aggressive in the understory, causing a decline in herbaceous species diversity, and has a long generation time, which makes it appear harmless for many years (Webster et al. 2006).

While Japanese honeysuckle is also an exotic invasive plant, it competes with native vegetation in a different way. Japanese honeysuckle takes advantage of forest edges and then moves into forests. Japanese honeysuckle has been found at forest/agricultural edges more abundantly and infiltrated forests further than other exotic plants in the coastal plain of North Carolina (Merriam 2003). It also populated 26% of measured edges in North Carolina. It, along with many other vines [English ivy (*Hedera helix* L.), kudzu, oriental bittersweet, and fiveleaf akebia (*Akebia quinata*)], can curb regeneration, overgrow vegetation in the understory, and have the potential to smother tree canopies. Both kudzu and Japanese honeysuckle are most obvious in disturbed areas and have abundant growth as noted by Carter and Teramura (1988). Japanese honeysuckle is a great competitor with native vegetation. It begins growing earlier in the spring, often has leaves for a longer period during the year, is well adapted to conditions of low light (Carter and Teramura 1988), compensates for herbivory (Cox 1999), and can damage seedlings and saplings (Gordon 1998). This species becomes a problem because it favors high light intensity and disturbed seed beds, as do many invasive plants. Loblolly pine, an early successional species managed in the southeastern US by many private landowners, also favors these conditions (Shelton and Cain 2002). This results in competition between an economically important tree species and an exotic invasive vine. Japanese honeysuckle vines can form dense mats, especially in more disturbed, high light conditions that may increase predation of large seed tree species, such as oaks (Snitzer et al. 2005). This happens due to dense cover that provides protection for seed consumers, such as squirrels, from predatory animals, such as hawks.

Tree-of-heaven has characteristics that allow it to invade forests in yet another way. This tree has a deep taproot even as a seedling that enables rapid growth and overtopping of native tree seedlings. Saplings of this species grow taller and have more extension and diameter growth than native species. Unlike Japanese honeysuckle, tree-of-heaven may be unpalatable to deer and should not be expected to be controlled by herbivory (Knapp and Canham 2000). Tree-of-heaven also has unique leaves and bark that have allelopathic chemicals which inhibit germination and growth of other plants in the surrounding soil (Cox 1999). The chemicals from this tree are very potent and work extremely well as herbicides on neighboring plants. Allelopathic chemicals are not unique to tree-of-heaven and have been found to occur in several other plants, such as red maple (*Acer rubrum* L.), black walnut (*Juglans nigra* L.), Japanese honeysuckle and fragrant sumac (*Rhus aromaticus* Ait.). These chemicals can have physiological impacts. Skulman et al. (2004) found chlorosis of loblolly and shortleaf pine seedling needles and shoots when grown with Japanese honeysuckle tissue, indicating possible allelopathy.

Effects on Wildlife

Wildlife can experience positive or negative effects from invasive plant species. Removal of some exotic invasive plants may result in a decline of the related wildlife species. Schiffman (1997) suggests there may be interdependent relationships that exist between these fauna and flora. However, the removal of these invasive plant species may also result in the emergence of other less common native species of plants, fungi, and invertebrates.

There are some negative impacts that wildlife can experience from the introduction of exotic invasive plants. The type of branch structure provided by shrubs is very important for the nesting success of several eastern deciduous bird species. Borgmann and Rodewald (2004) found nest predation to be higher for Northern cardinals and American robins in exotic shrubs than in native shrubs in rural landscapes. Greater nest predation was thought to be due to lower nest placement in the shrub due to branching structure and a greater surrounding shrub volume. Both of these factors seemed to contribute to mammalian predator search efficiency. Another example of a negative impact of an exotic invasive plant is the salt cedar. Salt cedar uses large amounts of water, increases saline concentrations, narrows channels widths, and damages wildlife habitat, but it has been found to provide nesting habitat for the endangered southwestern willow flycatcher (*Empidonax trailii extimus*). While this bird species seems to prefer salt cedar in some areas, the continuance of this invasive plant may degrade the habitat, preventing re-establishment of native vegetation at a later time (Zavaleta et al. 2001). This has caused a dilemma for managers who are unsure whether to remove salt cedar to stimulate native revegetation or allow it to grow to provide habitat for this endangered bird species. Another example is the exotic invasive purple loosestrife. Purple loosestrife has negatively altered waterfowl habitat in the northern US and Canada, causing a decline in several waterfowl species (Schiffman 1997). Uniform stands of this invasive plant form easily, especially with a long flowering season (June to September), and hamper the establishment and growth of native wetland plant species. The loss of the native wetland plant species means wildlife will suffer the loss of several sources of high quality nutrition.

While some exotic invasive plants can decrease quantities of food for wildlife, they can also serve as food sources for wildlife. Fall migratory songbirds often eat autumn olive fruits well into October (Suthers et al. 2000). These migrants also were found to prefer shrublands to woodlands, which many exotic invasive shrubs create. However, passage migrants preferred dogwood shrubland to multiflora rose shrubland. The exception to this was when multiflora rose was producing berries. At this time, there was no preference difference. Of non-frugivorous birds, with the highest number being Neotropical migrants, more used the exotic invasive multiflora rose shrubland than the native dogwood shrubland or red cedar shrubland. It was common for several fall migratory bird species to leave habitats when they became overgrown by trees or if habitats producing fruit were available. Both autumn olive and Japanese honeysuckle berries were highly consumed by fall migrants. Japanese honeysuckle berries made up 60% of the wood thrush diet and autumn olive made up 67% of the house finch diet in abandoned farm fields in New Jersey. Japanese honeysuckle is also good forage for eastern cottontails and white-tailed deer, but this herbivory may also increase biomass in the stem and leaves as compensation (Schweitzer and Larson 1999).

Landowner Losses

Losses of biological integrity and money are difficult to quantify, as they are different for different people. For example, Amur honeysuckle is well liked and accepted by gardeners and homeowners, but disliked by resource managers (McNeeley 1999). Landowners can experience losses economically and ecologically. Ecological harm includes the decline of the native species of fauna and flora and the replacement of their functional roles, decline in species diversity, and decrease in watershed production. Economic harm consists of losses in grazing, timber (Mack et al. 2000), the reduction of crop yield, structure damage, and monetary loss for control efforts (Hengeveld 1999).

The cumulative financial loss due to harmful exotic plants in the United States from 1906 to 1991 was estimated at $603 million (McNeeley 1999). The total direct and indirect cost for all exotic species of plants, animals, and microorganisms is more than $138 billion each year in the US (Mack et al. 2000). Kudzu continues to cause power outages and damage, train derailment, structural problems, and vegetation damage throughout the south. The estimated forest productivity loss from kudzu is $336 million with a total productivity loss of more than $500 million each year. Southern power companies spend $1.5 million every year just for removal of this species (Blaustein 2001). The cost continues to grow as invasive species become a larger problem and more people become aware of the potential consequences.

Materials and Methods

Overall Approach

This research was conducted as a pilot study to assess the threat of exotic invasive trees, shrubs, and vines to timber and wildlife habitat resources as correlated to private woodland characteristics. Field sampling was conducted on three privately owned tracts of woodland in Virginia. Paired, nested overstory, understory, and regeneration plots were used to compare plant species composition, structure, and regeneration in exotic invasive plant populations and not within exotic invasive plant populations. Transects were used to measure Habitat Suitability Index (HSI) model components in each of the paired plots to compare potential habitat quality for six wildlife species in exotic invasive plant populations and not within exotic invasive plant populations. Paired plots were used to ensure similar topographic, vegetative, and microclimate characteristics were present.

Field Sampling

Study Areas

One private landowner tract was chosen in each of three different physiographic provinces within the state of Virginia. One tract was placed in the Coastal Plain, one in the Piedmont, and one in the Blue Ridge (Figure 2). Due to the nature of this research, the three tracts were not chosen for comparison, but as case studies for potential impacts of exotic invasive plant species. The tracts were required to be privately owned.

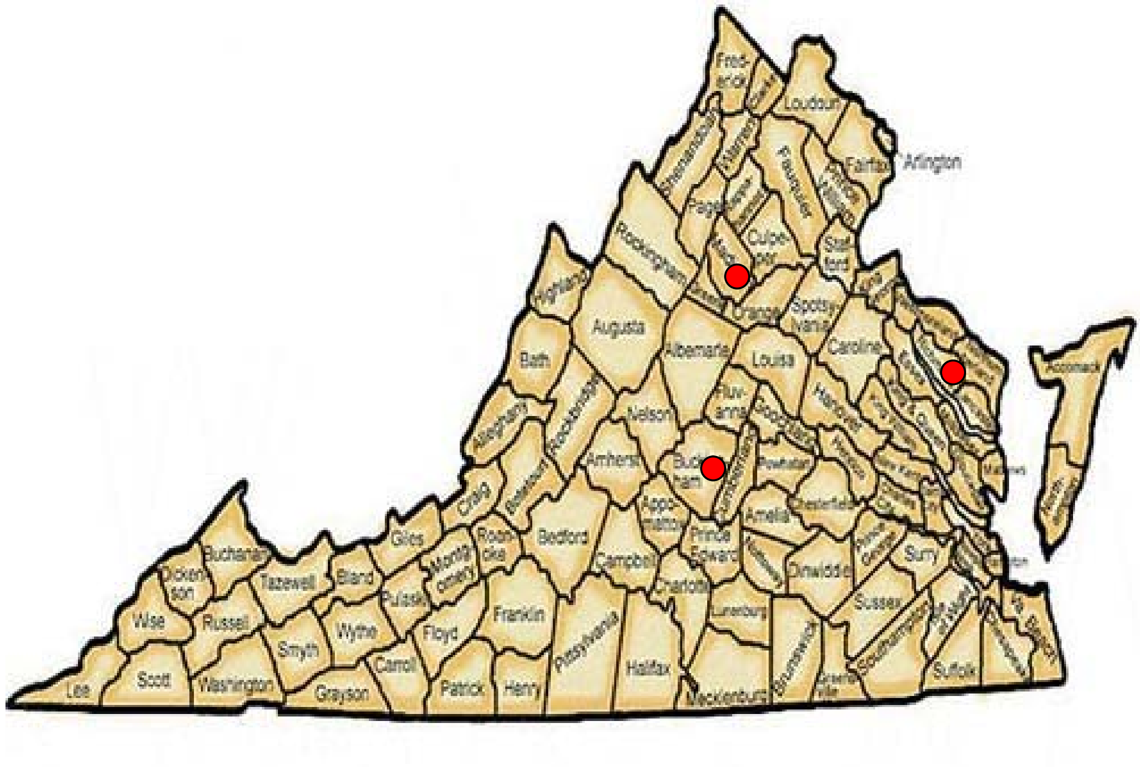


Figure 2. Site locations. Tract 1 is in Richmond County, Virginia, tract 2 is in Buckingham County, Virginia, and tract 3 is in Madison County, Virginia.

The Coastal Plain tract was located in Richmond County, outside the town of Farnham on Cedar Grove Road. Richmond County has an average winter temperature of 39°F and an average summer temperature of 76°F. The total precipitation each year is 42 inches. Twenty three inches of this precipitation commonly occurs from April to September. This area of the county is generally characterized by well drained to rather excessively drained soils that are sandy and loamy. The topography is steep to gently sloping to level (USDA SCS Soil Survey of Richmond County Virginia 1982). The property at this location is known as Cedar Grove Farm and encompasses 414 total acres, of which 318 acres are forested (Figure 3). The remaining acreage is farm fields, which currently alternate in the growth of corn and soybeans crops. Cedar Grove Farm is actively managed for loblolly pine and contains several stands of loblolly pine and mature hardwoods, streams, swamps, several interior forest roads used as access for forestry practices, and a powerline corridor. There are several farm fields used for growing crops, as well as a few private houses on surrounding properties. This property has been treated for scotchbroom, an exotic invasive plant, in the past. There are rural secondary roads directly meeting the property boundary on 3 sides. There are 10,965 feet of the property exposed to this disturbance and 2,121 feet exposed on each side of the powerline corridor crossing the property.

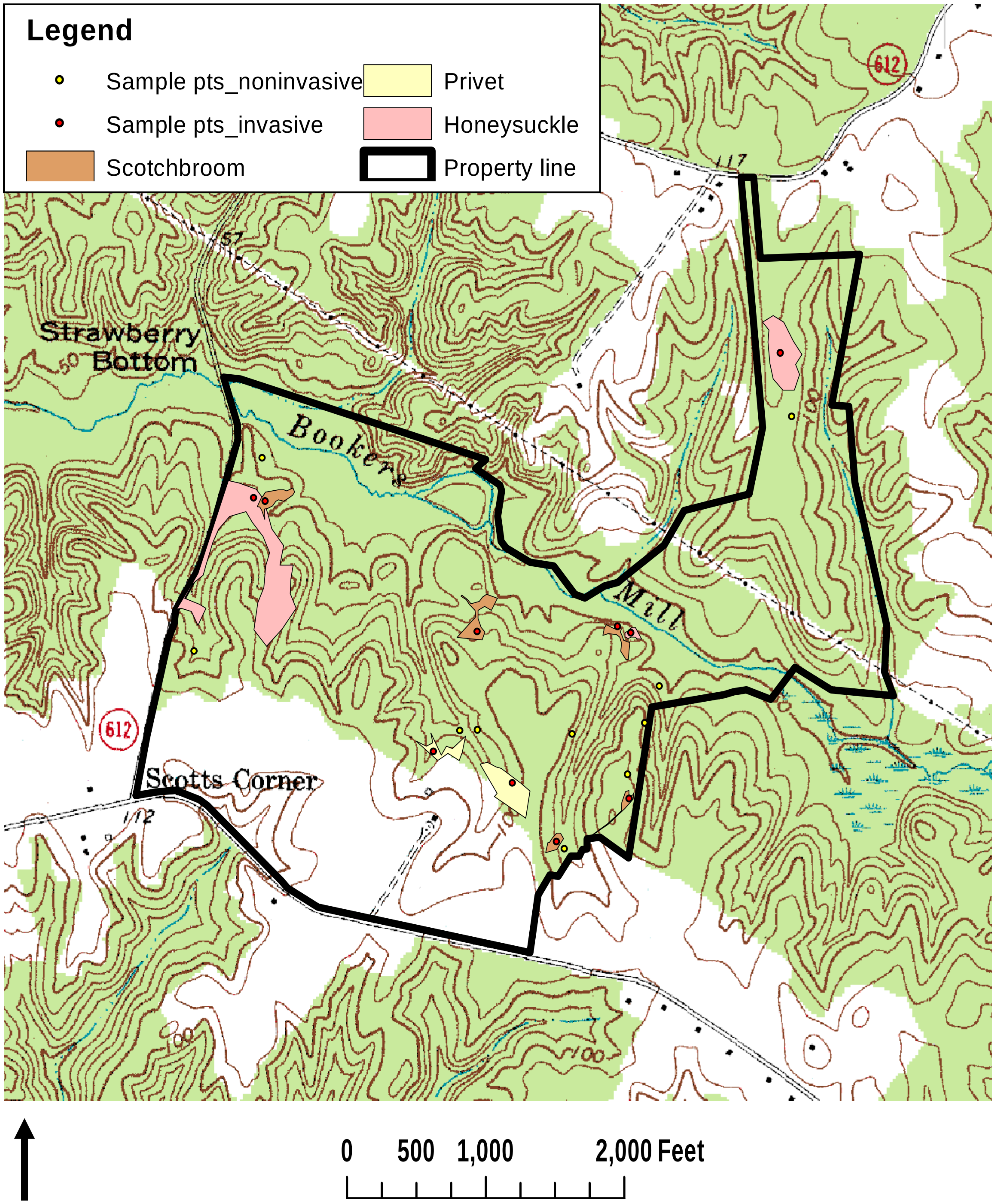


Figure 3. Exotic invasive plant populations and sample points on Cedar Grove Farm, Farnham, Virginia, August 2007.

The tract in the Piedmont was outside the town of Dillwyn in Buckingham County. Dillwyn has an average temperature in January of 36.7°F and an average temperature in July of 77.2°F. The average annual rainfall is 45 inches (County of Buckingham, Virginia 2006). USDA soil survey data are not available for this county at the present time. The property at this location is known as Kennedy Tree Farm. It is 1300 acres and contains four ponds, a powerline corridor, a gas pipeline corridor, 2 old home sites, numerous streams, and plentiful interior forest roads used as access for forestry practices (Figure 4). Kennedy Tree Farm is actively managed for loblolly pine and has several loblolly pine stands in different successional stages, mixed hardwood and loblolly pine stands, and hardwood stands. The gravel driveway is 1.4 miles long and a rural secondary road (Rt. 631) runs along the property boundary and through the property for 2.21 miles.

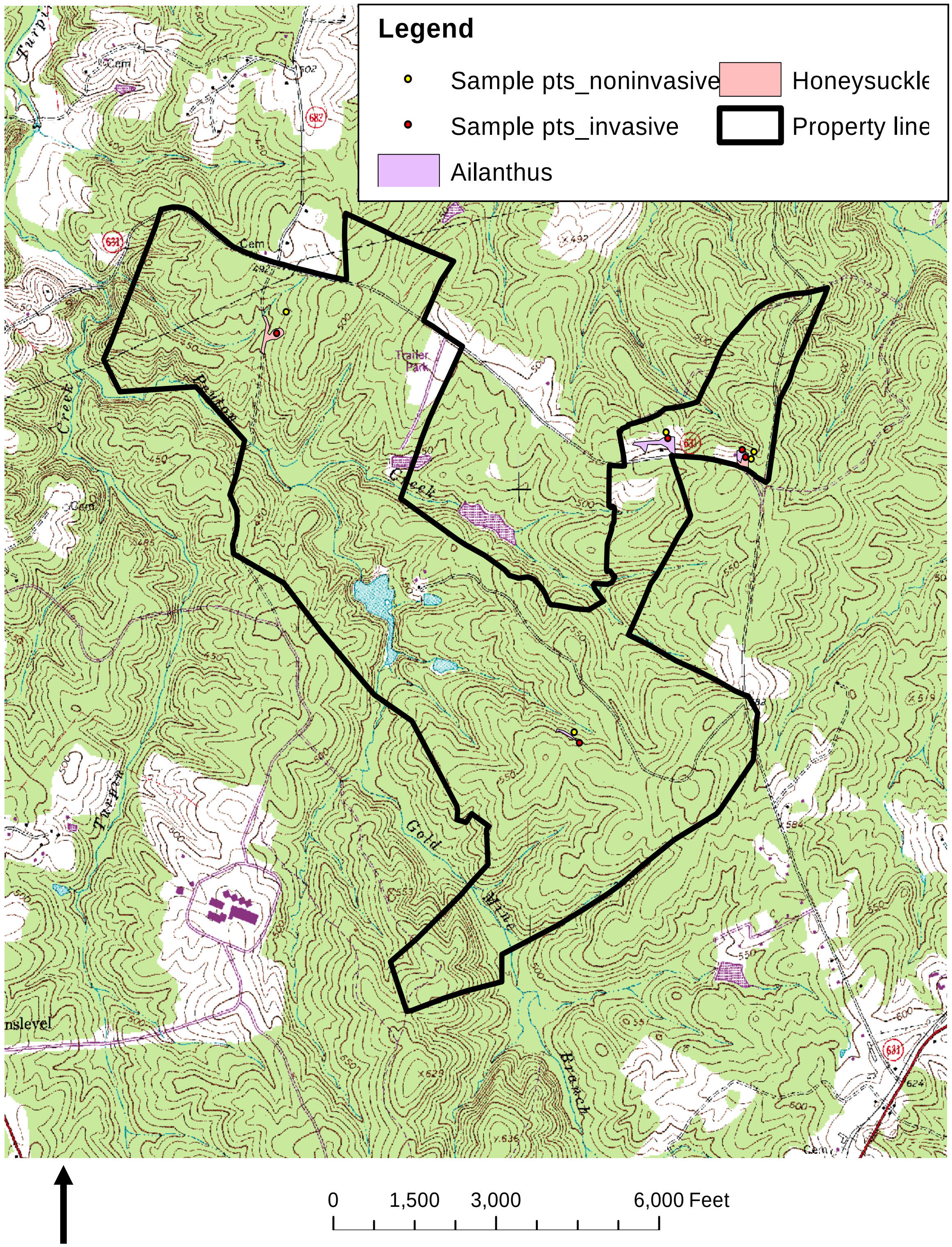


Figure 4. Exotic invasive plant populations and sample points on Kennedy Tree Farm, Dillwyn, Virginia, August 2007.

The Blue Ridge tract was in Madison County. Madison County has an average annual temperature generally between 54°F to 59°F in lower elevations and 45°F to 50°F in the mountains. Temperatures below 0°F or above 95°F are uncommon. The total precipitation each year is 42 inches in lower elevations to 51 inches in the mountains. About three inches per month of this precipitation occurs in the fall and more than 4 inches per month of precipitation usually occurs during the summer. The soils here are deep, stony loams that are well drained to poorly drained on floodplains, but eroded loams on excessively drained dissected uplands. Slope varies from 2% to 50% and elevation varies between 1000 feet to 4000 feet (USDA SCS Soil Survey of Madison County Virginia 1975). The property at this location is known as Beaver Run Farm. The survey area includes a total of 567 acres, of which 331 acres are forested (Figure 5). The remaining land is used as grazing for cattle, wildlife food plots, and hay fields. Several forested strips lead from the forest edge through the pastures, some following stream beds. Beaver Run Farm is managed for beef cattle. Several of the forest edges and pockets of forested areas surrounded by pasture are grazed. The majority of the forested area is comprised of hardwoods, with occasional eastern redcedar (*Juniperus virginiana* L.) and Virginia pine (*Pinus virginiana* P.Mill.) mixed into these hardwood stands. Also present on this property is a stand of white pine and a stand of eastern redcedar. There are numerous fence rows, several ATV trails, 3 ponds, abundant streams, a powerline corridor, and 2 old homesites. A dirt road is present in the survey area for 0.75 mile. The survey area is located 1.2 miles from a secondary road (Rt. 231).

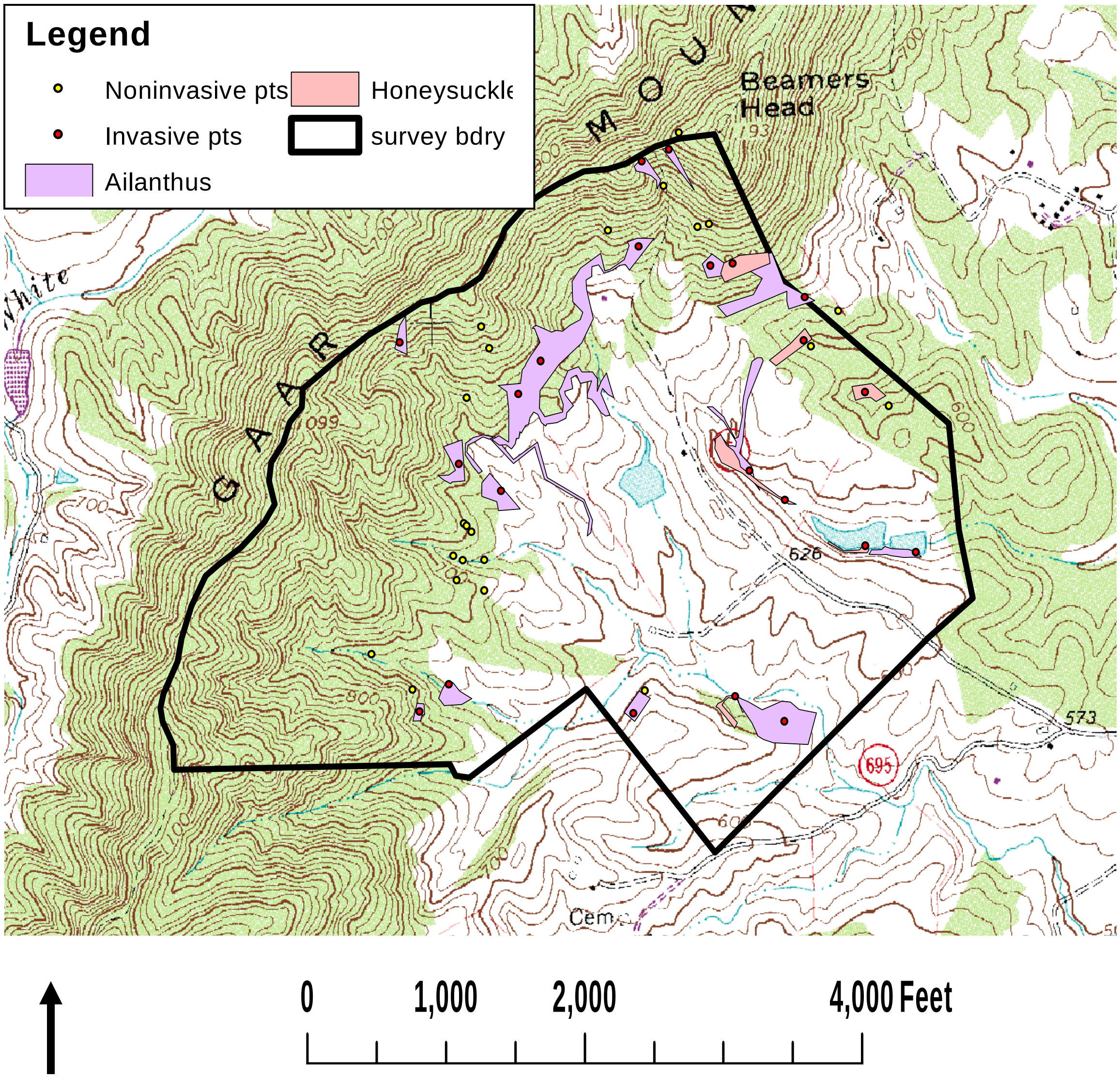


Figure 5. Exotic invasive plant populations and sample points on Beaver Run Farm, Madison, Virginia, August 2007.

Plot Design

The sampling design for this research was a two step process. Each private land tract was first inventoried for exotic invasive plant species with the use of transects. The transect lines, used as a type of grid system, were designed to locate all significant populations of exotic invasive plant species while surveying the entire tract of land. The transect lines were 0.5 chain to 2 chains apart, depending on the density of the vegetation, but were most commonly 1 chain apart. For example, if the transects were spaced 1 chain apart, one person walking a transect line would be able to clearly identify vegetation species 0.5 chain looking to the left and 0.5 chain looking to the right. If the vegetation was too dense to clearly identify vegetation species 0.5 chain away, then the transects would be moved closer together for that stand of vegetation. The transects were used as a line from which to sight exotic invasive plant populations. An exotic invasive plant population was considered significant if it was found continuously for 0.2 acre or more. The boundaries of each of the significant exotic invasive plant populations located during this process were entered into a Global Positioning System (GPS) unit. These points were then assessed on topographic maps of each tract of land using ESRI ArcGIS 9.2 to determine their size and proximity to disturbance areas.

The second stage of this research established paired plots to compare potential impacts to timber and wildlife habitat. After suitable exotic invasive plant populations that met the 0.2 acre size requirement were found and entered into a GPS unit, a sample point within the exotic invasive population and a paired sample point outside the population were randomly located for each significant population before returning to the field. The paired sample points outside of the exotic invasive population were designed to be close to the exotic invasive plots without being in the exotic invasive population. They also were designed to match all variables (slope, aspect, dominant species type, and age) in the exotic invasive sample point, with the exception of the exotic invasive plant. Some exotic invasive plots could not have a matching paired plot directly adjacent do to environmental limitations. In these cases, the noninvasive plots were established in areas on the property that were as close to a match of the invasive plot as possible for the topography and forest type variables. A 0.1 acre overstory plot was established in the exotic invasive population at the sample plot point that was randomly selected in the lab. At the center of the 0.1 acre overstory plot, a 12 inch long, 1 inch diameter section of polyvinyl chloride (PVC) pipe was placed into the ground to make these plots permanent for future research. A matching 0.1 acre randomly selected (in the lab) paired overstory plot not within the exotic invasive plant population was established and also staked in the center with 12 inch long, 1 inch diameter PVC pipe. To label the plots, each PVC pipe had a hole punched through both sides to allow a piece of wire to be strung through the pipe to hold a metal tag. Two types of tags were used. One was a circular permanent hard metal tag with numbers already present and the other was a rectangular semi-permanent tag that allowed for the desired numbers to be punched into it. In the interest of future research at these locations, a GPS point was marked at the PVC pipe at every plot center. At each of the plots, a forest assessment and wildlife habitat assessment were conducted.

Forest Assessment

A circular overstory plot of 0.1 acre was placed in every exotic invasive plot and every equivalent paired plot, as described above (Figure 6). All trees with a diameter at breast height (dbh) of 2 inches or greater were identified by species, dbh, canopy class, and height class. The canopy class of each overstory tree was classified as a dominant, codominant, intermediate, or suppressed canopy position. Five foot height classes were used to designate the tree height of each overstory tree. Slope, aspect, and snag dbh were recorded at this plot location. Addition notes/observations, such as location of the plot on an old homesite or forest edge (forest type, powerline corridor, road), wildlife markings, presence of other exotic invasive plants on the same plot, presence of exotic invasive plant as groundcover or arboreal, and pest damage to plants were also recorded. Percent canopy cover of overstory trees in the plot was also estimated by using cover class standards (Appendix A).

One understory plot was also placed in every exotic invasive and equivalent paired plot. The circular understory plots were 0.02 acre and were nested in the overstory plots, using the same center (Figure 6). All woody species with a dbh less than 2 inches and a height equal to or greater than 2 feet were recorded by species and number of stems. Percent cover for these species was also recorded, guided by the use of cover class standards (Appedix A).

Regeneration in every exotic invasive and equivalent paired plot was measured by three 0.004 acre plots within the 0.1 acre overstory plot (Figure 6). Three random transects were run in different directions and for different distances from the center of the 0.1 acre plot. A stem count of the number of seedlings less than 2 feet in height by species was performed. A random number generator was used to obtain random bearings and random distances.

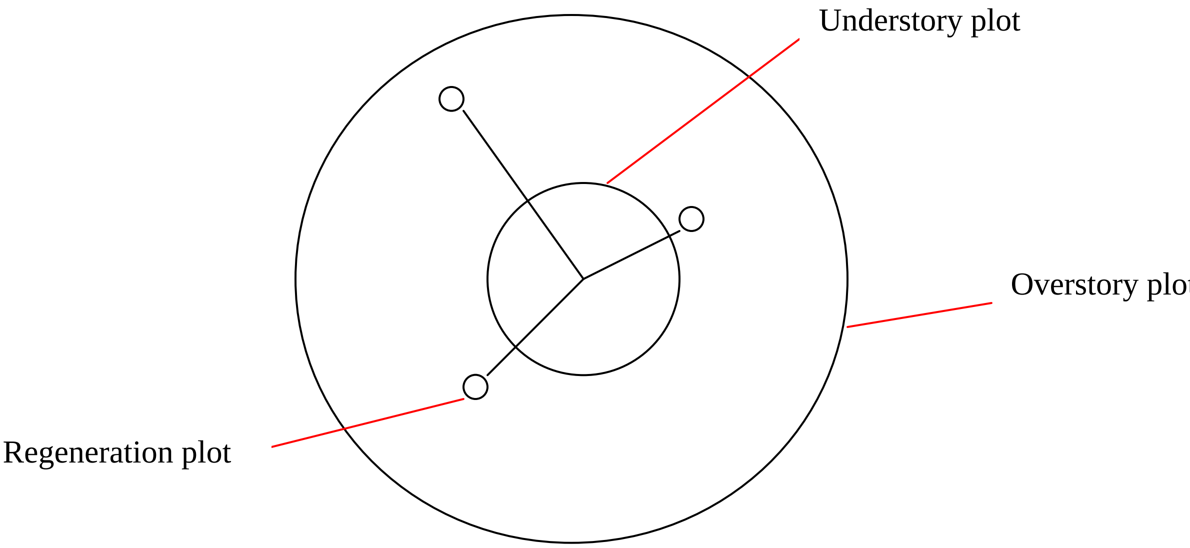


Figure 6. Sample forest assessment plot design. The exterior plot is 1/10th acre, the interior plot is 1/50th acre, and the three randomly placed regeneration plots are 1/250th acre.

Wildlife Habitat Assessment

Wildlife habitat was evaluated with the use of Habitat Suitability Index (HSI) models. HSI models propose the relationship between a species and a habitat, thereby estimating the degree of suitability of the habitat for a particular species of wildlife. This evaluation of habitat suitability was conducted for six species of wildlife at each of the exotic invasive plots and equivalent paired plots without the exotic invasive plant species. Bird and mammal wildlife species that represent several different guilds were selected to use in the habitat evaluation. Early successional, mid-successional, and late successional forest dwelling species were examined. The species selection was determined by making sure a wide variety of habitat needs were represented for several species that all need different forest cover types. The selection was used to ensure the habitat was present for several species of wildlife to survive on the three properties.

The eastern cottontail [*Sylvilagus floridanus* (J.A. Allen)] was chosen to represent early successional mammal species. The HSI model for this species was developed for the winter season because it is the most limiting season (Allen 1984). The winter cover component was also the life requisite used for determination of habitat suitability. The model has four habitat variables to determine habitat suitability for the life requisite of winter food or cover. These variables are (1) percent shrub crown closure (V1), (2) percent tree canopy closure (V2), and (3) percent canopy closure of persistent herbaceous vegetation (V3). All three variables were measured with the point intercept method. The point intercept method uses two 40 m perpendicular transects (Figure 10). Vegetation measurements were taken every 2 m along the transect, for a total of 40 measurements. Each point intercept transect was run through the forest assessment plot center, making the transect 20 m on each side of the plot center. The fourth variable, Diversity Index (DI), was not used for this application. Each of the habitat variables were quantified by creating equations for each habitat variable graph found in the HSI model (Appendix C). Then a final equation found in the HSI model representing the relationship between all habitat variables determined the life requisite suitability index (LRSI) values. All of these equations were entered into Microsoft Excel.

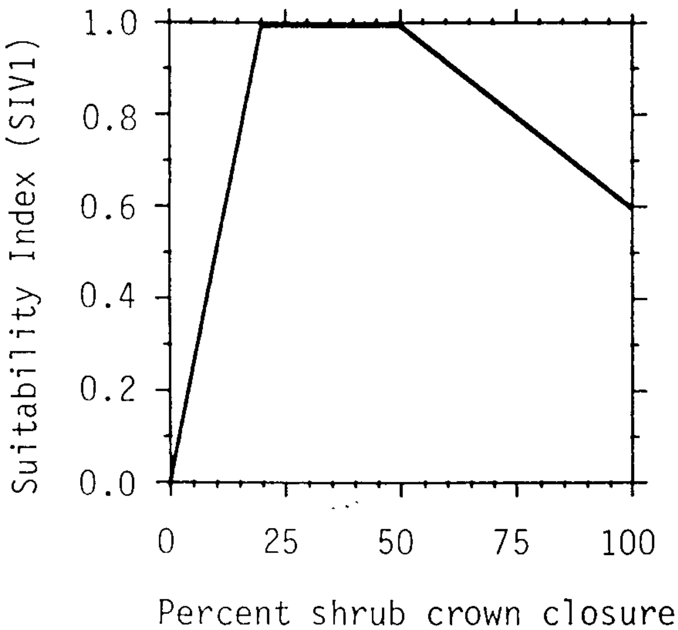


Figure 7. Percent shrub crown closure (V1) variable relationship for the winter food/cover life requisite for the eastern cottontail.

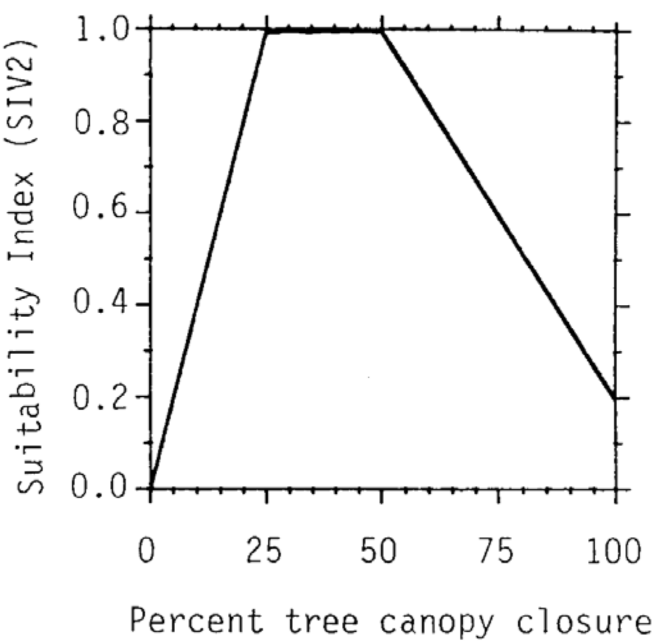


Figure 8. Percent tree canopy closure (V2) variable relationship for the winter food/cover life requisite for the eastern cottontail.

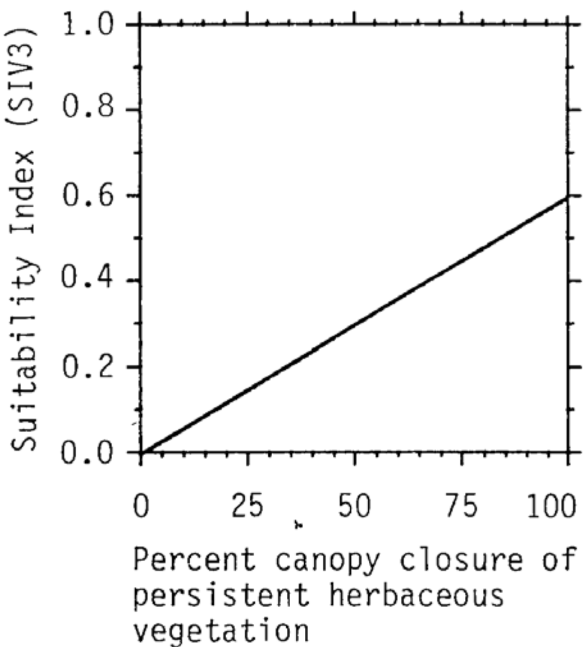


Figure 9. Percent canopy closure of persistent herbaceous vegetation (V3) variable relationship for the winter food/cover life requisite for the eastern cottontail.

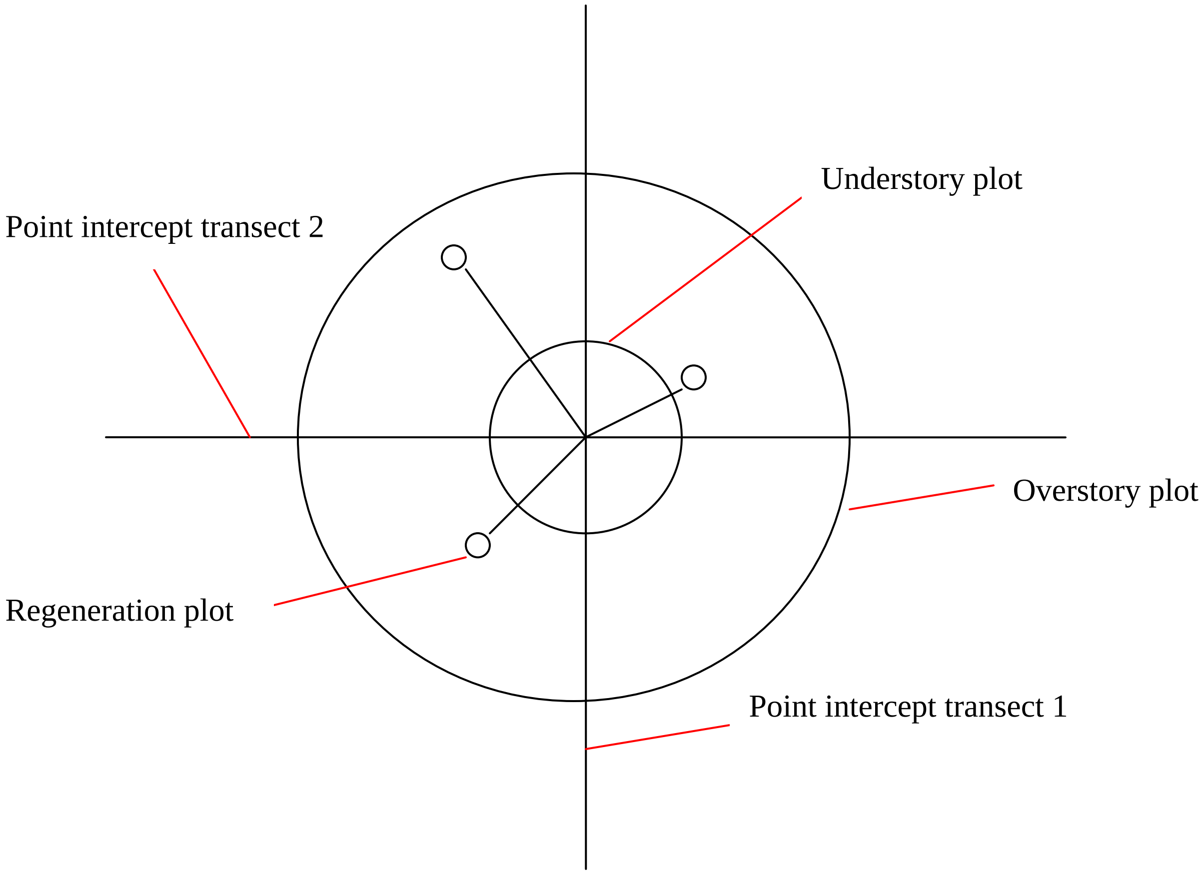


Figure 10. Sample wildlife habitat assessment design (shown with forest assessment plot design). Two perpendicular 40 meter point intercept transects run through the same plot center used for the forest assessment.

The gray squirrel (*Sciurus carolinensis* Gmelin) represents mid-successional and late successional mammal species, as well as cavity using species and species dependent on hard mast. Gray squirrels spend the most of their time in tree tops and may not be influenced by exotic invasive plants in the same way as species that live on the forest floor. The HSI model for this species applies for any season of the year (Allen 1987). There are three variables for the winter food life requisite. These variables are the proportion of total tree canopy cover that has 25 cm or greater dbh hard mast producing trees (V1), number of hard mast tree species (V2), and percent canopy cover of trees (V3). There are also two variables for the cover/reproduction life requisites, which are percent canopy cover of trees (V4) and mean dbh of overstory trees (V5). All of the variables except the percent canopy cover of trees were found by using the forest data already collected. The percent canopy cover of trees was found by measurements along the 40 m point intercept vegetation transect (Figure 10). Each of the habitat variables and final LRSI values were again quantified in Microsoft Excel as discussed above (Appendix C).

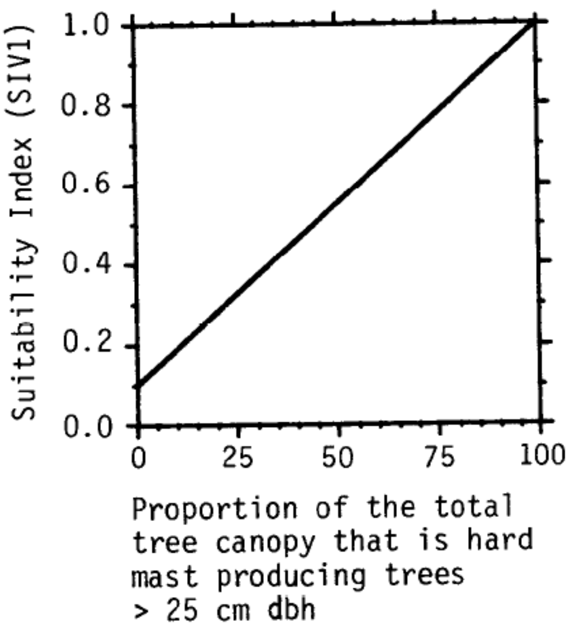


Figure 11. Proportion of total tree canopy cover that has 25 cm or greater dbh hard mast producing trees (V1) variable relationship for the winter food life requisite for the gray squirrel.

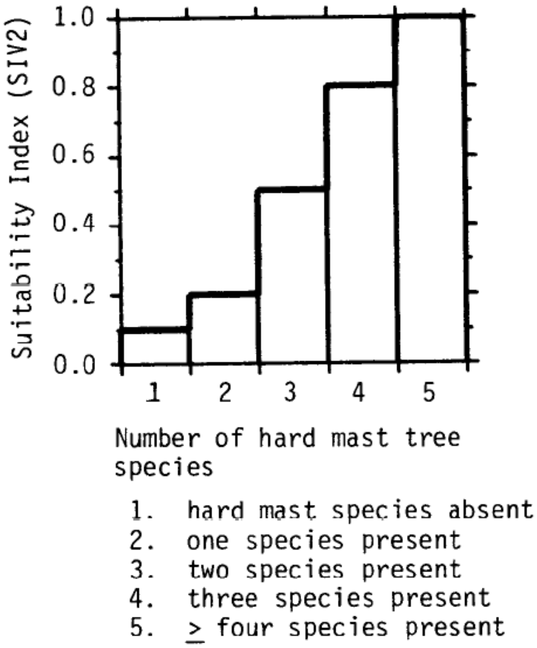


Figure 12. Number of hard mast tree species (V2) variable relationship for the winter food life requisite for the gray squirrel.

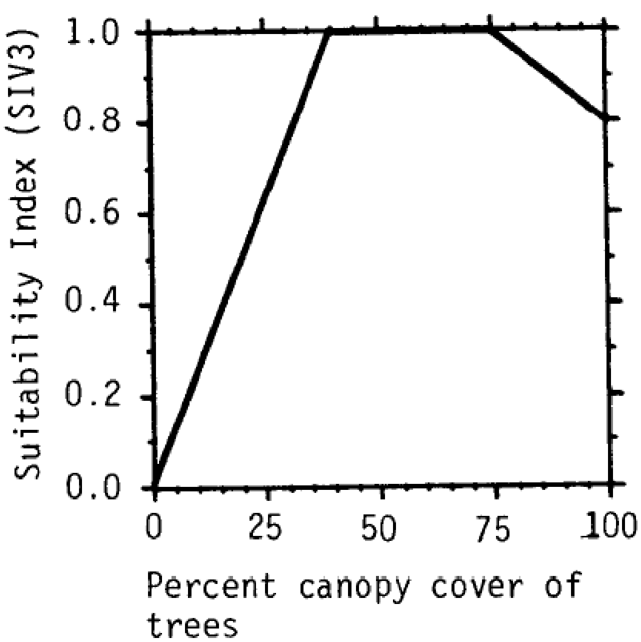


Figure 13. Percent canopy cover of trees (V3) variable relationship for the winter food life requisite for the gray squirrel.

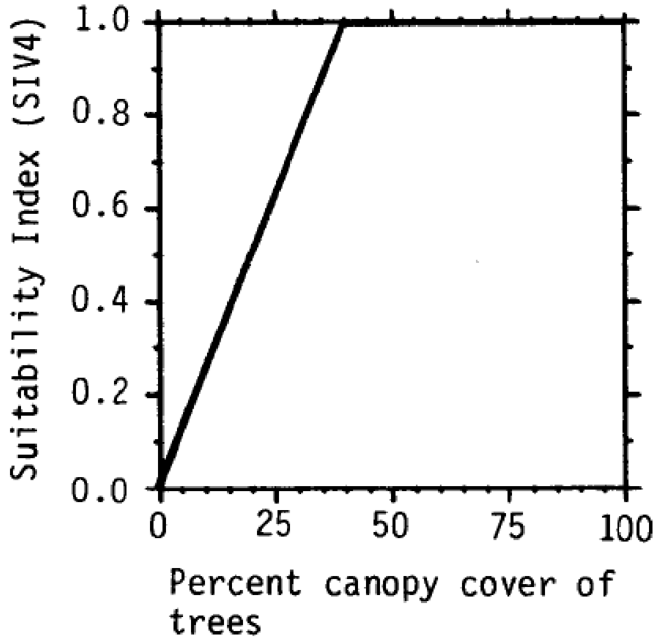


Figure 14. Percent canopy cover of trees (V4) variable relationship for the cover/reproduction life requisite for the gray squirrel.

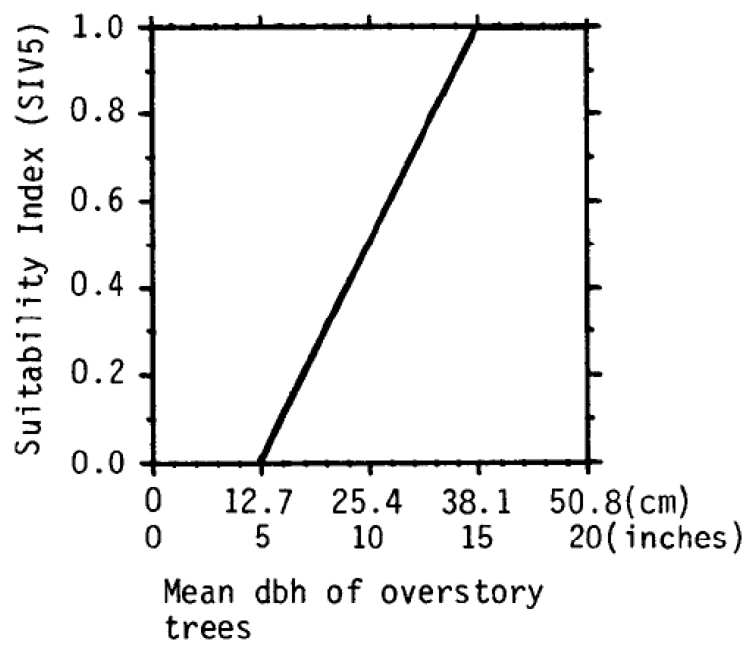


Figure 15. Mean dbh of overstory trees (V5) variable relationship for the cover/reproduction life requisite for the gray squirrel.

The downy woodpecker [*Picoides pubescens* (Linnaeus)] is a good representative of a mid- to late successional cavity nesting species. The HSI model was developed to fit any season of the year and has only two variables, one for the food life requisite and one for the reproduction life requisite (Schroeder 1982). To quantify the food life requisite, basal area (V1) was found from the forest overstory data. The reproduction life requisite variable is the number of snags greater than 15 cm dbh/0.4 ha (V2). This variable was also found by using the forest overstory data. Each of the habitat variables and final LRSI values were quantified in Microsoft Excel as discussed above (Appendix C).

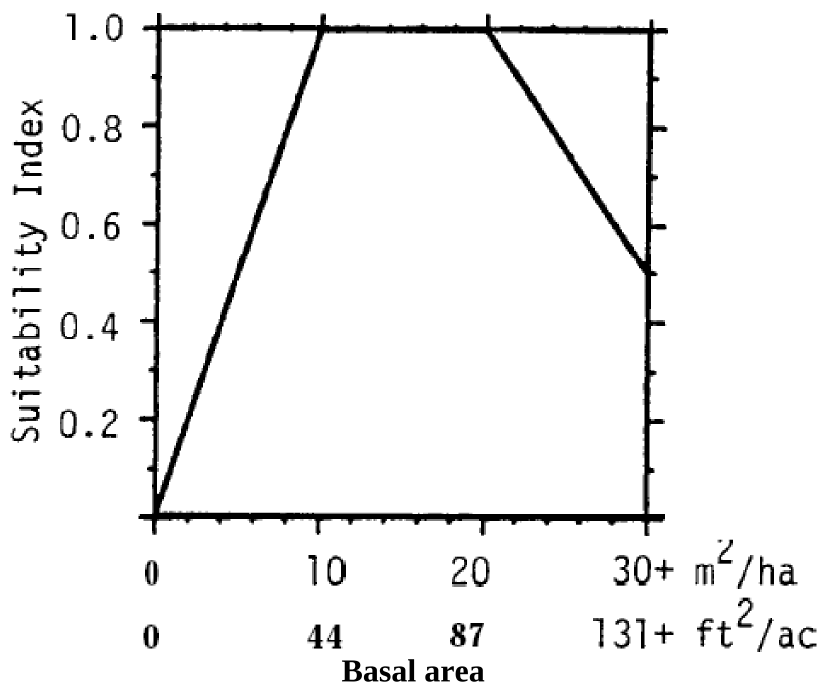


Figure 16. Basal area (V1) variable relationship for the food life requisite for the downy woodpecker.

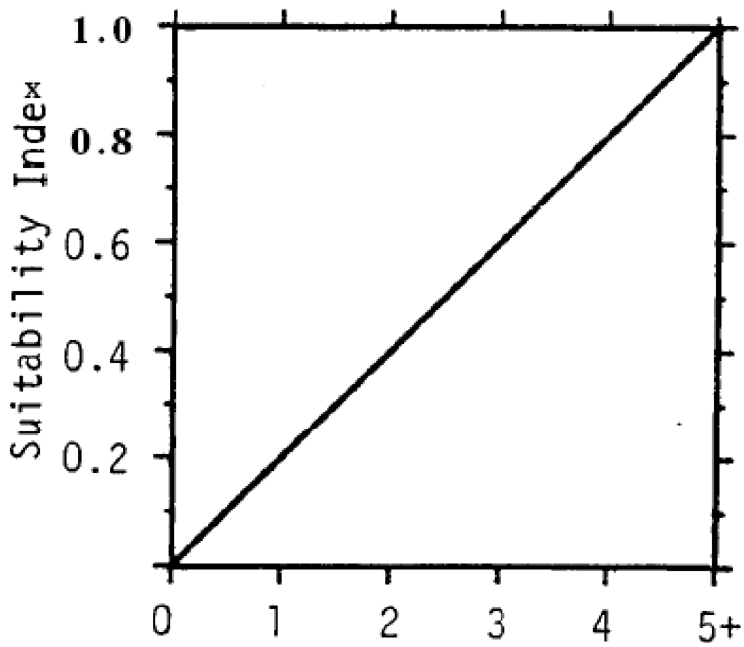


Figure 17. Number of snags greater than 15 cm dbh/0.4 ha (V2) variable relationship for the reproduction life requisite for the downy woodpecker.

The black-capped chickadee (*Poecile atricapillus* Linnaeus) is a good example of a mid- to late successional cavity nester that requires smaller dbh cavity trees. The HSI model for this species was developed for the breeding season (Schroeder 1983). It has three variables in two life requisites. The food life requisite has two variables, percent tree canopy closure (V1) and average height of overstory trees (V2). The variable for the reproduction life requisite is the number of 10 cm to 25 cm dbh snags for every 0.4 ha (V3). The 40 m point intercept vegetation transect (Figure 10) was used for the first food variable. Canopy height was found with measurements made with the use of a clinometer and the number of snags was found by using the forest data. Each of the habitat variables and final LRSI values were quantified in Microsoft Excel as discussed above (Appendix C).

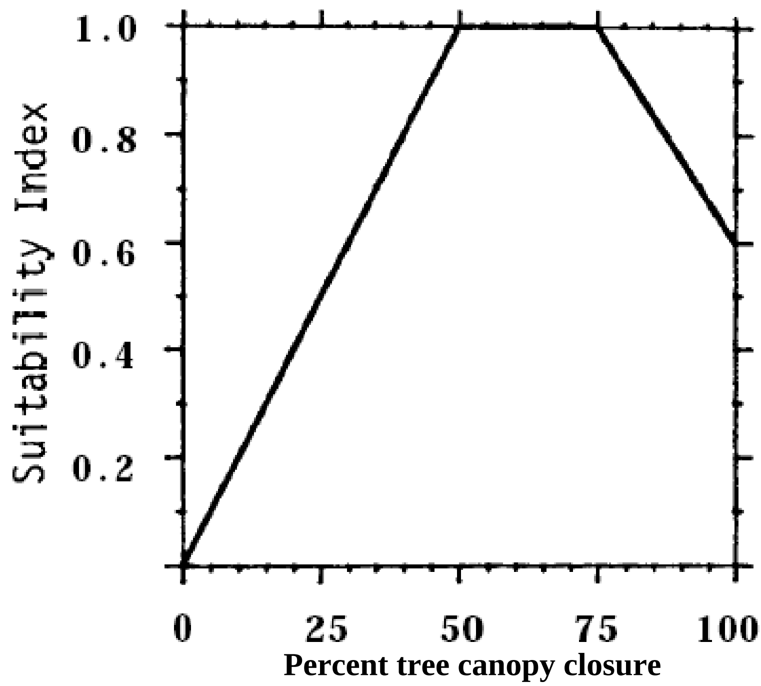


Figure 18. Percent tree canopy closure (V1) variable relationship for the food life requisite for the black-capped chickadee.

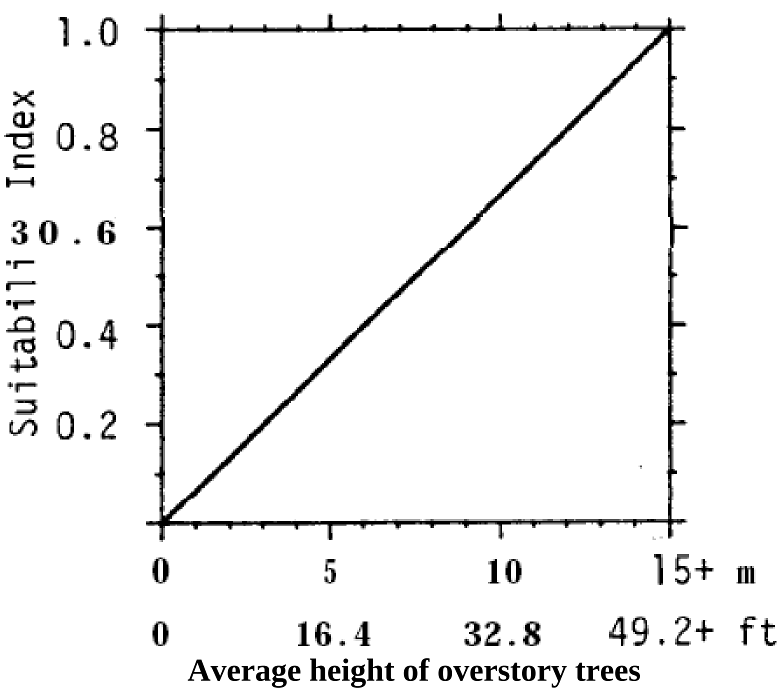


Figure 19. Average height of overstory trees (V2) variable relationship for the food life requisite for the black-capped chickadee.

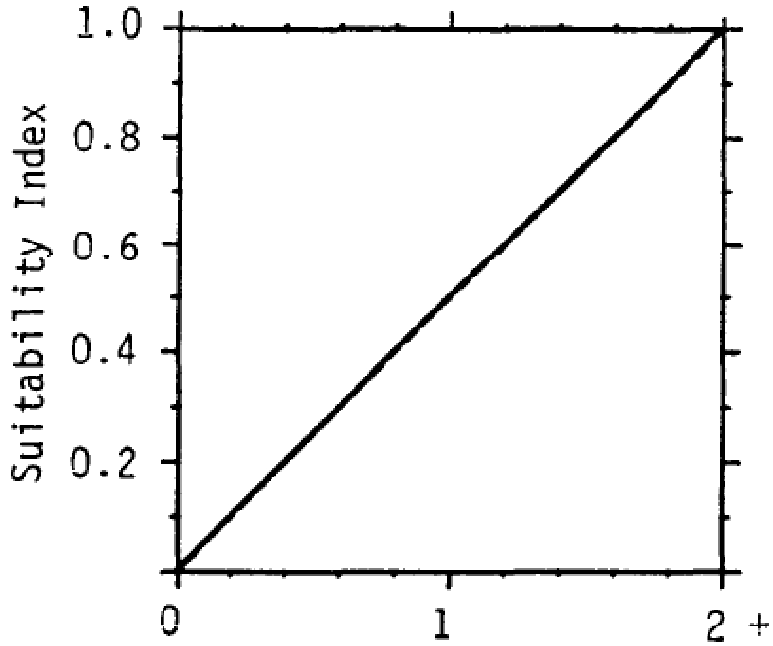


Figure 20. Number of 10 cm to 25 cm dbh snags for every 0.4 ha (V3) variable relationship for the reproduction life requisite for the black-capped chickadee.

Eastern wild turkey (*Meleagris gallopavo sylvestris* Vieillot) represents an upland gamebird that relies on a variety of habitats at different times of the year and may be influenced by changes to many forest habitats. The HSI model was developed for all seasons during the year (Schroeder 1985). There are three life requisites applicable for the cover types in this study. The first life requisite, summer food/brood habitat, has two variables. These variables are percent herbaceous canopy cover (V1) and average height of herbaceous canopy in the summer (V2). The second life requisite is fall, winter, and spring food and has 5 variables. These variables are (1) average dbh of hard mast producing trees 25.4 cm dbh or more (V3), (2) number of hard mast producing trees per 1 ha that are 25.4 cm dbh or more (V4), (3) percent canopy cover of soft mast producing trees (V5), (4) percent shrub cover (food) (V6), and (5) percent of shrub crown cover composed of soft mast producing shrubs (V7). The LRSI value equation takes into account a sixth variable, percent shrub cover (behavioral) (V8). The third life requisite, cover, has three variables. These variables are percent tree canopy cover (V9), average dbh of overstory trees (V10), and percent of forest canopy comprised of evergreens (V11). All variables, except the average dbh of overstory trees for the cover life requisite and variables 1 and 2 for fall, winter, and spring food, were measured by using the 40 m point intercept vegetation transect (Figure 10). The average dbh of overstory trees and variables 1 and 2 were found using the forest overstory data already available. Each of the habitat variables and final LRSI values were quantified in Microsoft Excel as discussed above (Appendix C).

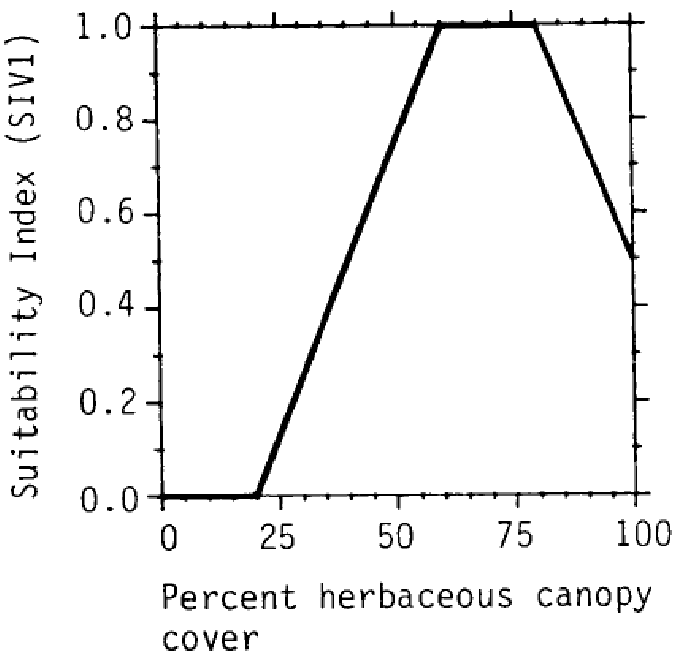


Figure 21. Percent herbaceous canopy cover (V1) variable relationship for the summer food/brood life requisite for the eastern wild turkey.

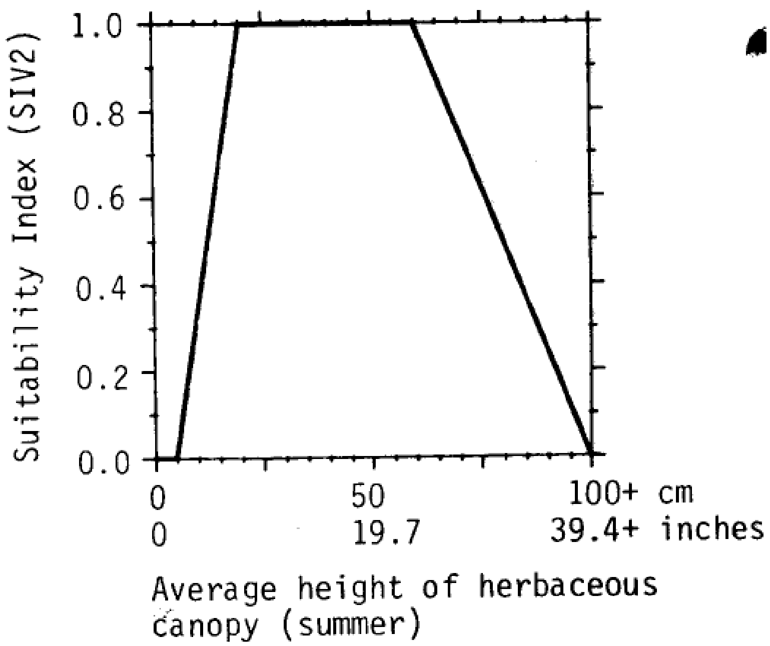


Figure 22. Average height of herbaceous canopy in the summer (V2) variable relationship for the summer food/brood life requisite for the eastern wild turkey.

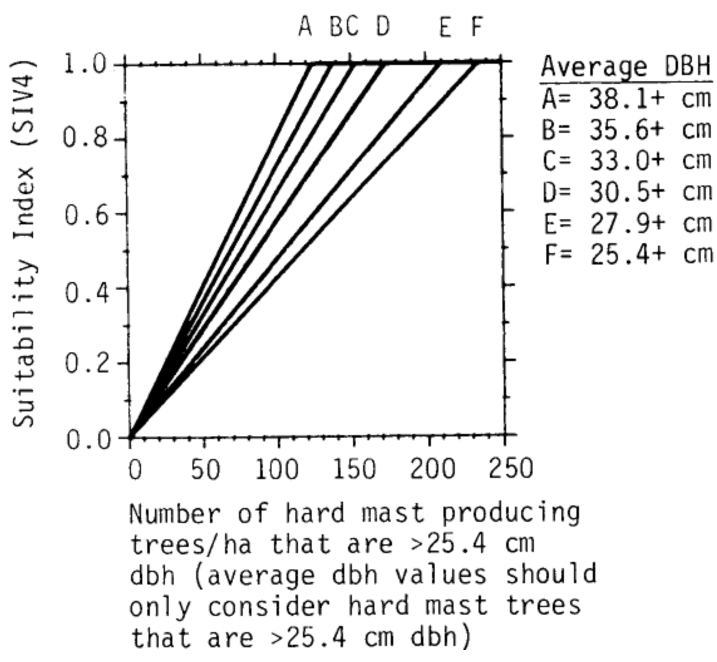


Figure 23. Average dbh of hard mast producing trees 25.4 cm dbh or more (V3) and number of hard mast producing trees per 1 ha that are 25.4 cm dbh or more (V4) variable relationship for the fall, winter, and spring food life requisite for the eastern wild turkey.

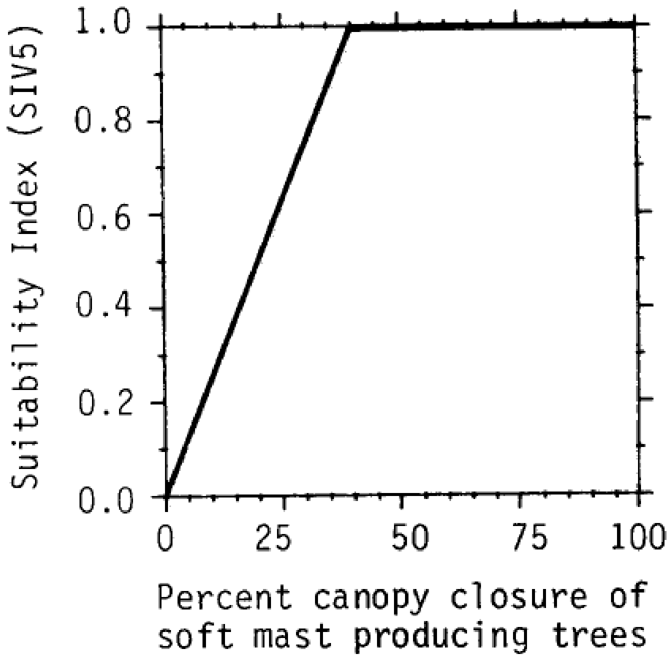


Figure 24. Percent canopy cover of soft mast producing trees (V5) variable relationship for the fall, winter, and spring food life requisite for the eastern wild turkey.

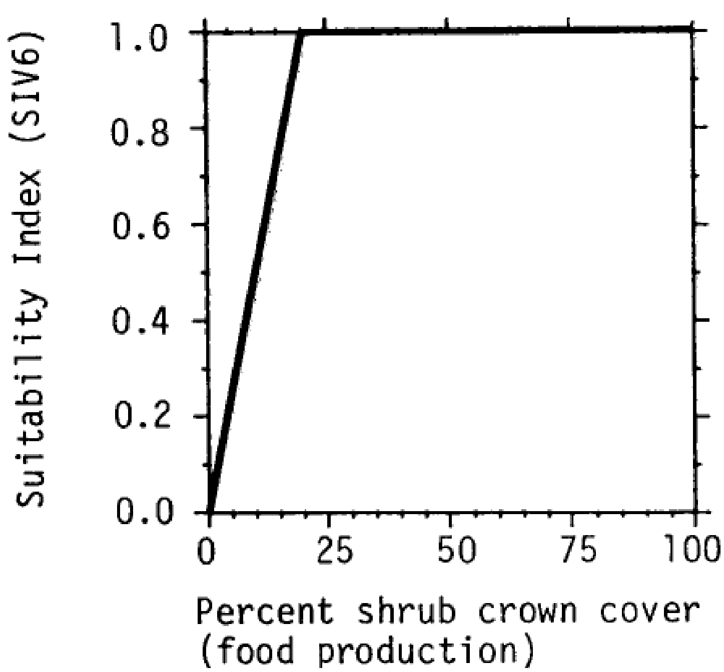


Figure 25. Percent shrub cover (food) (V6) variable relationship for the fall, winter, and spring food life requisite for the eastern wild turkey.

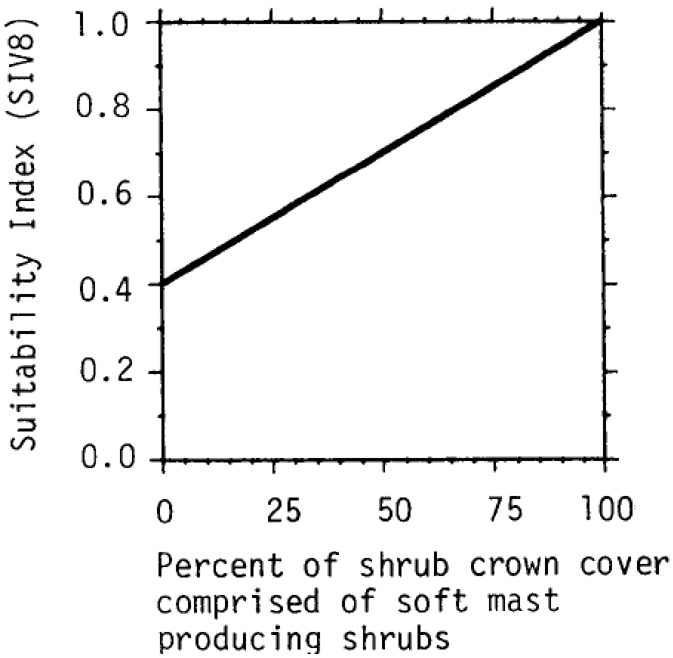


Figure 26. Percent of shrub crown cover composed of soft mast producing shrubs (V7) variable relationship for the fall, winter, and spring food life requisite for the eastern wild turkey.

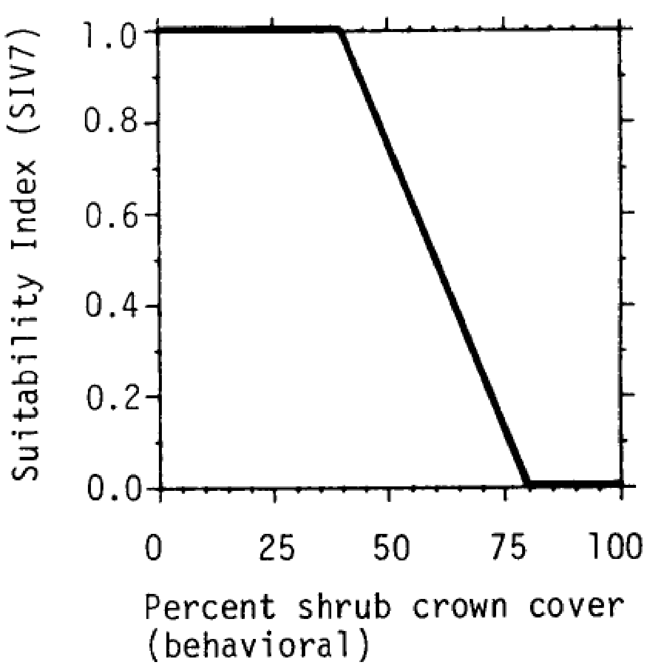


Figure 27. Percent shrub cover (behavioral) (V8) variable relationship for the fall, winter, and spring food life requisite for the eastern wild turkey.

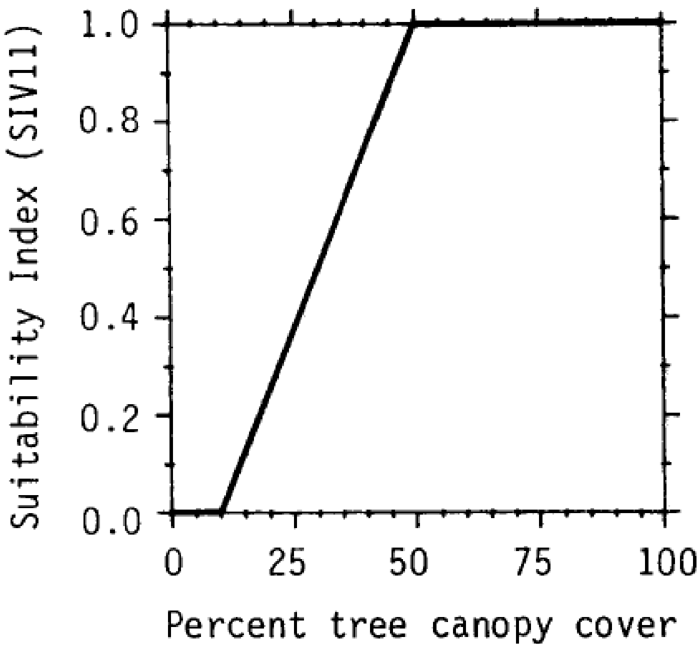


Figure 28. Percent tree canopy cover (V9) variable relationship for the cover life requisite for the eastern wild turkey.

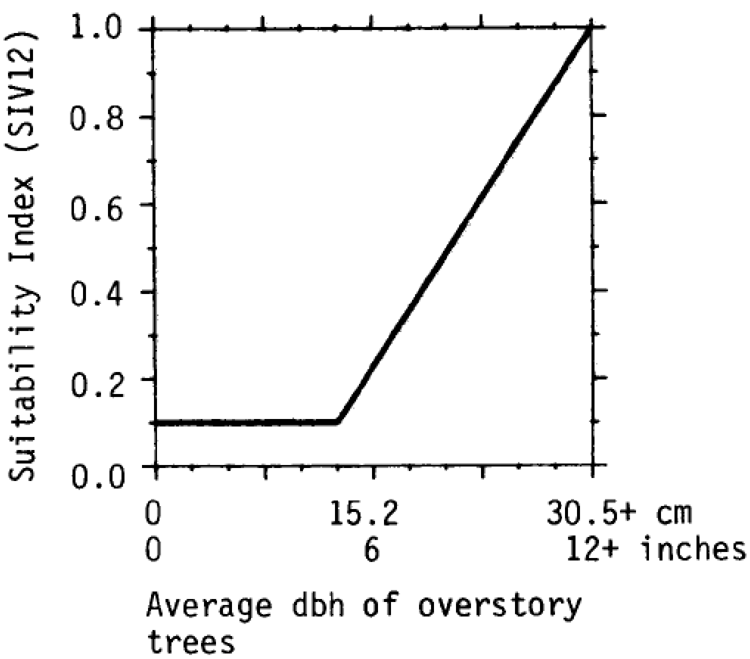


Figure 29. Average dbh of overstory trees (V10) variable relationship for the cover life requisite for the eastern wild turkey.

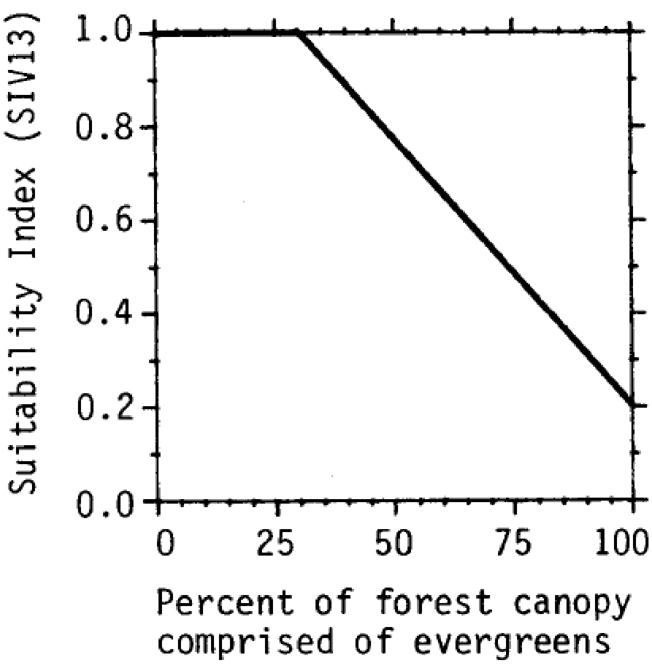


Figure 30. Percent of forest canopy comprised of evergreens (V11) variable relationship for the cover life requisite for the eastern wild turkey.

The veery [*Catharus fuscescens* (Stephens)] is a representative of species requiring mesic site conditions with relatively high understory cover. The HSI model for this species is for the spring and summer seasons (Sousa 1982). The life requisite used for this model is cover/reproduction. Four of the five variables were used to help determine habitat suitability for this species. The percent of cover type flooded was the variable not used. The four variables are percent deciduous shrub crown cover (V1), average height of deciduous shrubs (V2), percent herbaceous canopy cover (V3), and average height of herbaceous canopy (V4). All of these variables were measured using the 40 m point intercept vegetation transect (Figure 10). Each of the habitat variables and final LRSI values were quantified in Microsoft Excel as discussed above.

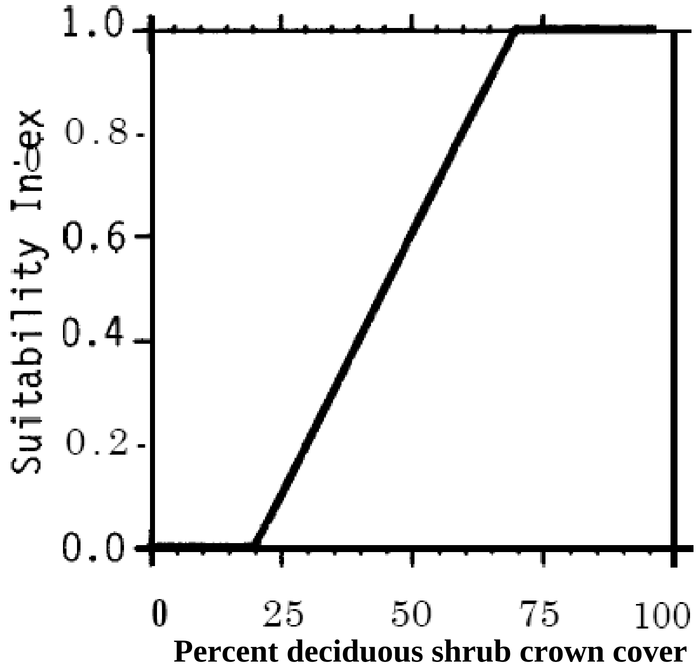


Figure 31. Percent deciduous shrub crown cover (V1) variable relationship for the cover/reproduction life requisite for the veery.

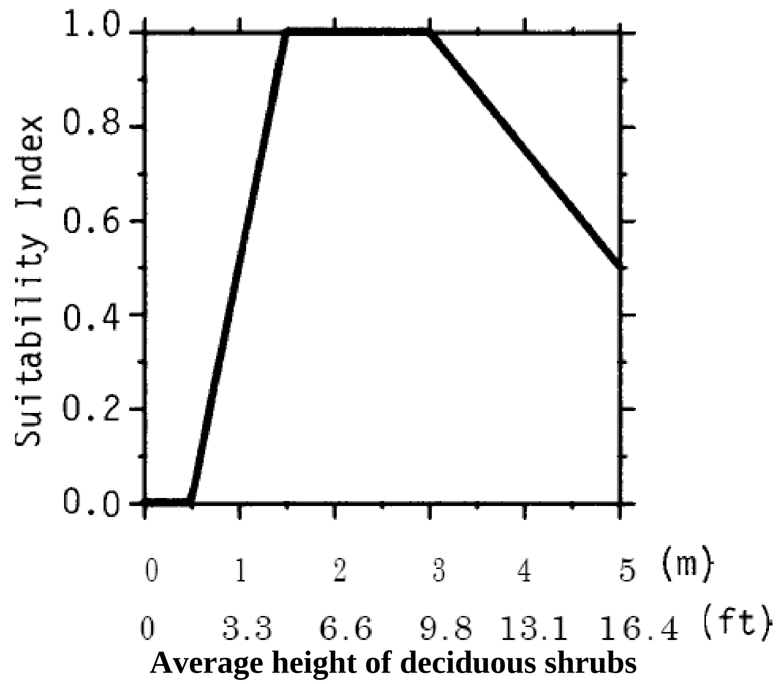
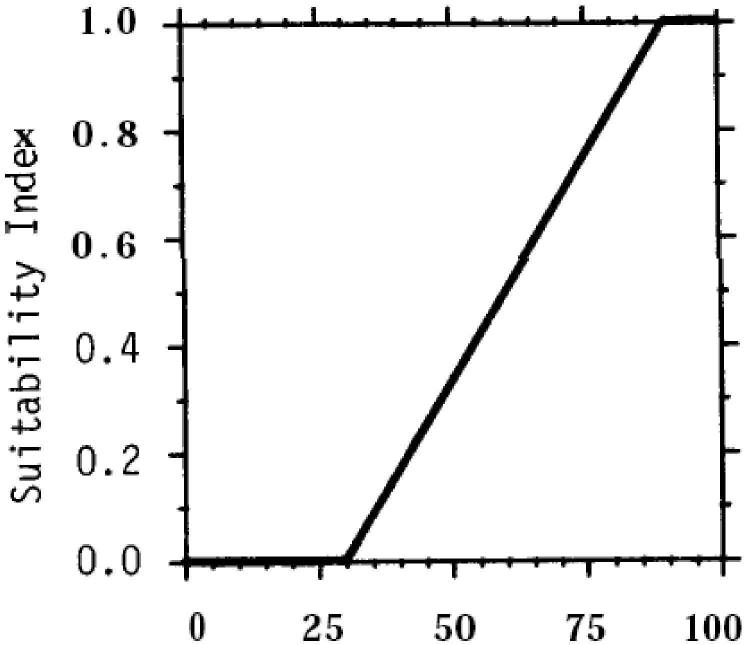
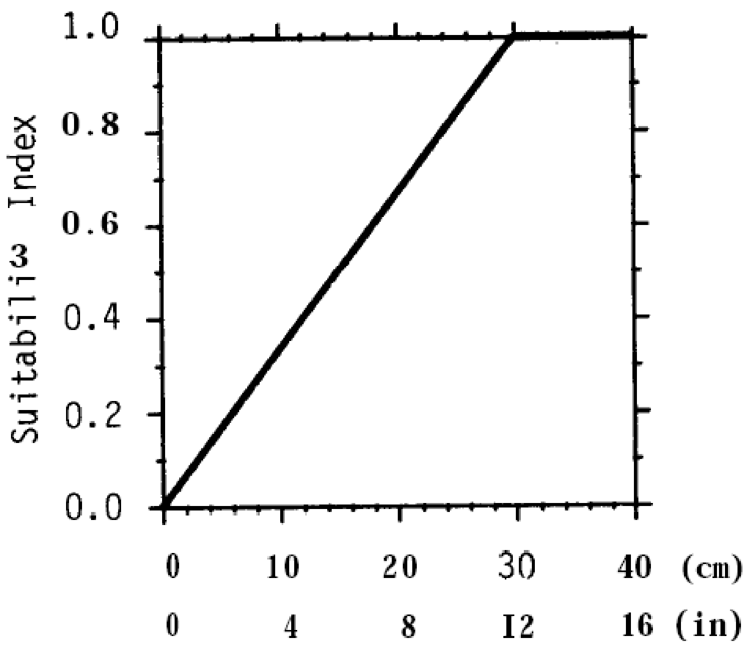


Figure 32. Average height of deciduous shrubs (V2) variable relationship for the cover/reproduction life requisite for the veery.



Percent herbaceous canopy cover
(late spring/early summer conditions)

Figure 33. Percent herbaceous canopy cover (V3) variable relationship for the cover/reproduction life requisite for the veery.



Average height of herbaceous canopy
(late spring/early summer conditions)

Figure 34. Average height of herbaceous canopy (V4) variable relationship for the cover/reproduction life requisite for the veery.

Proximity to Disturbance

Each exotic invasive population was related to its proximity to a disturbance area. Disturbance areas considered on each of the three properties were roads (paved, gravel, and dirt, including harvest/thinning roads), old homesites or barns, powerline corridors, gas pipelines, streams, recent harvests or thinnings (last 15 years), fence rows, pastures, and hay fields. The proximity of these exotic invasive populations to disturbance areas was determined by the use of the measurement tool on the Tools Toolbar in ESRI ArcGIS 9.2.

Data Analysis

After gathering all the data from all three tracts, the data were examined to determine significant differences between paired plots of exotic invasive plants and those without exotic invasive plants. The forest and wildlife habitat data were analyzed using a paired two sample for means t-test in the Analysis ToolPak in Microsoft Excel. The proximity of these populations to disturbance sites was also analyzed. A gain in the understanding of the role of exotic invasive plants and the impacts caused by these species has resulted from the analysis of the data from this pilot study.

Forest Analysis

The overstory plot data were analyzed for the number of species per plot (species richness), the total basal area per acre [basal area (BA)], and the total number of trees per acre (tree density). The understory plot data were analyzed for the number of species per plot (species richness), the total percent cover per plot (percent cover), and the total number of saplings per acre (sapling density). The regeneration plot data were analyzed for the number of species per plot (species richness) and the total number of seedlings per acre (seedling density). The forest data were entered into a Microsoft Excel spreadsheet and set up by these variables. All of these variables had a paired t-test run to determine if there was a significant difference between plots with the exotic invasive plants present and plots without the exotic invasive plants. The t-tests were run across all the plots collectively on each property, matching the invasive plots with the noninvasive plots. Then, t-tests were run on the data for all three properties together.

Wildlife Habitat Analysis

The habitat data were entered into a Microsoft Excel spreadsheet that was set up to calculate the LRSI for each of the six species. The Excel spreadsheet was set up by entering the previously mentioned equations that fit the graph for each variable required by each wildlife species to meet their life requisites. Then, a final equation was entered that characterized the relationship between all of the variables for each species. This final equation resulted in LRSI numbers between 0 and 1 for each wildlife species on each plot. An LRSI value of 0 meant the habitat was not suitable for that species and an LRSI value of 1 meant the habitat was very suitable for that species and provided all the necessary life requisites. HSI models provide a measure of quality for the habitat and allow individual habitat variables to be considered. These calculations were done for each plot (invasive and noninvasive) on every property. After the LRSI numbers were obtained, the paired t-tests were run across the plots for each wildlife species life requisite for each property, matching invasive plots and noninvasive plots. Then, this same analysis was run by paired t-test across all three properties. The eastern cottontail and the veery have only one life requisite that are used in this research. However, the gray squirrel, downy woodpecker, and black-capped chickadee have two life requisites, making a breakdown to two categories necessary for each of these species. The eastern wild turkey has three life requisites, making three categories necessary to analyze. The breakdown of these species into 2 or 3 categories based on life requisite will help to determine which habitat variable is affected more by the presence of exotic invasive plants.

Proximity to Disturbance Analysis

All exotic invasive plant populations that met the size requirement of 0.2 acre were assessed for their proximity to the nearest disturbance site. They were all measured to the nearest reasonable disturbance site in ESRI ArcGIS 9.2. Reasonable disturbance sites were determined by the position of the disturbance to the exotic invasive population. For example, if the nearest disturbance site was located downhill from a wind dispersed exotic invasive species, the disturbance was not considered in this analysis as the corridor of transport for that species into the area. Instead, the disturbance is considered as a possible area of future invasion.

Results and Discussion

Forest Characteristics

Cedar Grove Farm (Coastal Plain tract) had 10 significant exotic invasive populations that met the 0.2 acre size requirement (Figure 3, Table 1). Five populations were scotchbroom, two were Chinese privet, and three were Japanese honeysuckle. Scotchbroom population sizes were 0.67 acre, 0.24 acre, 0.29 acre, 0.45 acre, and 0.99 acre. Chinese privet population sizes were 0.66 acre and 1.97 acres. Japanese honeysuckle population sizes were 7.87 acres, 2.77 acres, and 0.22 acre. The largest Japanese honeysuckle population was a very light infestation on the eastern side of the tract and did not have sufficient amounts available for sampling in most areas. However, this may be a problem area in the future. This population is located in an area that had forestry practices conducted on it 13 years ago.

Kennedy Tree Farm (Piedmont tract) had 5 significant exotic invasive plant populations (Figure 4, Table 1). There were three populations of tree-of-heaven and two populations of Japanese honeysuckle. The tree-of-heaven population sizes were 0.26 acre, 0.41 acre, and 1.74 acres. The Japanese honeysuckle population sizes were 0.83 acre and 1.49 acres.

Beaver Run Farm (Blue Ridge tract) had 19 significant exotic invasive plant populations (Figure 5, Table 1). Thirteen populations were tree-of-heaven, with sizes of 11.59 acres, 0.96 acre, 0.46 acre, 0.52 acre, 0.36 acre, 0.42 acre, 1.05 acres, 2.19 acres, 0.23 acre, 0.74 acre, 0.59 acre, 3.69 acre, and 3.96 acres. The populations with sizes of 10.43 acres and 3.96 acres were sampled multiple times to ensure quality of the data.

The remaining six populations were Japanese honeysuckle. The sizes of these populations were 1.07 acres, 1.31 acres, 0.19 acre, 0.61 acre, 0.37 acre, and 0.73 acre

.Table 1. Number and dominant species of exotic invasive plant populations in three physiographic provinces of Virginia.

Tract	Number of populations	Dominant species & number of populations
Coastal Plain	10	Scotchbroom (5), Japanese honeysuckle (3), Chinese privet (2)
Piedmont	5	Tree-of-heaven (3), Japanese honeysuckle (2)
Blue Ridge	19	Tree-of-heaven (13), Japanese honeysuckle (6)

Overstory

The data did not show a significant difference in mean species richness of native overstory trees between invasive plots and noninvasive plots on the Coastal Plain or Piedmont tracts (Table 2). However, native species diversity of overstory trees declined with the presence of invasive plants on the Blue Ridge tract and over all tracts. Stohlgren et al. (2003) suggest the possibility that no cause-effect relationship exists for species richness between native and exotic species. This indicates other factors may be influencing species richness, such as saturation of the area with species or soil conditions (levels of moisture and pH). It may also be possible that native plants may already have filled the niches available (Gilbert and Lechowicz 2005).

The total basal area (BA) and BA of native species were significantly higher on noninvasive plots for the Coastal Plain and Blue Ridge tracts (Table 2). Total and native species BA was also significantly higher on noninvasive plots over all three tracts. Native species BA was lower than total BA on the Blue Ridge tract and over all tracts when the invasive plants were present. This makes sense, as the cross-sectional area, or growth, of overstory trees may be limited on plots with invasive plants, which may be causing a decline in timber production or quality. Another explanation could be that invasive plants occur in areas of low BA due to higher light levels caused by the absence of trees. Gordon (1998) also found reduced total basal area in tracts that were invaded in Florida.

The total overstory tree density was significantly higher on noninvasive plots on the Coastal Plain tract, but not on the other two tracts or over all three tracts (Table 2). Tree density of native species was higher on noninvasive plots on the Coastal Plain tract and on the Blue Ridge tract. One explanation could be the high number of overstory stems already present in the loblolly pine plantations on the Coastal Plain tract, which occurred in 25% of these sites. Another explanation could be a replacement of niches on the Piedmont tract. These data may also indicate invasive plants decrease the density of stems.

Table 2. Overstory forest characteristics on plots with invasive plants (I) and plots without invasive plants (NI) over the sample size of invasive populations (n) in 3 physiographic provinces of Virginia.

	Coastal Plain tract n = 10		Piedmont tract n= 5		Blue Ridge tract n= 19		All tracts n = 3	
	I	NI	I	NI	I	NI	I	NI
Native Species Richness (# spp./0.1 acre)	3.9	5.0	4.0	6.4	5.0*	6.6	4.3*	6.0
Total BA (ft^2/acre)	58.9*	89.5	84.5	97.4	115.1*	142.8	86.2*	109.9
Native Species BA (ft^2/acre)	58.9*	89.5	79.8	97.4	95.8*	142.8	78.2*	109.9
Total Tree Density (trees/acre)	265*	567	452	486	256	247	324	433
Native Tree Density (trees/acre)	265*	567	410	486	160*	247	278	433

* Indicates significantly different paired t-test plots within tract at $P \leq 0.05$.

Understory

Native species richness of the understory was lower when invasive plants were present on the Piedmont tract and over all tracts (Table 3). Diversity could show a substantial decline on the Piedmont tract due to the location of sample plots. Three of five invasive plots on this tract were sampled in forest conditions that were much more open than sampling on the other tracts. These open conditions, having fewer species present on invasive sample plots than noninvasive plots, were due to old homesites.

The percent cover of all woody understory plants on the Coastal Plain and Blue Ridge tracts was significantly higher on the invasive plots (Table 3). The percent cover on the invasive plots was almost double the noninvasive plots on the Coastal Plain tract and was double for the Blue Ridge tract. Exotic invasive Chinese privet and scotchbroom could account for the high understory cover on the Coastal Plain tract. Numerous small tree-of-heaven saplings could account for the difference on the Blue Ridge tract. Over all 3 tracts, the percent cover of the understory was also significantly higher in areas with invasive plants present. The percent cover may not be as impacted in the Piedmont because other understory species on noninvasive plots accounted for just as much percent cover as tree-of-heaven on invasive plots. In addition, Japanese honeysuckle was largely ground cover on this tract, preventing some regeneration from developing into forms large enough to be accounted for in the understory sampling. There was no difference in the percent cover of native vegetation species on any tracts individually or combined.

Sapling density was significantly higher only on the invasive plots on the Blue Ridge tract (Table 3). The invasive plots on the Blue Ridge tract had more than twice the number of saplings than the noninvasive plots. On the invasive plots, 69% of stems were tree-of-heaven. This could be due to the invasive nature of tree-of-heaven, which accounted for thirteen of nineteen exotic invasive populations on the property. The mass production of seedlings and allelopathic nature of tree-of-heaven explains these results.

Similarly, Wyckoff and Webb (1996) and Martin (1999) found stem density of Norway maple to be high under the invasive Norway maple canopy. There may be no difference shown on the Coastal Plain and Piedmont tracts because tree-of-heaven saplings have been shown to be as numerous as native saplings (Knapp and Canham 2000). Sapling density of native species showed no difference on any tracts.

Table 3. Understory forest characteristics on plots with invasive plants (I) and plots without invasive plants (NI) over the sample size of invasive populations (n) in 3 physiographic provinces of Virginia.

	Coastal Plain tract n = 10		Piedmont tract n = 5		Blue Ridge tract n = 19		All tracts n = 3	
	I	NI	I	NI	I	NI	I	NI
Native Species Richness (# spp./0.1 acre)	4.1	5.4	2.8*	4.2	2.6	3.3	3.2*	4.3
Total % Cover (% cover/0.1 acre)	78.0*	41.6	40.5	24.2	54.3*	27.2	57.6*	31.0
Native % Cover (% cover/0.1 acre)	66.5	41.6	24.0	24.2	28.7	27.2	39.7	31.0
Total Sapling Density (saplings/acre)	255	301	194	128	301*	122	250	184
Native Sapling Density (saplings/acre)	211	301	130	128	94	122	145	184

* Indicates significantly different paired t-test plots within tract at $P \leq 0.05$.

Regeneration

Regeneration was the most impacted forest variable by invasive plants for all tracts. The data show invasive plants decrease the density and the diversity of seedlings (Table 4). The native species richness of seedlings on all tracts individually and collectively was significantly higher on noninvasive plots. Total and native species seedling density was also significantly higher on noninvasive plots on all tracts individually, as well as collectively. Total seedling density on all tracts is consistently

2.5 to 3 times greater on noninvasive plots than on invasive plots. Native seedling density is 4 times greater on noninvasive plots than on invasive plots.

Japanese honeysuckle has been shown to impact regeneration of several species. In Arkansas, pine regeneration was insufficient due to Japanese honeysuckle (Cain 1991). Similarly, hardwood regeneration can be hard to establish and subsequently grow if Japanese honeysuckle is present. Japanese honeysuckle grows poorly in mature hardwood stands, as shown by the absence of this species in these stands on each of the three tracts. However, if it occurs in small amounts in any stand type and a disturbance occurs (natural or man-made) it may take over. Mature forests often have low frequency and density of invasive plants because low light intensities on the forest floor, especially in dense understory areas where a “secondary closed shrub canopy” may appear (Robertson et al. 1994). Hardwood regeneration, particularly oak, that is slow growing is often overtopped, can have reduced growth, or develop malformations of shoots when partial overstory removals occur in an attempt to establish and free adequate oak regeneration (Gardiner and Yeise 2000). It has also been noted that tree-of-heaven may have a window for regeneration and may not be able to survive beneath existing full canopy conditions (Knapp and Canham 2000), indicating invasive plot regeneration may be lacking.

Table 4. Forest characteristics on regeneration plots with invasive plants (I) and plots without invasive plants (NI) over the sample size of invasive populations (n) in 3 physiographic provinces of Virginia.

	Coastal Plain tract n = 10		Piedmont tract n = 5		Blue Ridge tract n = 19		All tracts n = 3	
	I	NI	I	NI	I	NI	I	NI
Native Species Richness (# spp./0.1 acre)	4.0*	7.5	2.8*	8.0	4.7*	7.8	3.8*	7.8
Total Seedling Density (seedlings/acre)	271*	733	168*	496	541*	1540	327*	923
Native Seedling Density (seedlings/acre)	191*	733	122*	496	359*	1540	224*	923

* Indicates significantly different paired t-test plots within tract at $P \leq 0.05$.

Wildlife Habitat

Eastern cottontail

Variable values for the LRSI for this species and all other wildlife species show changes that take place in particular habitat components. For example, the eastern cottontail will have the most favorable potential habitat quality, as determined by this index method, when the percent shrub crown closure and percent tree canopy closure are 20% to 50% and 25% to 50%, respectively (Figure7, Figure9). In addition, the greater the percentage of persistent herbaceous vegetation, the better the potential habitat quality. The percent shrub crown closure is highest on the Coastal Plain tract with exotic invasive plant presence (Table 5). The percentage of herbaceous canopy cover is higher with the presence of exotic invasive plants on the Piedmont and Blue Ridge tracts and over all tracts. However, percent shrub canopy cover remains relatively the same on the Blue Ridge tract. The combination of these individual variables, led the winter cover LRSI habitat for the eastern cottontail to be significantly higher on invasive plots on the Coastal Plain and Piedmont tracts, while remaining similar on the Blue Ridge tract (Table 6). No difference in habitat for this species was seen when data from all three tracts was combined. The habitat suitability for this species was doubled with the presence of exotic invasive plants on the Coastal Plain and Piedmont tracts. It is reasonable to expect habitat for this species to be enhanced by invasive plants because one characteristic of some invasive plants is dense growth and this species revels in brushy cover. Very dense cover, such as may be found in Japanese honeysuckle thickets, would be excellent habitat for this species. On the Coastal Plain and Piedmont tracts, Japanese honeysuckle consisted of 30% and 40% of the plots, respectively. Twenty six percent of Blue Ridge plots were Japanese honeysuckle. Japanese honeysuckle also provides good forage for this species (Sheldon and Causey 1974). The Coastal Plain and Piedmont tracts may be better suited for supplying this type of habitat due to the management of loblolly pine, in which many early successional stands were present. The Blue Ridge tract is largely comprised of mature hardwood forest, which does not provide much shrub cover, a necessary variable for good eastern cottontail rabbit habitat.

Table 5. Average life requisite suitability index (LRSI) variable values on plots with invasive plants (I) and plots without invasive plants (NI) over the sample size of invasive populations (n) in 3 physiographic provinces of Virginia.

	Coastal Plain tract n = 10		Piedmont tract n = 5		Blue Ridge tract n = 19		All tracts n = 3	
Variable	I	NI	I	NI	I	NI	I	NI
% decid. shrub canopy cover	1.66	0.00	3.22	0.00	2.46*	1.30	2.44	0.43
% Shrub Canopy Cover	4.20*	0.54	3.22	0.00	2.46	3.54	3.29	1.36
% Tree canopy cover	44.31*	60.98	57.78	63.26	78.30	73.51	60.13	65.92
% herb. canopy cover	12.39	4.04	14.29*	1.06	12.82*	3.17	13.16*	2.76
% total tree canopy w/hard mast trees (≥25 cm dbh)	0.75	0.00	2.11	0.00	2.81*	10.70	1.89	3.57
# hard mast tree species	0.20	0.70	0.40	1.00	0.77*	2.05	0.46	1.25
mean dbh of overstory trees (>80% height of tallest tree in stand)	26.44	23.48	19.85	21.72	37.07*	47.32	27.79	30.84
# of snags >15 cm dbh/0.4 ha	4.00	5.00	0.00	0.00	17.27	12.27	7.09	5.76
basal area	2.22	3.36	3.18	3.66	4.33*	5.37	3.24*	4.13
# of snags 10-25 cm dbh/0.4 ha	4.00*	10.00	8.00	2.00	17.27	14.55	9.76	8.85
average height overstory trees	18.61	18.56	13.85	15.30	23.19*	26.57	18.55	20.15
average dbh hard mast producing trees ≥25.4 cm dbh	4.65	0.00	7.08	0.00	15.48	26.53	9.07	8.84
# hard mast trees/ha ≥25.4 cm dbh	1.00	0.00	6.00	0.00	5.45*	22.27	4.15	7.42
% soft mast tree canopy cover	8.40	8.05	20.65	21.84	36.65	26.20	21.90	18.70
% soft mast shrub canopy cover	1.66	0.00	3.22	0.00	2.46*	1.30	2.44	0.43
% evergreen canopy cover	17.70*	31.30	27.44	29.04	2.67	3.67	15.94	21.34
average dbh of overstory	26.44	23.48	19.85	21.72	37.07*	47.32	27.79	30.84
Average herbaceous veg. height (cm)	19.25	6.53	35.64	1.79	10.40*	3.44	21.76	3.92
Shrub height (m)	0.22*	0.01	0.08	0.00	0.13	0.21	0.14	0.07
% shrub canopy cover-food	1.63	0.00	3.22	0.00	2.46*	1.30	2.44	0.43
% shrub canopy cover-behavior	4.20*	0.54	3.22	0.00	2.46	3.54	3.29	1.36

* Indicates significantly different paired t-test plots within tract at P ≤ 0.05.

Table 6. Life Requisite Suitability Index (LRSI) values on plots with invasive plants (I) and plots without invasive plants (NI) over the sample size of invasive populations (n) in 3 physiographic provinces of Virginia.

Species and Life Requisite	Coastal Plain tract n = 10		Piedmont tract n = 5		Blue Ridge tract n = 19		All tracts n = 3	
	I	NI	I	NI	I	NI	I	NI
Eastern cottontail	0.41*	0.20	0.39*	0.16	0.29	0.28	0.36	0.21
Gray squirrel- winter food	0.09*	0.13	0.11	0.16	0.13*	0.23	0.11	0.17
Gray squirrel- cover/reproduction	0.42	0.48	0.49	0.56	0.88*	0.98	0.59*	0.67
Downy woodpecker- reproduction	0.20	0.30	0.00	0.00	0.77	0.64	0.32	0.31
Downy woodpecker- food	0.22	0.34	0.32	0.37	0.43*	0.54	0.32*	0.41
Black-capped chickadee- food	0.78	0.91	0.92	0.95	0.95	0.96	0.88	0.94
Black-capped chickadee- reproduction	0.30*	0.70	0.40	0.20	0.73	0.68	0.48	0.53
Eastern wild turkey- food/brood	0.10	0.00	0.07	0.00	0.04	0.02	0.07	0.01
Eastern wild turkey- food	0.13	0.10	0.31	0.24	0.37	0.38	0.27	0.24
Eastern wild turkey- cover	0.33	0.40	0.34	0.44	0.87	0.97	0.52*	0.60
Veery	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.00

* Indicates significantly different paired t-test plots within tract at $P \leq 0.05$.

Gray squirrel

Gray squirrel winter food habitat was significantly higher on noninvasive plots on the Coastal Plain and Blue Ridge tracts (Table 6). This life requisite is based on the number of hard mast producing trees. The larger the dbh of hard mast producing trees and the greater the number of hard mast producing trees, the better the habitat (Allen 1987) (Table 5). This is evident on the Blue Ridge tract in areas without exotic invasive plants. The impact seen here is low, but the invasive plants could be filling the niches of these mast trees or blocking reproduction by shading out the forest floor. On the Blue Ridge tract, cover/reproduction habitat for the gray squirrel was significantly higher on the noninvasive plots. There was no difference on the tracts in the other two physiographic provinces. This could be the result of dense forests of large mature trees necessary for good tree cavity habitat (Allen 1987) found on this tract. However, when all tracts were combined, the cover/reproduction habitat for the gray squirrel was significantly higher on the noninvasive plots. The cover/reproduction habitat could be better on the noninvasive plots because the invasive plants could be decreasing the percent canopy cover and the average overstory dbh. One other cause could be that the majority of invasive populations found on the Blue Ridge tract were tree-of-heaven and this species is taking up space that would normally be occupied by larger diameter, full canopy tree species. The Blue Ridge tract was the most significantly impacted for this species because it has the largest number of sample plots on mast producing areas, the other two tracts had most sample plots in loblolly plantations.

Downy woodpecker

The downy woodpecker reproduction habitat had no difference on any of the individual tracts (Table 6) or the combined data for all three tracts. This suggests the number of snags greater than 15 cm for each 0.4 ha did not change between invasive plots and noninvasive plots on any of the tracts, which is supported by the individual variable data for this life requisite (Table 5). However, food habitat for the downy woodpecker was significantly higher on the noninvasive plots on the Blue Ridge tract and for all tracts combined. The food life requisite is directly based on basal area, so if any decline in basal area occurs, this species will be impacted. The Coastal Plain tract had greater BA in areas without the exotic invasive plant (Table 5). As explained by the forest data earlier, this may be due to invasive plants growing in areas of reduced BA due to more light or an impact of invasive plants decreasing growth. Yahner (1988) found that in central Pennsylvania, the food habitat for this species in spring is frequently induced edges between clearcut and matures stands, which is common on the Coastal Plain tract and the Piedmont tract, which is also where exotic invasive plants commonly occur. However, in the winter this species often likes to move into forest interiors for less harsh habitat. Yahner (1988) also found this species to use mature stands nearer to immature stands even though these immature stands were utilized very rarely.

Black-capped chickadee

Food habitat for the black-capped chickadee had no difference on any of the individual tracts (Table 6) or when data from all three tracts were combined. This indicates there was no change in the overstory canopy closure and the average overstory tree height on noninvasive and invasive plots (Table 5). The reproduction habitat for the black-capped chickadee was significantly higher on the noninvasive plots on the Coastal Plain tract. No differences were seen on the Piedmont or Blue Ridge tracts. Noninvasive plots on the Coastal Plain tract have a greater number of 10 cm to 25 cm dbh snags 0.4 ha than invasive plots (Table 5). This could be due to lack of snags in the loblolly pine plantations, where most invasive plot sampling took place. The average overstory height and percent tree canopy closure were also higher on noninvasive plots on the Coastal Plain tract. When all tracts were combined, no difference was seen between invasive plots and noninvasive plots for the black-capped chickadee reproduction habitat. Similar findings by Yahner (1988) hold true for this species as they do for the downy woodpecker.

Eastern wild turkey

There was no difference in the food/brood habitat, food habitat, or cover habitat for the eastern wild turkey on any of the individual tracts (Table 6). However, over all three tracts, cover habitat for the eastern wild turkey was significantly higher on noninvasive plots. Noninvasive plots provided better cover habitat on the Blue Ridge and Coastal Plain tracts due to greater overstory dbh and higher overstory canopy cover (Table 5). A substantial difference between invasive and noninvasive plots may occur on the Blue Ridge tract due to invasive plots being present in areas of mature hardwood, instead of pine plantations with smaller overstory dbh and percent cover as is more common in sampled plots on the Coastal Plain and Piedmont tracts. The Blue Ridge tract had more hard mast producing trees larger than 25.4 cm in areas without exotic invasive plants and greater height and percent of herbaceous canopy in areas with exotic invasive plants (Table 5). However, these variables did not change enough between areas with and without exotic invasive plants to make a noticeable difference in the LRSI values. While habitat may not have been very suitable as measured by this index method, eastern wild turkeys or their signs (feathers, scratchings, nests) were seen on all tracts. Japanese honeysuckle grows readily in several of the pine stands this species will use and is eaten by this species (Sheldon and Causey 1974). The areas this bird uses changes throughout the year, so several stands of different types are needed by this species. While the Piedmont and Coastal Plain tracts do not have very suitable habitat based on the HSI model, both of these properties have multiple distinct habitats that would meet the habitat requirements for this species, as they provide many induced edges (man-made features with many successional stages) (Yahner 1988). This may not be reflected in the data because the data only shows a small fraction of the property and may not include areas that are very suitable for this species.

Veery

Habitat for the veery had no significant change on any of the individual tracts (Table 6) or over all three tracts. The habitat quality for this species was very poor and may not be adequate on any of the tracts. Habitat for this species may be present at other locations that were not sampled on the properties. Habitat quality was slightly enhanced on the Coastal Plain tract by invasive plants, but not notably. It may have been increased here by greater shrub height (Table 5), perhaps due to scotchbroom. Shrub height was not substantially changed on any other plots on any of the properties. Deciduous shrub cover and height of herbaceous canopy were greater on invasive plots on the Blue Ridge tract, as was herbaceous canopy cover on the Blue Ridge, Piedmont, and overall tracts (Table 5). However, these changes were not great enough to change the potential cover/reproduction habitat. Despite the minor increase in habitat quality on the Coastal Plain tract, the habitat in the invasive plots is still unsuitable for this species.

Disturbance Areas

There was a recurring trend of the majority of the nearest edge of exotic invasive plant populations on all properties to be found within 20 feet of a disturbance site (Figure 35). These disturbance sites were very likely the pathway of entry for the exotic invasive populations found on these properties. On the Coastal Plain tract, all ten exotic invasive populations were found within 50 feet of a disturbed area. Of these ten populations, two were closest to a paved road, six were closest to harvest roads, and two were closest to a farm crop field. Six of the ten populations were within 20 feet of a disturbance site (two adjacent to crop fields, one adjacent to a paved road, and three adjacent to harvest roads). Three of five exotic invasive populations on the Piedmont tract were found within 20 feet of a disturbance site. One of these populations was nearest to a harvest road and the other three were closest to old homesites. The old homesites on this tract were also adjacent to a paved road and powerline corridor. The fourth population was 25 feet from the nearest disturbance. The fifth exotic invasive population on this tract was classified as 650 feet from a disturbance site. It was located about 200 feet from a stream, which was considered a disturbance site for this research. However, at this location the population was uphill from the disturbance and probably was not established due to this stream. On the other hand, the stream could serve as a dispersal corridor for this species. An old forest harvest road, still open for access, was used as the nearest disturbance site instead of the stream. In addition, a mower was observed cutting vegetation along the roadside of Rt. 631, a paved road that runs through the property, while sampling was being conducted. This could potentially act as a spreader of invasive plant seeds or rooting nodes. Fourteen exotic invasive populations were found within 20 feet of a disturbance on the Blue Ridge tract. Seven of these populations were found in grazed pockets of forest surrounded by farm pasture, four populations were flanking farm pasture, two adjacent to an ATV trail, and one nearest to a powerline corridor. One of the remaining populations was found within 100 feet and the other was found within 250 feet of farm pasture.

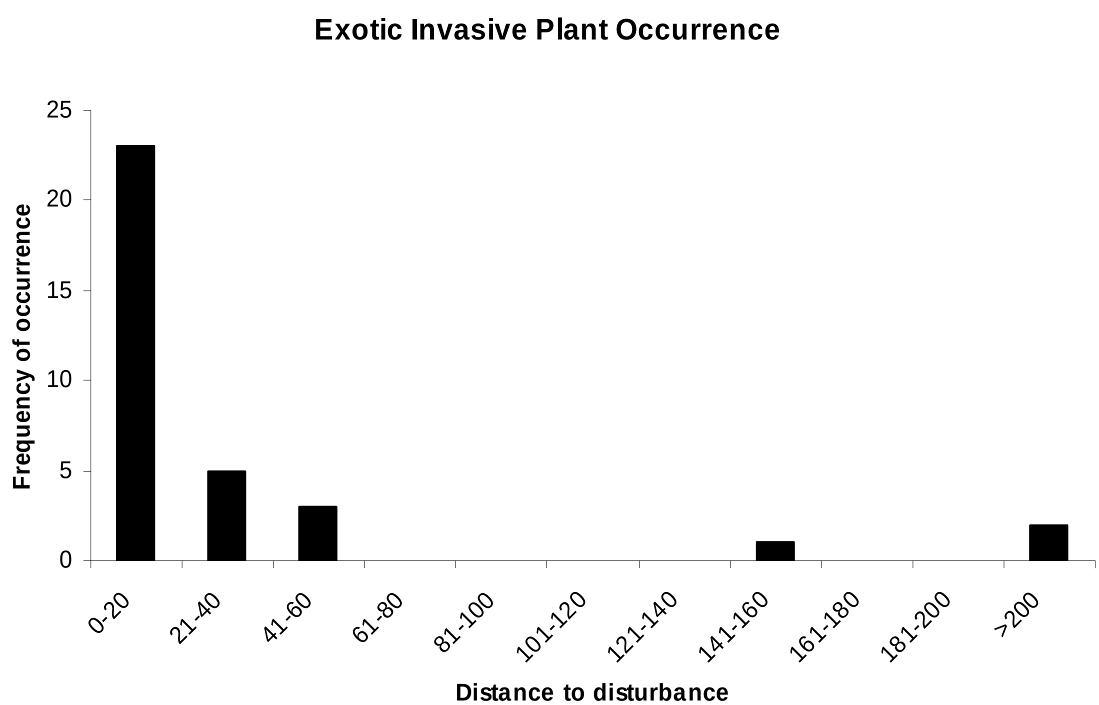


Figure 35. Frequency of occurrence of exotic invasive plant populations by distance to the nearest disturbance site on 3 physiographic provinces of Virginia.

Gilbert and Lechowicz (2005) found species richness of exotics increasing with increasing distance from the property boundary, but there was no effect on this variable when compared to distance from disturbed areas within the property. The latter disagrees with the results from this research, which included all disturbance sites, the majority of which were within the tract. Hansen and Clevenger (2005) found exotic plant species in high abundance along highway and railway corridors and up to 25 meters into surrounding habitats. This also agreed with the data from this research. Interstate highways in North Carolina had the highest number of occurrences of “starts”, which are 1meter to 3 meter lengths of exotic plants (Merriam 2003). However, when broken down by physiographic province, the greatest “starts” in the Coastal Plain were found at interstate highways, at stream banks in the Piedmont, and at stream banks in the Mountains (Merriam 2003). Electrical rights of way were extremely close behind stream banks in the Piedmont, 50.2 versus 50.6 “starts.” Gelbard and Belnap (2003) found total species richness of exotics to be greater than 50% within communities adjacent to paved roads than within communities next to dirt, high-clearance, rarely graded roads. They also found roadside verges to be wider next to paved roads rather than rarely used dirt roads. A greater verge width meant a greater percentage of exotic species cover within the community next to these areas. As discussed earlier, edges can be sources of disturbance. Several species of wildlife are attracted to edges and use them frequently. Wildlife are also known to consume seeds of invasive plants, often transporting them to other locations, including edges. This raises the question of whether invasive plants are present at edges due to wildlife deposits, as a result of the disturbance that created the edge, or as a combination of these and other variables.

Forest Inventory & Analysis

The Forest Inventory & Analysis center, run through the US Forest Service collects data on forest health, including information on invasive plant species (Ridley et al.). This entity of the US Forest Service uses a predetermined list of invasive plant species that may occur on the proposed plot location. This helps them know what to look for when conducting field work. The FIA collects data on the status, trends, and resource conditions of forestland and then analyzes it. Some of these data are made available to the public.

Information acquired from FIA data states the greatest number of live trees in Virginia of tree-of-heaven occurs on privately owned land (Table 7). The tree density (trees/ac) is greatest in Virginia on state and locally owned land. The private ownership class accounts for the largest amount of acreage in the state. Therefore, the large number of tree-of-heaven on private land could be due to the amount of land being surveyed over the entire state or could be due to characteristics of privately owned land, such as highly fragmented and disturbed areas that provide easy entry for invasive plants.

Table 7. Quantity of tree-of-heaven by ownership class in Virginia.

Ownership	Area (acres)	Number of live trees	Trees/Acre
USFS	1,687,692	33,097	0.020
Other Federal	231,382	111,886	0.484
State & Local	440,175	4,155,227	9.440
Private	12,922,527	63,241,807	4.894

Conclusions

Forest characteristics and wildlife habitat can be changed by exotic invasive plants. Forest composition and basal area of overstory species is negatively impacted by exotic invasive plants, as is the amount and species richness of forest regeneration. Exotic invasive plants provide a greater amount of understory cover, which may improve wildlife habitat quality for some species. Diversity of habitat types is important to support a variety of wildlife species. Better habitat for the eastern cottontail rabbit can be found in exotic invasive plant populations. However, gray squirrel winter food and cover/reproduction habitat, downy woodpecker food habitat, and eastern wild turkey cover habitat are negatively impacted by exotic invasive plant populations. The type of disturbance most commonly associated with exotic invasive populations differs for each tract. However, over all tracts, harvest/interior forest roads and grazed areas are most common, each with 8 occurrences. All but one of these populations were within 50 feet of these two types of disturbances.

Control of exotic invasive plants is important to prevent ecosystem changes. The following recommendations are only suggestions for control of exotic invasive plants. They should be implemented if the exotic invasive plants are deemed a considerable threat to the management concerns for each property. Management of the property for timber production, wildlife habitat, recreation, or aesthetics will require a different combination of treatments. Treatment is based on management concerns and will differ for each landowner. It may not eradicate the problem species, but may be able to aid in control. An integrated approach, a combination of biological, chemical, and mechanical treatments, may be the best solution for some areas. Careful consideration and planning by the landowner is necessary before executing any proposal.

On Cedar Grove Farm, the scotchbroom is probably causing a decline in tree density and basal area, increasing understory cover, and contributing to the decline of regeneration diversity and density. Japanese honeysuckle is likely contributing to the decline in diversity and density of regeneration, not only on this property but also on Kennedy Tree Farm and Beaver Run Farm. Chinese privet on Cedar Grove Farm may also be playing a role in these impacts, but is only found in the hardwood stands. Regeneration of hardwoods may decline in subsequent years, but food habitat for songbirds may increase. The ecosystem change in the hardwood stands may be responsible for the decrease in the suitability of gray squirrel habitat. However, all of the invasive plants may be contributing to the increase in suitability of eastern cottontail habitat.

Scotchbroom may be controlled by the application of herbicide, which has taken place on this property in the past with a combination of Garlon and Arsenal and may still be the best available treatment at this time. Velpar is another chemical that may be used to control this species. Several chemical applications will be needed to due the high seed bank viability of scotchbroom. The control of this species may be furthered with the use of a controlled burn before the application of herbicides. This may help to reduce the amount of scotchbroom biomass and the seed bank of scotchbroom in the soil (Alexander and D'Antonio 2003). However, a prescribed burn on Cedar Grove Farm allowed scotchbroom to quickly establish before the planted loblolly pine could establish itself. Biocontrol by the broom weevil (*Bruchidius villosus* (F.)) may destroy 80% of seeds from this plant (Redmon et al. 2000). Mechanical removal may also be used in combination with these methods, but is very labor intensive and can become expensive.

Japanese honeysuckle was noted to vary in occurrence between early summer (survey of property) and late summer (sampling) on all three tracts of land. This may be due to drought conditions or herbivory by white-tailed deer, which eat this species as 49.4% of their total year round diet (Sheldon and Causey 1974). Foliar application of a 3-5% solution of Garlon 4 or treating freshly cut stems with a 20% solution of Garlon 3A from July to October should be effective. Chemicals should be kept away from desirable plants during this process. A controlled burn before application of herbicides may help reduce density of mats and cut vines that have climbed to the overstory vegetation (Miller 2003). Plants that have high survival in the seed bank would require several applications over several years for effective treatment. However, Shelton and Cain (2002) found seed viability in the seed bank to be low for Japanese honeysuckle (less than 5% survival for 3 years). Grazing by cattle may be a feasible control method for Beaver Run Farm, but can help to spread seeds of invasive plants.

On Cedar Grove Farm, Chinese privet can be chemically controlled by completely wetting all leaves from August to December with a 3% solution of Garlon 3A, a basal spray of Garlon 4 in a 20% solution, or a 20% solution of Garlon 3A apply to cut stems (Miller 2003). Chinese privet has no seed bank survival past the first winter, so one application of herbicides could effectively release native vegetation (Shelton and Cain 2002).

Tree-of-heaven on Kennedy Tree Farm and Beaver Run Farm can be controlled by stem injection of Garlon 3A for large trees. Control of saplings can be obtained with a basal spray of Garlon 4. Seedlings and small saplings can be controlled by wetting all leaves thoroughly with Garlon 4 from July to October. Burning may provide temporary control of seedlings and small saplings, but will not eliminate the problem. Disking, brush mowing, and hand pulling are some examples of mechanical methods. Mechanical removal used alone can be costly, labor intensive, and may spread seeds or segments that can resprout (Miller 2003).

The result of the introduction of exotic invasive plants can be unpredictable and some areas may be more susceptible to invasion than others. It is important to remember disturbance areas may bring in large, concentrated quantities of exotic invasive plants, but these may also provide important wildlife habitat by serving as landscape diversity and food, cover, and edge species habitat. Once exotic invasive plants present themselves as a problem, biological, mechanical, or chemical treatment methods may be employed. However, an integrated treatment approach may be the best option. Awareness and education of the horticultural industry, highway maintenance personnel, railway maintenance personnel, right-of-way (gas and electrical) personnel, and the public is essential to prevent further spread of exotic invasive plant species. In addition, better thought out and flexible management plans are crucial to combating this environmental and economic problem.

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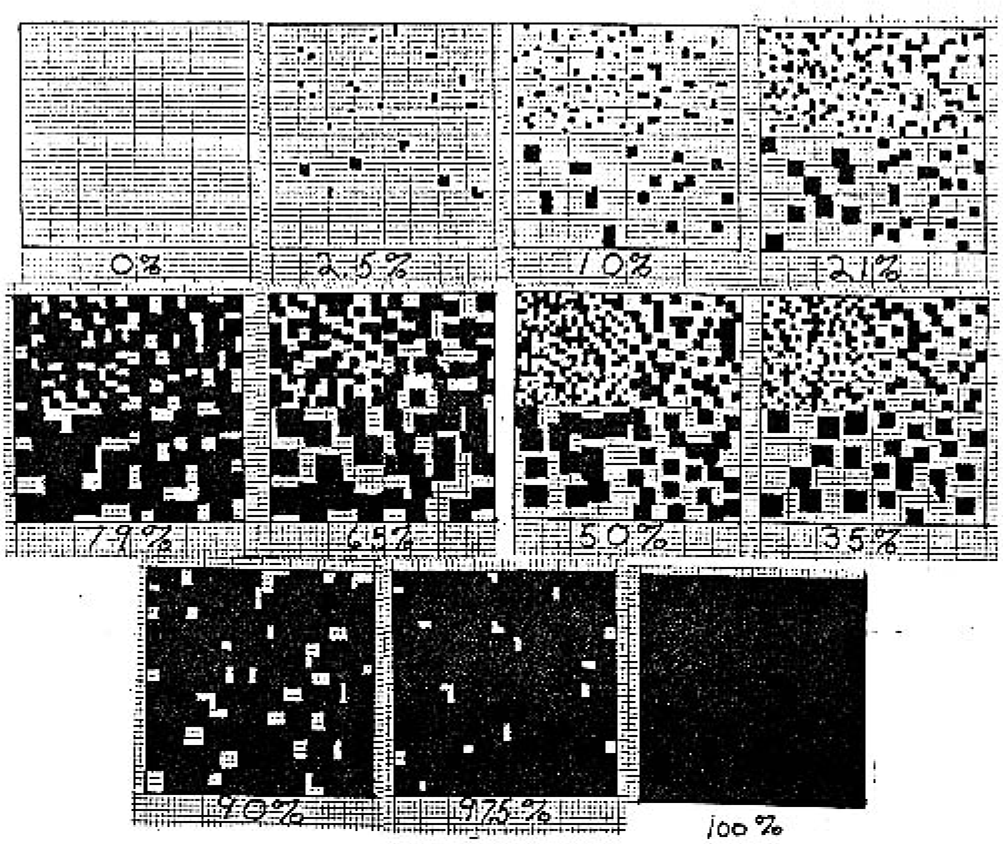
Appendix A:
Cover Class Types

COVER CLASS STANDARDS



**Appendix B:
GPS Plot Locations**

Table 8. GPS point latitude (LAT) and longitude (LON) locations for invasive plots (I) and noninvasive plots (NI) on the Coastal Plain tract.

Coastal Plain tract					
	I			NI	
GPS pt	LAT	LON	GPS pt	LAT	LON
22	37.8843703	-76.5980546	65	37.8920032	-76.5876170
23	37.8836942	-76.5957042	66	37.8865163	-76.6051805
24	37.8823996	-76.5943676	67	37.8848470	-76.5972791
25	37.8870730	-76.5968040	68	37.8848733	-76.5967586
26	37.8834070	-76.5923240	69	37.8848132	-76.5939609
27	37.8899050	-76.6032060	70	37.8908704	-76.6032630
28	37.8934279	-76.5879791	71	37.8822455	-76.5941352
29	37.8871074	-76.5922658	72	37.8839381	-76.5922963
30	37.8872396	-76.5926696	73	37.8850928	-76.5918200
31	37.8899696	-76.6034981	74	37.8859188	-76.5914027

Table 9. GPS point latitude (LAT) and longitude (LON) locations for invasive plots (I) and noninvasive plots (NI) on the Piedmont tract.

Piedmont tract					
	I			NI	
GPS pt	LAT	LON	GPS pt	LAT	LON
55	37.5852683	-78.4499298	56	37.5855191	-78.4500191
57	37.5846851	-78.4458146	58	37.5845851	-78.4451652
59	37.5843804	-78.4456382	60	37.5842912	-78.4453303
61	37.5901679	-78.4715065	62	37.5910455	-78.4709548
63	37.5725296	-78.4552819	64	37.5729900	-78.4555581

Table 10. GPS point latitude (LAT) and longitude (LON) locations for invasive plots (I) and noninvasive plots (NI) on the Blue Ridge tract.

Blue Ridge tract					
I			NI		
GPS pt	LAT	LON	GPS pt	LAT	LON
1	38.4073736	-78.2813662	33	38.4091636	-78.2936695
2	38.4079618	-78.2828150	34	38.4083398	-78.2924755
3	38.4110806	-78.2772919	35	38.4112115	-78.2908590
4	38.4112629	-78.2787974	36	38.4113202	-78.2911416
5	38.4076566	-78.2858832	37	38.4143891	-78.2779758
6	38.4084317	-78.2913864	38	38.4157767	-78.2802622
7	38.4078430	-78.2922806	39	38.4185369	-78.2835483
8	38.4147168	-78.2786749	40	38.4185973	-78.2832059
9	38.4159113	-78.2804743	41	38.4194820	-78.2845337
10	38.4168842	-78.2804046	42	38.4185210	-78.2862352
11	38.4176621	-78.2832000	43	38.4206673	-78.2840342
12	38.4176947	-78.2825287	44	38.4165555	-78.2794108
13	38.4133752	-78.2909001	45	38.4159577	-78.2898857
14	38.4181389	-78.2853279	46	38.4164460	-78.2901149
15	38.4149085	-78.2890602	47	38.4148621	-78.2906075
16	38.4156350	-78.2883624	48	38.4107701	-78.2910623
17	38.4127422	-78.2896564	49	38.4118453	-78.2905748
18	38.4200498	-78.2851693	50	38.4120393	-78.2907989
19	38.4203037	-78.2843489	51	38.4119852	-78.2907166
20	38.4123423	-78.2811653	52	38.4112048	-78.2902192
21	38.4130276	-78.2822056	53	38.4105173	-78.2902405
22	38.4162100	-78.2925380	54	38.4081604	-78.2855228

Appendix C:
Wildlife Habitat Life Requisite Suitability Index Equations

Eastern Cottontail

Variable 1 equation: =ROUND(IF(V1>=100,0.6,IF(V1>50,(1-(0.008*(V1-50))),IF(V1>=20,1,(IF(V1>0,0.05*V1,0))))),2)

Variable 2 equation: =ROUND(IF(V2>=100,0.2,IF(V2>50,(1-(0.016*(V2-50))),IF(V2>=25,1,(IF(V27>0,0.04*V2,0))))),2)

Variable 3 equation: =ROUND(0.006*V3,2)

Winter cover LRSI equation: =ROUND(MIN(1,((((V1*4)+V2)/5)+V3)),2)

Gray Squirrel

Variable 1 equation: =ROUND(IF(V1>=100,1,(IF(V1>0,0.009*V1,0.1))),2)

Variable 2 equation: =ROUND(IF(V2>=4,1,(IF(V2=3,(0.8),IF(V2=2,0.5,(IF(V2=1,0.2,0.1)))))),2)

Variable 3 equation: =ROUND(IF(V3>=100,0.8,(IF(V3>75,(1-(0.008*(V3-75))),IF(V3>=40,1,(IF(V3>0,0.025*V3,0)))))),2)

Winter food LRSI equation: =ROUND((((V1*V2)^0.5)*V3),2)

Variable 4 equation: =ROUND(IF(V4>=40,1,(IF(V4>0,0.025*V4,0))),2)

Variable 5 equation: =ROUND(IF(V5>=38.1,1,(IF(V5>12.7,0.03937*(V5-12.7),0))),2)

Cover/reproduction LRSI equation: =ROUND(((V4*V5)^0.5),2)

Downy woodpecker

Variable 1 and food LRSI equation: =ROUND(IF(V1>=30,0.5,(IF(V1>20,(1-(0.05*(V1-20))),IF(V1>=10,1,(IF(V1>0,0.1*V1,0)))))),2)

Variable 2 and reproduction LRSI equation: =ROUND(IF(V2>=5,1,(IF(V2>0,0.2*V2,0))),2)

Black-capped chickadee

Variable 1 equation: =ROUND(IF(V1>=100,0.6,(IF(V1>75,(1-(0.016*(V1-75))),IF(V1>=50,1,(IF(V1>0,0.02*V1,0)))))),2)

Variable 2 equation: =ROUND(IF(V2>=15,1,(IF(V2>0,0.066667*V2,0))),2)

Food LRSI equation: =ROUND(((V1*V2)^0.5),2)

Variable 3 and reproduction LRSI equation:
=ROUND(IF(V3>=2,1,(IF(V3>0,0.5*V3,0))),2)

Eastern wild turkey

Variable 1 equation: =ROUND(IF(V1>=100,0.5,(IF(V1>80,(1-(0.025*(V1-80))),(IF(V1>=60,1,(IF(V1>20,0.025*(V1-20),0))))))),2)

Variable 2 equation: =ROUND(IF(V2>=100,0,(IF(V2>60,(1-(0.025*(V2-60))),(IF(V2>=20,1,(IF(V2>5,0.066667*(V2-5),0))))))),2)

Summer food/brood LRSI equation: =ROUND(((V1*V2)^0.5),2)

Variable 3 and 4 equation:
=ROUND(IF(V3>=38.1,(IF(V4>=124,1,(0.008065*V4))),((IF(V3>=35.6,(IF(V4>=137,1,(0.007299*V4))),(IF(V3>=33,(IF(V4>=154,1,(0.006494*V4))),(IF(V3>=30.5,(IF(V4>=174,1,(0.005747*V4))),(IF(V3>=27.9,(IF(V4>=210,1,(0.004762*V4))),(IF(V3>=25.4,(IF(V4>=235,1,(0.004255*V4))),0)))))))))))),2)

Variable 5 equation: =ROUND(IF(V5>=40,1,(IF(V5>0,0.025*V5,0))),2)

Variable 6 equation: =ROUND(IF(V6>=20,1,(IF(V6>0,0.05*V6,0))),2)

Variable 7 equation: =ROUND(IF(V7>=100,1,(IF(V7>0,((0.006*V7)+0.4),0.4))),2)

Variable 8 equation: =ROUND(IF(V8>=80,0,(IF(V8>40,(1-(0.025*(V8-40))),1))),2)

Fall, winter, and spring food LRSI equation:
=ROUND(((((MIN(1,(V3&4+V5)))+(V6*V7))/2)*V8),2)

Variable 9 equation: =ROUND(IF(V9>=50,1,(IF(V9>10,0.025*(V9-10),0))),2)

Variable 10 equation: =ROUND(IF(V10>=30.5,1,(IF(V10>12.65,0.05042*(V10-12.65),0.1))),2)

Variable 11equation: =ROUND(IF(V11>=100,0.2,(IF(V11>30,(1-(0.01142857*(V11-30))),1))),2)

Cover LRSI equation: =ROUND((V9*V11*V10),2)

Veery

Variable 1 equation: =ROUND(IF(V1>=70,1,(IF(V1>20,0.02*(V1-20),0))),2)

Variable 2 equation: =ROUND(IF(V2>=5,0.5,(IF(V2>3,(1-(0.25*(V2-3))),(IF(V2>=1.5,1,(IF(V2>0.5,1*(V2-0.5),0))))))),2)

Variable 3 equation: =ROUND(IF(V3>=90,1,(IF(V3>30,0.0166667*(V3-30),0))),2)

Variable 4 equation: =ROUND(IF(V4>=30,1,(IF(V4>0,0.03333*V4,0))),2)

Cover/reproduction LRSI equation: =ROUND(MIN(1,(((V1*V2)^0.5)+(0.5*(V3*V4)^0.5))),2)

Vita

Dawn N. Aksamit was born in Silver Spring, Maryland to Robert and Linda Aksamit. She grew up in Rockville, MD with two older sisters. A love of the outdoors, wildlife, and traveling was instilled in Dawn from a young age by her father. Dawn received a Bachelors of Science in Forestry, concentrating in Environmental Resource Management, in May 2005. She was guided to the study of exotic invasive plants by Shep Zedaker while working for him in the summer of 2005. She began a Masters of Science degree in Forestry in August 2005 and completed all degree requirements in January 2008.