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Investigating distribution and treatments for effective mechanical and herbicide application for controlling oriental bittersweet (Celastrus orbiculatus Thunb.) vines in an Appalachian hardwood forest

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Investigating Distribution and Treatments for Effective Mechanical and Herbicide Application for Controlling Oriental Bittersweet *(Celastrus orbiculatus* Thunb.) Vines in an Appalachian Hardwood Forest

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ABSTRACT

Investigating Distribution and Treatments for Effective Mechanical and Herbicide Application for Controlling Oriental Bittersweet *(Celastrus orbiculatus* Thunb.) Vines in an Appalachian Hardwood Forest

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This document discusses two exotic-invasive plant species related research studies that were conducted in an Appalachian hardwood forest in north central West Virginia. The first study characterizes the distribution of oriental bittersweet *(Celastrus orbiculatus* Thunb.) in a timber harvested area in north central West Virginia. Canopy profiles were used to create a visual picture of distribution of *C. orbiculatus* vines from the forest edge transition to the interior of the forest. In the second study, the efficacy of herbicides triclopyr and glyphosate were tested using basal bark, cut-stump, mechanical cut, and deer fencing to control *C. orbiculatus.*

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Literature Review

Introduction

The distinction of the American life style depends highly on healthy hardwood forests. These forests can be thought of as massive filters for air and water contamination, as well as providing flooring, cabinets, furniture, and various paper products. Hardwood forests are not only valuable because of the filtration and wood products they provide, but also the biodiversity and habitats they contain. The Appalachian Mountain Region also accounts for twenty percent of total hardwood lumber production used in final products, and provides over 50,000 jobs to Americans in surrounding areas (Appalachian Hardwood Manufacturers, Inc. 2007).

Managing hardwood forest is complex and difficult. The United States Department of Agriculture Forest Service has identified four main threats to forests: fire and fuels, loss of open space, unmanaged recreation, and exotic-invasive species (United States Forest Service 2006). These threats can result in devastating effects on hardwood forests.

Prior to European settlement, forest fires happened naturally. In the late 1800's, forest fires were removed from the ecosystem through fire suppression policies (MacCleery 1994). The fire suppression policies lead to the buildup of "woody fuel". If large amounts of understory vegetation catch fire, this could lead to catastrophic wildfires causing serious damage to surrounding habitats, trees, and vegetation. Since the early 1900's, the U.S. Forest Service has revised its fire suppression policies, and is experimenting with controlled fire.

Forestland is lost daily to rapid development. Nearly 0.55 ha per minute, 825 ha per day, and 297,201 ha of forested land per year are lost in the United States due to development. It is estimated that by 2030, 10,521,826 ha of forested land will be lost due to development. Currently, one third of Americans live in the rural undeveloped areas. This includes 77,699,643 ha developed on private land. Eight percent of these rural areas are within ten miles of National Forest. Over half of the United States forested land is privately owned (United States Forest Service 2006).

Part of the degradation to hardwood forests comes from recreational use. Off-road vehicles (ORV) cause severe damage to forestland. ORV can cause increased erosion, soil compaction, conflict between different types of recreation, disturbance of habitat and wildlife, and can cause spread of exotic-invasive plant species. These soil disturbances can cause exotic-invasive animal and plant species to infest hardwood forests in increasing competition to existing natural species.

One issue of growing concern is the impact that exotic-invasive plants species have on natural vegetation. These plants are a threat to hardwood forests because they alter natural habitats by out-competing native vegetation. This reduces biodiversity of native vegetation, and therefore reduces its regeneration potential of tree and plant species (Chornesky and Randall 2003 and Huebner 2003).

To initiate a discussion of exotic-invasive plant species, it is essential to begin with definitions. Executive Order 13112 (1999) defines exotic-invasive species as: "alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health." Exotic-invasive plant species are defined as non-native, introduced organisms that become established in a new location, with the potential to cause ecological harm and threat to native vegetation (Chornesky and Randall 2003). An exotic is a species that is not native by a large distance (Jackson et al. 2007). An exotic-invasive plant species is one that is not native and has the ability to establish itself in a new environment and reproduce without assistance.

It is estimated that over 3,500 exotic plant species have been introduced into the United States. Of the 3,500 exotic plant species, 1,050 are estimated to be invasive plant species (Swearingen, 2007). It is projected that exotic-invasive plant species are dispersing through the United States at a rate of 700,000 ha per year (Babbitt 1998).

Exotic-invasive species can be classified into three main categories: potentially, moderately, and highly exotic-invasive. Species classified as potentially exotic-invasive are locally regenerated, and therefore have a limited rate of spread. Moderately exotic-invasive species are classified as spreading, but occur in low densities within a particular location. Highly exotic-invasive species are classified as dominant vegetation that is considered to be a threat to the natural plant community (Binggeli 1996).

Exotic-invasive woody plant species include lianas, shrubs, trees, and vines. Lianas are defined as woody climbing vegetation with roots in the forest floor and leaves in the full sun of tree canopies. Lianas are not self-supporting and must wrap, braid or loop around surrounding vegetation or itself to reach the canopy (Putz and Holbrook 1991, Carlquist 1991, and Gentry 1991).

Exotic-invasive species are considered to be a threat to biodiversity, because they often out-compete native vegetation through rapid growth, higher productivity of seed source, and ability to adapt to varying habitats (Walker and Steffen 1997). Exotic-invasive species often lack native enemies, such as, disease and predators. The rapid growth and shade tolerance of many exotic-invasive species make them aggressive competitors with regeneration from native species, especially following silvicultural treatments and natural disturbances.

Celastrus orbiculatus

One exotic-invasive species that has become a serious threat in eastern hardwood forests is oriental bittersweet (*Celastrus orbiculatus* Thunb.). *Celastrus orbiculatus* is also known by the common name Asiatic bittersweet. *C. orbiculatus* is native to eastern Asia. In its native habitat, it is not a forest species. *C. orbiculatus* is a deciduous woody vine that was first introduced into the United States in 1860's. It was first discovered as a naturalized species in Connecticut in 1916. By 1974, this species was found in 33 states and had become naturalized in 21 states. It has become a serious threat to native plant communities in the eastern United States (Patterson 1974, Southeast Exotic Pest Plant Council Invasive Plant Manual 2003). As of 2009, *C. orbiculatus* has been collected in thirty-two counties in West Virginia (West Virginia Atlas 2009). *C. orbiculatus* is currently listed as a noxious weed in Connecticut, Massachusetts, New Hampshire, North Carolina, and Vermont, but is not listed in West Virginia.

Silvics

C. orbiculatus is a deciduous, perennial woody vine. It can reach a maximum length of 1,828 centimeters and diameter of 10.16 centimeters. Leaves are alternate, variable in size, and shape is ovate with serrate margins. It is glabrous and has an abruptly pointed leaf tip. The leaves are suborbicular to obovate, less than twice as long as wide and leaf scars are flush with the stem. The stems are light brown with visible lenticels on younger stems and the petioles are 1 - 3 centimeters in length. It is recognized by twining, light to dark brown branches. The flowers are small and greenish yellow, with male and female flowers bore on separate plants in axillary cymes. Flowers have five sepals and petals are greenish-yellow, and bloom in early summer and fruit in fall. The fruit is green changing to bright red as it matures and the pollen is white. The mature fruit is a bright red berry that grows in clusters. The fruits have three chambers of ovary with each containing 1-2 seeds (Southeast Exotic Pest Plant Council Invasive Plant Manual 2003).

Oriental bittersweet is different from the native American bittersweet (*Celastrus scandens* L.), in that the flowers are found in axillary cymes in clusters. American bittersweet flowers are found in terminal panicles; its fruit is borne in cymes with more than one seed. The fruit is bright orange, and the pollen is yellow. American bittersweet leaves tend to roll and are oblong to oblong-ovate, twice as long as long as wide (Leicht-Young et al. 2007 and Southeast Exotic Pest Plant Council Invasive Plant Manual 2003).

Problems Associated with Oriental Bittersweet

C. orbiculatus hybridizes with native bittersweet creating a fertile hybrid that is notably more dynamic than the native species (Pooler et al. 2002). This hybrid is considered just as much a threat to native vegetation as *C. orbiculatus.* Furthermore, the berries of the hybrid are considered poisonous. The berries can cause internal upsets and discomfort to external skin (Hwang et al. 2000).

Range

Originating outside of the United States, *C. orbiculatus* can be found over most of eastern United States and District of Columbia. *C. orbiculatus* occurs in Maine south to Florida, west to Louisiana, and north to Wisconsin (Steward et al. 2003). It is most common in mixed hardwood forests in Connecticut, Maine, New York, and states lying within the southern Appalachian Mountain Region.

Site

C. orbiculatus can be found in dense canopies. It has the ability to flourish in light gaps (Leicht and Silander 2006, Schnitzer and Bongers 2002, Schintzer 2005, and Schintzer et al. 2004). Full sun or partial sun allows *C. orbiculatus* to invade disturbed areas in the forest. This vine is unusual in that its seedlings are extremely shade tolerant. According to Ellsworth et al. (2004), seedlings can be established in a dense forest understory, with a high proportion of seedlings surviving light levels as low as two percent. *C. orbiculatus* seedlings can double their photosynthesis rate in these low light areas (Greenberg et al. 2002).

C. orbiculatus has a well developed root and vascular system that can search for water and nutrients which will create intense competition with surrounding vegetation. Recent studies suggest that competition with surrounding vegetation can cause saplings to allocate nutritional resources to above ground biomass at the expense of their below ground biomass (Schnitzer 2005). *C. orbiculatus* has the ability to capitalize on both above and below ground biomass especially during a dry season. Since, its roots can reach deeper than surrounding vegetation it can continue to capitalize on its above ground growth (Schnizter 2005).

C. orbiculatus is associated with moist environments, midstory vegetation, canopy gaps, and silvicultural disturbances. *C. orbiculatus* is most likely to be found on sites that are not oak dominated, less acidic soil, concave surfaces, and increasing elevation (< 600 meteres) (McNab and Loftis 2001 and Pande et al. 2007).

Pathogens

Records of natural enemies associated with the genus *Celastrus* are rare. There are only three fungi reported to infect it: *Microsphaera celastri, Uncinula sengoku,* and *Amazonia celastri.* These are sac fungi, which are beneficial to the soil; however it disrupts the growth of *C. orbiculatus*. Six arthropod species (*Hypothenenmus eruditus, Plinachtus bicoloripes, Aphis clerodendri, Unaspis euonymi, Trioza celastrae,* and *Yponomeuta sociatus)* have been reported to cause damage to *C. orbiculatus* (Fanglan 1979).

Reproduction and Propagation

C. orbiculatus has three methods of pollination: wind, mammal, and insect. Generally, hymenopterous insects, such as bees, are pollinators of *C. orbiculatus.* The seed is easily dispersed into the interior of the forest by birds and small mammals that consume the seeds (Greenberg et al. 2001). *C. orbiculatus* is dispersed into the forest interior, where it persists as advanced regeneration and responds to a release from overstory shade. On a site with available light, water, and nutrient resources, *C. orbiculatus* will respond to a release with rapid growth. Humans also contribute significantly to seed dispersal by ornamental plantings and by decorating with fruiting stems, then discarding them outside (Dreyer et al. 1987).

Deer browsing appears to have no effect on the species diversity of exotic-invasive plants, but generally can reduce *C. orbiculatus* (Bowers 1993). Deer may help control the spread of *C. orbiculatus* in forest interiors with slight browsing. Exotic-invasive vines tend to be more tolerant of herbivory than native plant species. Once herbivory has taken place, exotic-invasive vines have the ability to respond to browsing with growth rates faster than native plant species.

If the soil has an increase in nitrogen fertilizer, the growth rates will respond faster (Leger et al. 2007). Exotic-invasive species have traits, such as additional chemical compounds, that could help maintain their robustness towards browsing (Cappuccino and Arnason 2006). These traits make the effects of deer browsing less evident on exotic-invasive species. Native plants have individual species that browse specifically on them, whereas exotic-invasive do not have individual species that are host specific (Leger et al. 2007). For example, deer browsing decreases the richness of native plant species, but not those of exotic-invasive plant species (Rossell et al. 2004).

Germination is at its highest in low light levels; however, the seedlings can increase photosynthesis when exposed to direct sunlight. The plants develop and expand by root suckers, root remains, and runners (Bergmann et al. 1999). It produces seed reserves that are established in the soil within a year and can be viable for several years. Seedlings can grow in thickets, fencerows, forest, and roadsides in partial to full sun and can overtop trees up to 213.36 cm tall after one growing season (Ellsworth et al. 2004).

As an Invader

C. orbiculatus is a nuisance because it can easily overtop native trees and vegetation with rapid growth over stumps, saplings, and mature trees. This twining vine can shade, suppress, and ultimately kill native vegetation. Traits that contribute to *C. orbiculatus* invasiveness include efficient use of minerals and water (Webster et al. 2006), exclusion of other species (Dreyer et al. 1987), mammal dispersal of seeds (Bowers 1993), natural robustness, ability to form a seed bank, and ability to form thickets (Dreyer et al. 1987).

Forest areas are invaded by *C. orbiculatus* as its vines grow into the upper canopy supported on the stems of shrubs and trees. Foliage produced by these vines blocks sunlight from the leaves of supporting woody stems and from plants on the forest floor. The dense cover of this vine can increase a tree's susceptibility to breakage. Woody vines damage young trees by increasing the threat of girdling, ice, wind, and overtopping (Webster et al. 2006). Trees and shrubs can be weakened and killed as the vine spirals around their stems, eventually constricting the flow of water and nutrients transported by phloem and xylem tissues. As *C. orbiculatus* vines grow into the crowns of woody vegetation, the effected surface area of plant crowns increase and add additional stress to the supporting stems. Ice and wind cause structural damage to supporting plants as the increased surface area promotes ice buildup and additional wind stress. These added stress factors occur as *C. orbiculatus* reduces the supporting plants' ability to photosynthesize and produce secondary stem growth that could support these additional loads (Dreyer 1994).

Shade tolerance, root suckering, rapid vegetative growth under high light conditions, and high fecundity all contribute to the success of *C. orbiculatus* (Greenberg et al. 2001). The growth and shade tolerance of this introduced woody vine makes it a successful competitor with tree regeneration after silvicultural treatments or natural disturbances. Because *C. orbiculatus* can grow from tree crown to tree crown through the forest canopy, when an infested tree is harvested, neighboring trees can be damaged; as a tree falls, vines that are interconnected with adjacent trees pull on those trees and can strip the tree of foliage and branches. Thus, large amounts of woody vines in forest canopies can increase the size of the gaps in forests when trees are harvested (Schnitzer et al. 2004).

An invasion of exotic-invasive plant species may be triggered by natural or man-made disturbances (Dreyer 1994). Vines are competitive invaders in disturbed forests (Silveri et al. 2004). *C. orbiculatus* seedlings are often present in late-succession deciduous forests where an open area caused by individual or multiple tree-fall gaps is created. Prior to an anthropogenic disturbance, such as logging, if seed reserves are present in the forest soils then exotic-invasive species can become established and can out-compete native reproduction. The effects of logging can trigger growth of these seeds, and create a problem for land managers (Silveri et al. 2004). Forests are especially susceptible to the establishment of exotic-invasive species during forest management operations that disturb forest soils (Randall and Marinelli 1996).

Canopy disturbance promotes *C. orbiculatus* reproduction which then can present a serious problem for forest managers as vines compete with native species and inhibit forest regeneration (Webster et al. 2001). *C. orbiculatus* is an aggressive invader that can dominate all vegetation levels of forested and open areas (McNab and Meeker 1987). *C. orbiculatus* uses a "sit and wait" strategy by establishing and persisting in low light conditions under undisturbed forest canopies, and grows rapidly following a canopy disturbance often overtopping and girdling surrounding trees (Greenberg et al. 2001).

In contrast to large, catastrophic disturbances, small disturbances to the forest floor expose bare soil to light which may promote seed germination and establishment. Small disturbances like single tree falls, turkey and deer scratching, and low intensity fires expose bare patches of soil, and allow increased light to reach the forest floor. These small openings in leaf litter provide an opportunity for *C. orbiculatus* to germinate and become established. Conversely, intact tree leaf litter has been shown to reduce establishment of seedlings through biochemical effects, reduced soil temperature, and shading (Ellsworth et al. 2004).

Uses of Oriental Bittersweet

The bark of *C. orbiculatus* is a source of fine fiber (Institutum Botanicum Academiae Sinicae 1994). Esters from the fruits and roots of *C. orbiculatus* can be used as a pesticide, anti-tumor activity, and reverse multidrug resistance in cancer cells (Guo et al. 2004, Hwang et al. 2000, Institutum Botanicum Academiae Sinicae 1994, Kim et al.

1997, and Kim et al. 1998). It has been used in folk medicine to treat rheumatoid arthritis and bacterial infections (Kim et al. 1998).

Horticulturists were attracted to it because of its rapid growth rate and resistance to insects and disease, and particularly because of its persistence bright red berries, which could be used in dried floral arrangements (Barton et al. 2004). This woody vine was described as an ideal species for highway landscaping and for home ornamental plantings. In the 1970s, it was used along highways for erosion control, because of its rapid growth and extensive root systems (Dreyer et al. 1987).

Controls

Effective control of woody exotic species is an expensive, long-term effort that usually requires a combination of mechanical treatments, targeted herbicide applications, and continuous monitoring. Recovery to natural areas is unpredictable because previous vegetation is severely altered with high infestation of *C. orbiculatus.* Removal methods often further disrupt remnants of previous plants (Dreyer 1994).

Recommendations for control of *C. orbiculatus* depend on the extent of invasion, the habitat in which it occurs, the resources available to land management agencies, and to some extent management philosophy. Many sources describing recommendations for controlling *C. orbiculatus* are in the form of information sheets and weed control guidebooks, such as, Bergman (1999), Dreyer (1994), Greenbuerg et al. (2001), Hutchinson (1992), Miller (2002), and Southeast Exotic Pest Plant Council Invasive Plant Manual (2003).

Mechanical means are recommended for small populations, in areas where herbicide cannot be used (Southeast Exotic Pest Plant Council Invasive Plant Manual 2003) or if labor resources are readily available (Hutchinson 1992). Mechanical methods include cutting (Southeast Exotic Pest Plant Council Invasive Plant Manual 2003), hand pulling (Hutchinson 1992), and mowing. In order to eliminate *C. orbiculatus*, the vines should be removed from the site once they are cut, mowed, or pulled to avoid re-rooting (Webster et al. 2006). Any portions of the root system not removed will potentially re-sprout. The general inefficiency of mechanical treatments indicates that herbicide may be a necessary part of a control program (Ding et al. 2006, Dreyer 1988, McNab and Meeker 1987, and Southeast Exotic Pest Plant Council Invasive Plant Manual 2003).

In areas of high infestation, cutting and treating the stump with glyphosate or triclopyr amine can kill *C. orbiculatus*. High infestation areas are areas that are densely covered with exotic-invasive vines. These areas cannot be easily treated with mechanical treatments, such as cutting, mowing, or pulling, since it is physically difficult to access these sites using manual methods. These areas are ideally suited for chemical control methods. 2, 4 - D (Hutchinson 1992), glyphosate, or triclopyr (Dreyer 1988) are commonly recommended herbicides for *C. orbiculatus* (Miller 2002, Southeast Exotic Pest Plant Council Invasive Plant Manual 2003, and Webster et al. 2001). Glyphosate is a non-selective herbicide that controls both woody and herbaceous broadleaf plants by inhibiting the shikimic acid pathway, a pathway that manufactures proteins for growth (Cox 1998). Glyphosate is water soluble, while triclopyr has two forms: amine (water soluble) and ester (oil soluble). Glyphosate amine is ideal to use with a surfactant. Surfactants allow for herbicide to adhere to noxious plants and lower the surface tension of water. This will increase plant uptake of the herbicide (Langeland 2003).

Triclopyr is a selective herbicide that controls woody and herbaceous broadleaf plants by mimicking the plant hormone, auxin. Plant auxins control plant growth functions. Triclopyr causes the uncontrolled cell division and cell growth of the plant leading to death (Tu et al. 2001). An advantage to using triclopyr is that it does not kill monocots, such as grasses, sedges, and liliaceous plants. These species will continue to thrive and prevent soils from being completely exposed (Miller 2002). Exposed soil can create a microsite that can be susceptible to invasion by exotic-invasive species. These herbicides can be applied to plants using various methods: foliar, injected, applied to cut stems, and through the bark via oil-based carriers (Langland 2003). These methods are applied depending on local conditions, state of invasive plant development, and management objectives and philosophies.

Foliar applications are generally applied with spray nozzles from aerial or directed spray equipment. Herbicide labels (2009a and 2009b) recommend foliar applications for glyphosate or triclopyr ester a 2 % volume to volume mixture with water. Foliar application should thoroughly wet the foliage and stems, but should not drip off.

Hutchinson (1992) found that foliar application of triclopyr effectively "reduce *C. orbiculatus"*.

Cut-stump or basal bark treatments are best for situations where foliage is inaccessible or difficult to treat without incidental damage to associated plants. Cut surface applications target the herbicide being applied to the cambium of a freshly cut surface. Cut surface application is used to treat vines that are growing within or around surrounding vegetation, or growing in the canopy of other tree species. Herbicide labels (Anonymous 2009a and Anonymous 2009b) recommend cut-stump applications of glyphosate or triclopyr with a 25 % volume to volume mixture with water to control *C. orbiculatus.*

Basal bark treatments can be used on stems of vines growing in dense patches or those with their foliage high in the canopy. Triclopyr ester combined with mineral oil or diesel oil can be sprayed directly on stems of undesirable plants. One common basal bark treatment is a 20 % triclopyr in oil to control *C. orbiculatus* (Anonymous 2009b). In basal bark applications, the lower 30 – 50 cm of the vine is sprayed with the oil soluble herbicide. Basal bark treatments can be sprayed with a backpack sprayer, a small spray bottle, or from large skidder-mounted mist blowers for commercial applications in pine plantations for hardwood control. It is practical for all vegetation smaller than 15 cm in diameter and practical where dead vegetation can be left standing (Langeland 2003).

It is commonly recommended that treatments be applied to exotic-invasive plants prior to their producing fruit (Panda et al. 2007). Minimizing the production of fruits will minimize seed dispersal. In order to minimize damage to surrounding vegetation, timing the herbicide application in early spring, before plant nutrient uptake of native species, or in late fall when most native species are dormant, will selectively target *C. orbiculatus* (Southeast Exotic Pest Plant Council Invasive Plant Manual 2003). Ellsworth et al. (2003) found that after two years *C. orbiculatus* seedling emergence from the seed bank averaged 0.9 seedling/m^2 in fifteen plots. Current recommendations for controlling *C. orbiculatus* specify that in order to reduce seed dispersal, herbicide applications should be applied before *C. orbiculatus* produces fruits.

Currently, there are no biological control treatments for *C. orbiculatus* (Dreyer 1994), however, other methods of control include mammal herbivory. Deer browsing appears to have no effect on the species diversity of exotic-invasive plants, but generally can reduce *C. orbiculatus* (Bowers 1993). Blossey (1991) and Carpenter and Cappuccion (2005) suggest that herbivore browse can contribute to the control of exotic-invasive species, thus further preventing the spread. Exotic-invasive species tend to be more tolerant of herbivory than native plant species. In greenhouse studies with simulated herbivory (clippings), *C. orbiculatus* had higher growth rates after damage (Aston and Lerdau 2008).

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CHAPTER 2

Distribution of oriental bittersweet in a timber harvested area in northern West Virginia

Introduction

Oriental bittersweet (*Celastrus orbiculatus*) is an exotic-invasive species that threatens forest health in many areas of the eastern United States. Based on herbarium records, *C. orbiculatus* was first recorded in Hampshire County, West Virginia in 1977. Also, herbarium records fail to predict a distribution pattern of *C. orbiculatus* (Huebner 2003). As of 2009, *C. orbiculatus* has been identified in thirty-two counties in West Virginia (West Virginia Atlas 2009). *C. orbiculatus* is currently listed as a noxious weed in Connecticut, Massachusetts, New Hampshire, North Carolina, and Vermont, but not in West Virginia.

C. orbiculatus is an invasive vine that can easily overtop native trees and vegetation with its rapid growth over stumps, saplings, and mature trees. This twining vine can shade, suppress, and ultimately kill native vegetation. *C. orbiculatus* is an effective invasive species due to its efficient use of minerals and water (Webster et al. 2006), exclusion of other species (Dreyer et al. 1987), mammal dispersal of seeds (Bowers 1993), natural robustness, ability to form a long lasting seed bank, and ability to form thickets (Dreyer et al. 1987).

Forest areas are invaded by *C. orbiculatus* as its vines grow into the upper canopy supported on the stems of other shrubs and trees. Foliage produced by these vines then blocks sunlight from reaching the leaves of supporting woody stems and plants on the forest floor. The vine's dense cover can reduce the production of seeds from surrounding vegetation. The dense cover also can increase a tree's susceptibility to breakage. Woody vines damage young trees by increasing the threat of girdling, ice, wind, and overtopping (Webster et al. 2006). Trees and shrubs can be weakened and killed as the vine spirals around their stems, eventually constricting the flow of water and nutrients transported by phloem and xylem tissues. As *C. orbiculatus* vines grow into the crowns of woody vegetation, the affected surface area of plant crowns increase, adding additional stress to the supporting stems. Due to the increased surface area, ice and wind cause structural damage to supporting plants through increased ice buildup and additional wind stress. These added stress factors coincide with *C. orbiculatus* caused reductions in the supporting plants' ability to photosynthesize and produce secondary stem growth that could support these additional loads (Dreyer 1994).

Shade tolerance, root suckering, rapid vegetative growth under high light conditions, and high fecundity all contribute to the success of *C. orbiculatus* (Greenberg et al. 2001). The fast growth and shade tolerance of this introduced woody vine allows it to successfully compete with tree regeneration after silvicultural treatments or natural disturbances. Also, because *C. orbiculatus* can grow from tree crown to tree crown through the forest canopy, when an infested tree is harvested, neighboring trees can be damaged; as a tree falls, vines that are interconnected with adjacent trees pull on those trees and can strip the tree of foliage and branches. Thus, large amounts of woody vines in forest canopies can increase the size of the gaps in forests when trees are harvested (Schnitzer et al. 2004).

An invasion of exotic-invasive plant species may be triggered by natural or man-made disturbances (Dreyer 1994). Vines are competitive invaders in disturbed forests (Silveri et al. 2004). *C. orbiculatus* seedlings are often present in late-successional deciduous forests where openings are created by individual or multiple tree-fall gaps. If seed reserves are present in forest soils prior to anthropogenic disturbances, such as logging, exotic-invasive species can become established and out-compete native reproduction. The effects of logging can trigger growth of these seeds and create a problem for land managers (Silveri et al. 2004). Forests are especially susceptible to the establishment of exotic-invasive species during forest management operations that disturb forest soils (Randall and Marinelli 1996).

Canopy disturbance promotes *C. orbiculatus* reproduction, presenting a serious problem for forest managers as vines compete with and inhibit native forest regeneration (Webster et al. 2001). *C. orbiculatus* is an aggressive invader that can dominate all vegetation levels of forested and open areas (McNab and Meeker 1987). *C. orbiculatus* uses a "sit and wait" strategy by establishing and persisting in low light conditions under undisturbed forest canopies, and grows rapidly following a canopy disturbance often overtopping and girdling surrounding trees (Greenberg et al. 2001).

In contrast to large, catastrophic disturbances, small disturbances to the forest floor may promote seed germination and establishment by exposing bare soil to light. Examples include single tree falls, turkey and deer scratching, and low intensity fires. These small openings in leaf litter provide an opportunity for *C. orbiculatus* to germinate and become established. Conversely, intact tree leaf litter has been shown to reduce establishment of seedlings through biochemical effects, reduced soil temperature, and shading (Ellsworth et al. 2004).

Forest edges are suitable habitats for exotic-invasive plant species because of high light levels. Yates et al. (2004) found that mean density of *L. japonica* in a fragmented landscape in Illinois decreased from edge to interior forest conditions, and mean heights were greater in edge conditions. Therefore, low light conditions may present a limiting factor for invasion of exotic-invasive species into the forest interior.

Edge oriented species are those that can respond to forest edge effects (Kremsater and Bunnel 2003). Matlack (1994) found exotic-invasive species were found primarily within 5 m or less of the forest edge, although some species could be found up to 40 m. These edge observations were usually on north facing sites, but in analysis, a species' mean distance from edge was not sufficient to create a recognizable pattern on different aspects. Similarly, Meiners et al. (2002) found that exotic-invasive species had maximum abundance within 20 m of the forest edge.

Most research concerning exotic-invasive species has been conducted in relatively undisturbed forests. Given the recent intensification of timber harvesting in West Virginia, we undertook an investigation to characterize the invasion of *C. orbiculatus* in a managed forest in north central West Virginia. The primary objective of this study was to provide insight into the structure of these invasions in managed forest ecosystems.

Specifically, the study investigates changes in the size structure and age structure of *C. orbiculatus* and associated vegetation from edge to interior forest.

Methods

Study Site

The study was set up on a private forest property in Marion County, West Virginia (39º 45´ N, 80º 16´ W). The property is located north of Fairmont State College and south of US Route 250, near the old Fairmont State College soccer field (Figure 2.1).

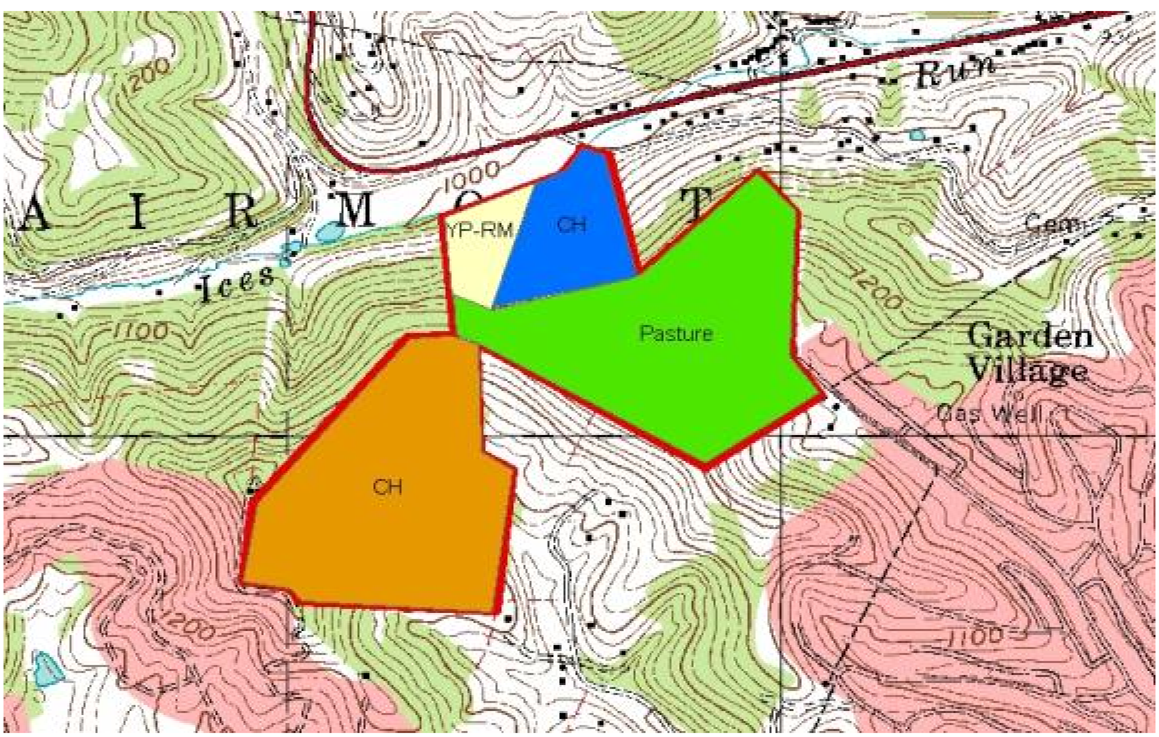

Figure 2.1. Study property forest cover types. * Note YP-RM = Yellow-poplar/ Red Maple stands and CH = Cherry/Cover Hardwood stands.

The property is approximately 35 ha and has an elevation of 457.2 m above mean sea level. The average temperature is 11.2 ºC and the average precipitation is 99 cm (USDA, NRCS 2008). The slopes are generally north or east-southeast facing. Dominant forest cover is composed of two types of forest types; cove hardwoods and yellow-poplar-red maple. Based on a 2008 inventory, the most abundant overstory species (trees ≥ 10 cm diameter at breast height (DBH)) include red maple (*Acer rubrum* L.), American elm (*Ulmus americana* L.), and black cherry (*Prunus serotina* Ehrh.) (Table 2.1).

Table 2.1. Mean overstory composition values (IV = 0.5 * (relative density + relative basal area)) of transect tree species.

Species	Relative Basal Area %	Relative Species Density%	Importance Value (IV)
Acer rubrum	24.7	15	19.84
Ulmus americana	13.54	12.75	13.14
Prunus serotina	17.68	7.69	12.68
Platanus occidentalis	10.9	5.45	8.17
Liriodendron tulipifera	8.85	6.01	7.42
Vitis spp.	1.6	11.63	6.61
Quercus rubra	11.43	11.46	11.44
Juglans nigra	6.13	4.89	5.5
Crataegus spp.	1.2	9.38	5.28
Carya glabra	1.35	6.57	3.95
Ulmus rubra	1.35	4.89	3.11
Acer saccharum	1.28	4.3	2.85
Total	100	100	100

Forest soils on the property are comprised of Westmoreland silt loam (63 %), Culleoka - Westmoreland silt loams (30 %), and Clarksburg silt loam (7 %). Westmoreland soils are generally found on uplands and are deep well-drained soils with a 5.6 pH. These soils are loam – silty loam clay. Culleoka - Westmoreland soils are not as deep as Westmoreland soils, and found on uplands with a 5.6 pH. These soils are loam – silty loam clay. Lastly, Clarksburg soils are generally deep soils found on foot slopes and are well drained with a 5.8 pH. These soils are silt loam and are heavily influenced by colluviation (NRCS 2008, USDA 1982).

A dot grid was used with aerial photos dating back to 1938 to estimate changes in tree and shrub cover. Photos for 1938 and 1967 were taken in October, the 1953 photos were taken in May, and the 1981 and 2007 photos were taken in November. Due to the low resolution of these photos, particularly the earlier photos, land cover percents may not be fully accurate, since some were taken in late fall/early winter. In 1938, woody plants covered 83 percent of the study site and most of the woody vegetation is present on the southern side of the property. Evidence on the 1952 aerial photos suggests that a timber harvest or other clearing operation took place sometime in the early 1950's (18 % woody cover). Also, in the 1952 photos, a power line right-of-way (ROW) is present. In 1967, the woody vegetation cover was 30 percent, and most of the woody vegetation is above the southern side of the ROW. By 1981, forest cover had grown to 55 percent and woody vegetation was present on both sides of the ROW. As of 2007, woody vegetation cover is 83 percent. Field observations indicate that this forest is an old growth forest with old large alive and dread trees, which is represented by the clearing operations in the 1952 aerial photos.

As mentioned above, in 1951, a Chesapeake Emerson ROW was established on the property. The ROW runs-east west along the north side of the property, near route 250. The ROW is approximately 26 m wide. Currently, the Allegheny Power Company maintains the ROW. Only trees that are considered dangerous or will be potentially dangerous to the ROW are cut every four to eight years. The ROW is mowed and treated with herbicided every ten years regardless of condition (*Personal communication*, D. Delaney Allegheny Power Company 2008).

Forest management operations over time have included grapevine removal to reduce damage to regeneration in 1994, 1995, 1997, and 2001 (Wildman 2001). The property had 108,361 board feet in international 1/4 Inch scale of timber harvested during the dry season (winter months) of 2001. The forester for the research property administered a timber harvest in 2001. During the timber cruise, the forester noticed an unidentified vine on neighboring properties that was later identified to be *C. orbiculatus (Personal communication*, J. Wildman, WV Division of Forestry; 2008).

Transects

Six transects were established on a north-facing slope perpendicular to the east-west running right-of-way (ROW) to demonstrate the change in *C. orbiculatus* abundance from edge to the interior forest (Figure 2.2). Three transects extended uphill from the southern edge of the ROW, and three extended downhill from the northern edge of the ROW corridor; hence, while all transects were located on a north aspect, the edge vegetation for the transects on the northern side of the ROW were directly illuminated by sunlight, while edge vegetation along the southern side of the ROW were shaded by trees along the edge. Locations of the transects were purposefully chosen to intersect areas containing high infestations of *C. orbiculatus* located along the ROW/forest edge. We defined the edge boundary to be the first trees adjacent to the ROW although in some areas, patches of shrubs exist between the grassy ROW and the trees. The transects started at the ROW/forest edge and extended into the forest for 50 m. For edge/interior comparisons of *C. orbiculatus* densities, each 50 m transect was divided into interior and exterior proportions. The first 20 m of the transect was considered the edge, and last 20 m of the transect was considered the interior; with a 10 m buffer between the edge and interior forest (Figure 2.2).

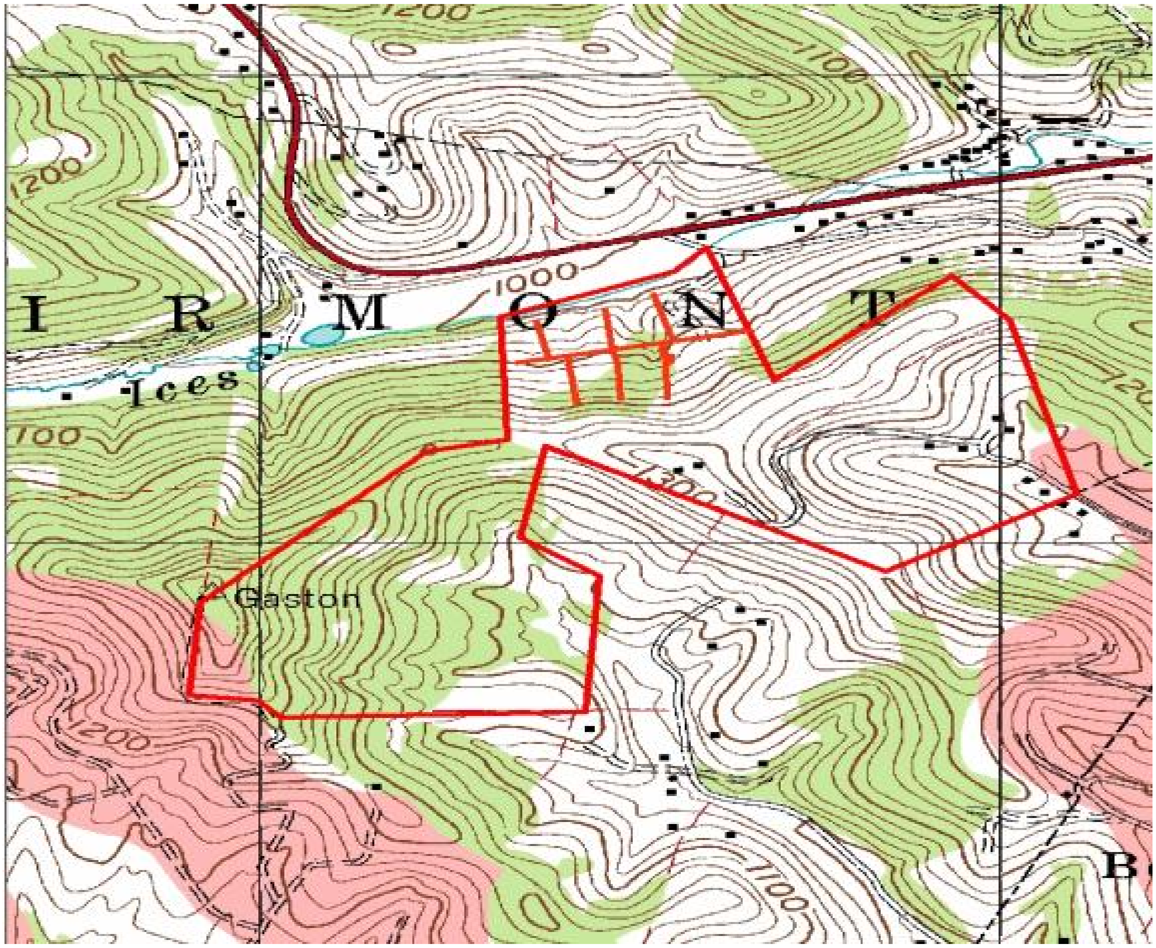

Figure 2.2. Six transects selectively chosen to show the change in abundance of *C. orbiculatus* along the ROW.

Transects served as the centerline for data collection. Data collection was taken within 1.83 m of the transect centerline. Each 50 m transect was partitioned into 5 m intervals. At each 5 m interval, a variable width strip plot was used to quantify stem density of *C. orbiculatus*. Basal segments of *C. orbiculatus* within 1.83 m of the transect centerline were cut at 10 cm (D 10) above ground level and collected to determine age in the laboratory. D10 of these stems were measured during sampling. Woody stems greater than 6 cm diameter at breast height (DBH) were mapped within 1.83 m of the transect centerline. The condition of the tree (live or dead), crown heights, crown spread, diameter, and distance from transect, and slope distances were recorded for each tree.

Tree DBH was measured using a diameter tape. The slope distance was measured using a 61 m nylon tape. Tree heights were measured using an Impulse 100 Standard Laser (Laser Tech. Inc.). Shrub heights were measured with a 7 m height pole. Tree and shrub crown spread along the transect was measured by estimating the crown edge intersection with the nylon tape transect centerline.

Light measurements were recorded at the starting and ending points of each 5 m interval using a Decagon light wand (Li-2000; Li-COR Bioisciences, Lincoln, NE). Two light measurements were recorded at each point. A height pole was used to take an upper light level reading at 7 m using an external sensor, and a lower light reading taken using the 1m long light sensor wand at a height of 1 m.

Analytical methods

All statistical analyses were performed using SAS 9.1 software (SAS Institute, 2003), with a significance determined at an alpha = 0.05. Effects of independent variables were assessed using the General Linear Model (GLM) procedure. Two-factor ANOVA was used to test the side of the ROW (N or S) and position (Edge or Interior) of *C. orbiculatus* seedling densities. The SAS CORR procedure was used to explore linear relationships between C. orbiculatus densities and light and cover microsite variables.

Species percent coverage (PC) was calculated for each transect by species using the formula:

$$PC = \frac{\text{Amount Observed within 5 m Quadrat}}{\text{Total Observed}}$$

Results

Transect Composition

Berberis thunbergii was the most abundant shrub species along all transects, while *Carya glabra, Acer rubrum,* and *Crataegus spp.* were the most abundant tree species. *Lonicera spp., Lindera spp.,Carya glabra, Crataegus spp., Fraxinus americana, Platanus occidentalis, Celastrus orbiculatus,* and *Vitis spp* were more abundant on southern site edges. *Berberis thunbergii, Ligustrum sinense, Acer rubrum, Acer saccharum, Juglans nigra, Liriodendron tulipifera, Prunus serotina, and Ulmus rubra* were more abundant on northern site edges. *Vitis spp.* was more abundant on edge sites, and *Celastrus orbiculatus* was more abundant in interior sites. All shrub species, except *Lindera spp.*, along transects are considered exotic-invasive to the Appalachian Region (Table 2.2).

Table 2.2. Shrub, tree, and woody vine species percent coverage of edge and Interior portions of vegetation transects.

	Southern		Northern	
Species	Edge (%)	Interior (%)	Edge (%)	Interior (%)
Shrubs				
Berberis thunbergii	16.22	0	29.2	4.44
Lonicera spp.	43.57	6.25	13.33	0
Ligustrum sinense	20.96	42.1	57.78	28.57
Lindera spp.	73.74	34.95	67.14	63.66
Trees	0	0	0	0
Acer rubrum	18.46	40.13	20	34.36
Acer saccharum	0	0	14.29	0
Carya glabra	7.69	7.69	0	0
Crataegus spp.	7.69	15.38	0	0
Fraxinus americana	2.56	16.02	0	0
Juglans nigra	0	8.33	14.29	14.29
Liriodendron tulipifera	0	5.13	14.29	14.29
Platanus occidentalis	26.67	0	0	0
Prunus serotina	16.67	0	36.34	14.29
Quercus rubra	0	0	6.67	13.33
Ulmus americana	26.93	19.49	43	75.83
Ulmus rubra	0	8.33	0	0
Woody Vines	0	0	0	0
Celastrus orbiculatus	30.77	114.98	14.56	23.61
Vitis spp.	51.17	28.74	17.24	0

C. orbiculatus seedling densities

Higher average *C. orbiculatus* seedling densities were found in the interior of the forest (320.88 m^2) compared to lower average seedling densities on the edge of the forest (152.30 m^2). Seedling densities of *C. orbiculatus* on northern and southern sites were not statistically different (p = 0.304) (Table 2.3). Forest edges had higher average light levels compared to the interior of the forest (Table 2.4).

Table 2.3. Edge and interior seedling densities of *C. orbiculatus* along transects (p = 0.304)**.**

	Seedling Density m^2		
Side	Edge	Interior	*Mean*
S	268.20	373.56	320.88 a
N	104.41	200.19	152.30 a
Mean	186.30 a	286.88 a	236.59

Table 2.4. Edge and interior light densities along transects.

	Light Level (PPFD µmole/m^2/s)		
Side	Edge	Interior	*Mean*
S	468.25	144.51	306.38 a
N	104.41	200.19	152.30 a
Mean	286.33 a	172.35 a	229.34

C. orbiculatus seedling density was negatively correlated with the total amount of combined shrub and tree crown cover within each quadrant; indicating that as seedling density decreases, the total amount of shrub and tree crown cover increases (r = -.0727; p = 0.007). Similarly, *C. orbiculatus* seedling density was again negatively correlated with the total amount of just shrub crown cover within each quadrant; indicating that as seedling density decreases, the total amount of shrub crown cover increases (r = -.0689; p = 0.013; Figure 2.3). Finally, there was no correlation between the total amount of tree crown cover and seedling density within each quadrant (r = -.0440; p = 0.153). The shrub crown cover is influencing the correlation with the total shrub and tree crown cover, since there is no correlation with tree crown cover (Table 2.5).

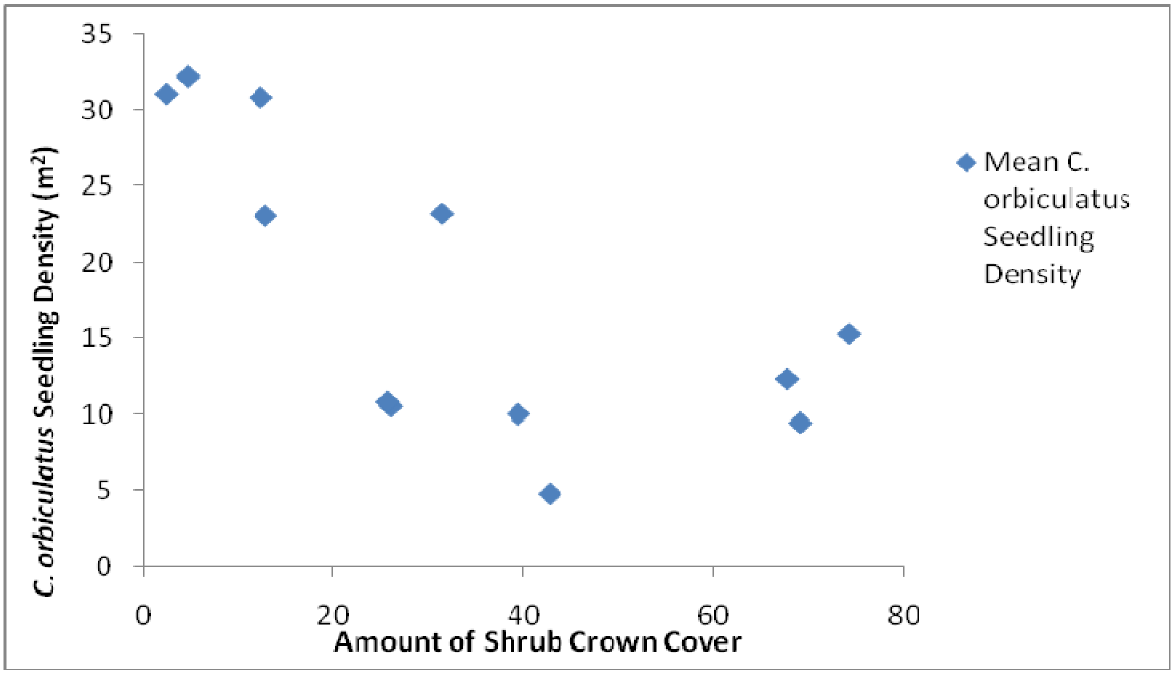

Figure 2.3. The correlation between the amount of total shrub crown coverage and *C. orbiculatus* seedling density (m^2) (p = 0.013).

Table 2.5. Correlation factor variables related to *C. orbiculatus* seedling density.

	C. orbiculatus Seedling Density	
Factor	Correlation Coefficient	P- Value
Shrub and Tree Crown Cover	-0.0727	0.007
Shrub Crown Cover	-0.0689	0.013
Tree Crown Cover	-0.440	0.153

C. orbiculatus Age

Vines ranged in age from 4 – 45 years. The oldest vine along the transects was a 45-year-old grapevine. The oldest *C. orbiculatus* vine found was 23 years in age and established in 1985 (Figure 2.4). Most vines were established after 1983, with *Vitis spp.* having greater abundance in the late 1980s and early 1990s. An increasing abundance of *C. orbiculatus* vines developed in the 1990s.

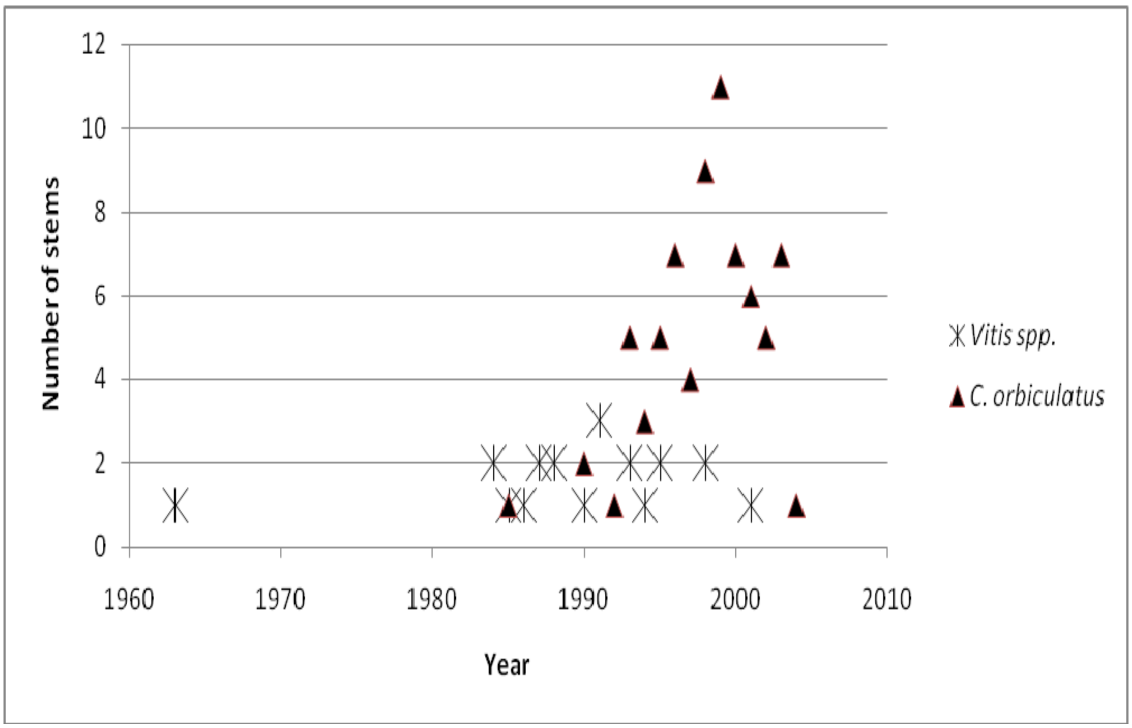

Figure 2.4. Establishment dates of *Vitis spp.* and *C. orbiculatus* along transects.

Only vines larger than 1 cm were cut and aged along transects. Vine diameters range from 1 cm to 8 cm, with one vine larger than the others. There are increasing linear trends for both species, however, the 45-year-old grapevine has a large influence on the linear relationship (*Vitis spp*. $r^2 = 0.2655$ and *C. orbiculatus* $r^2 = 0.3906$). This positive trend indicates smaller diameters are found in relation to older vines (Figure 2.5).

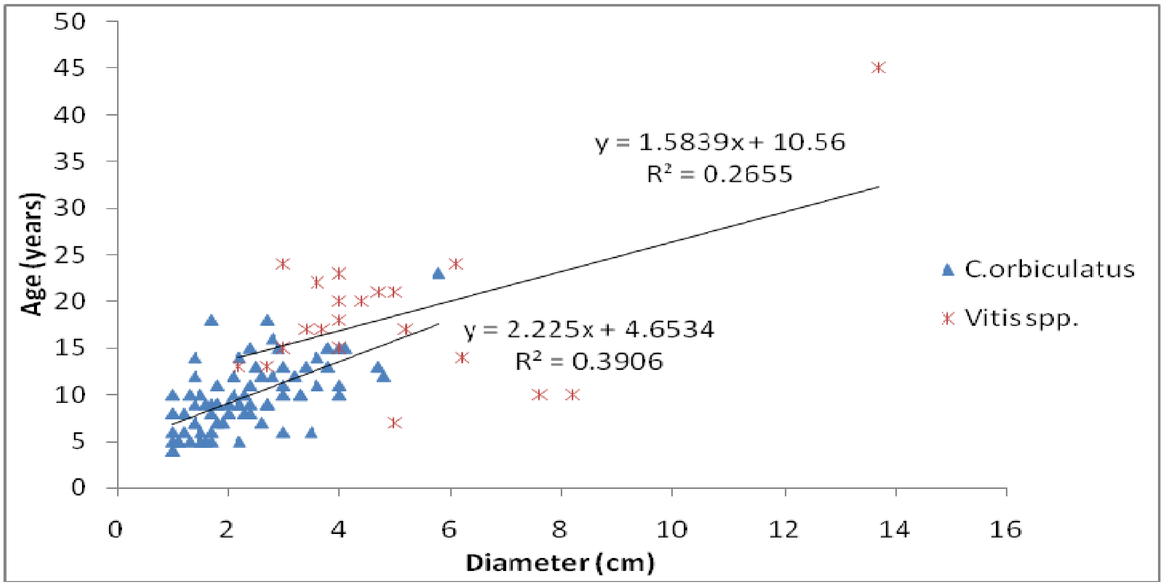

Figure 2.5. Vines larger than 1 cm in diameter found along transects ages and diameters.

There is a slight negative linear relationship with vines found on nothern facing sites (*Vitis spp*. r^2 = 0.0.235 and *C. orbiculatus* r^2 = 0.0.365), indicating that younger vines are found further away from the forest edge. Vines found on southern sites have a slight postive linear relationship *(Vitis spp*. r^2 = 0.0.951 and *C. orbiculatus* r^2 = 0.0.566), indicating older vines are closer to the forest edge (Figure 2.6 and Figure 2.7).

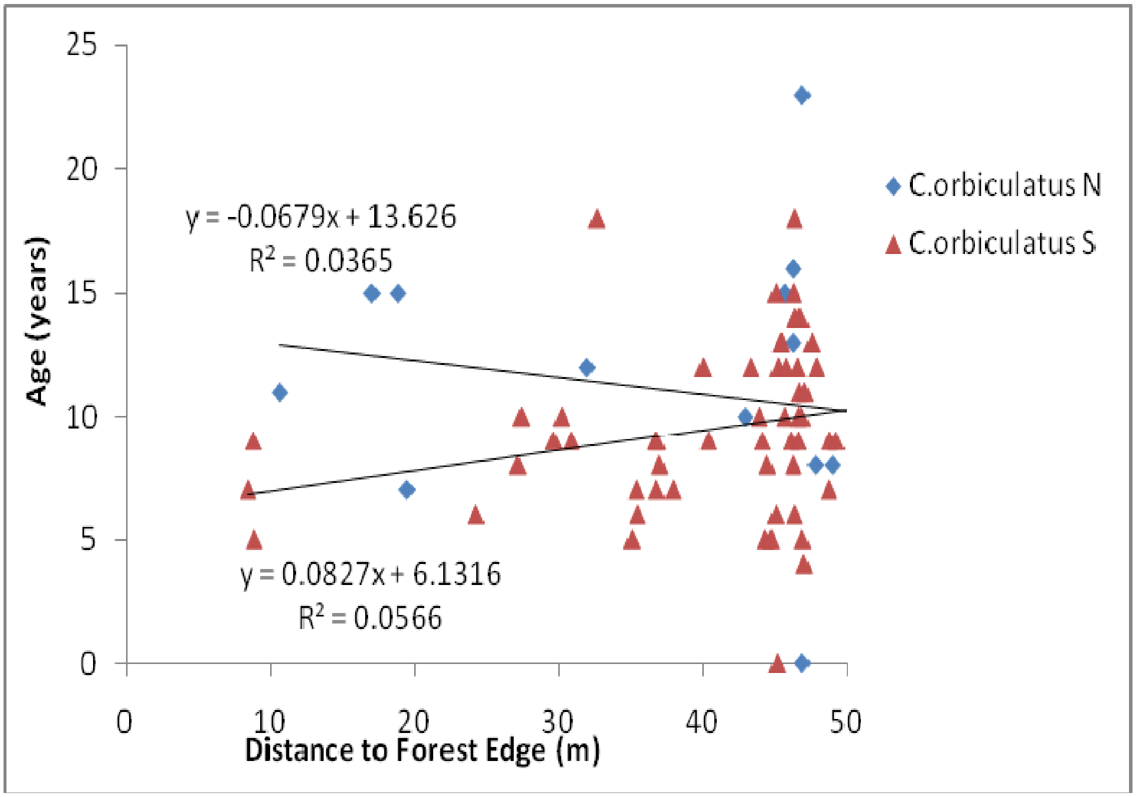

Figure 2.6. Ages of *C. orbiculatus* along all transects with distance to forest edge.

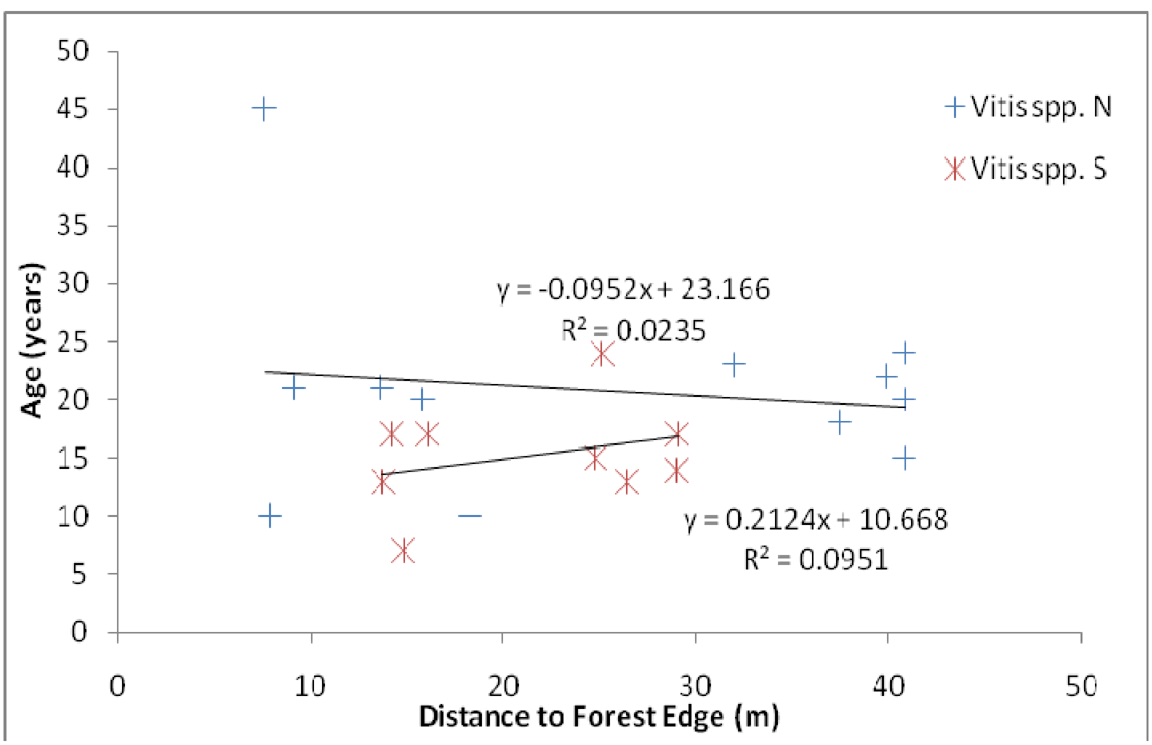

Figure 2.7. Ages of *Vitis spp.* along all transects with distance to forest edge.

C. orbiculatus was present on all transects. *Vitis spp.* was present in lower abundance on most transects. Tree species with larger diameter, crown spread, and height were found in the interior of the forest. Shrub species densely covered the edges of all transects, and all transects had canopy gaps within the interior of the forest (Figure 2.8, Figure 2.9, Figure 2.10, Figure 2.11 Figure 2.12, and Figure 2.13).

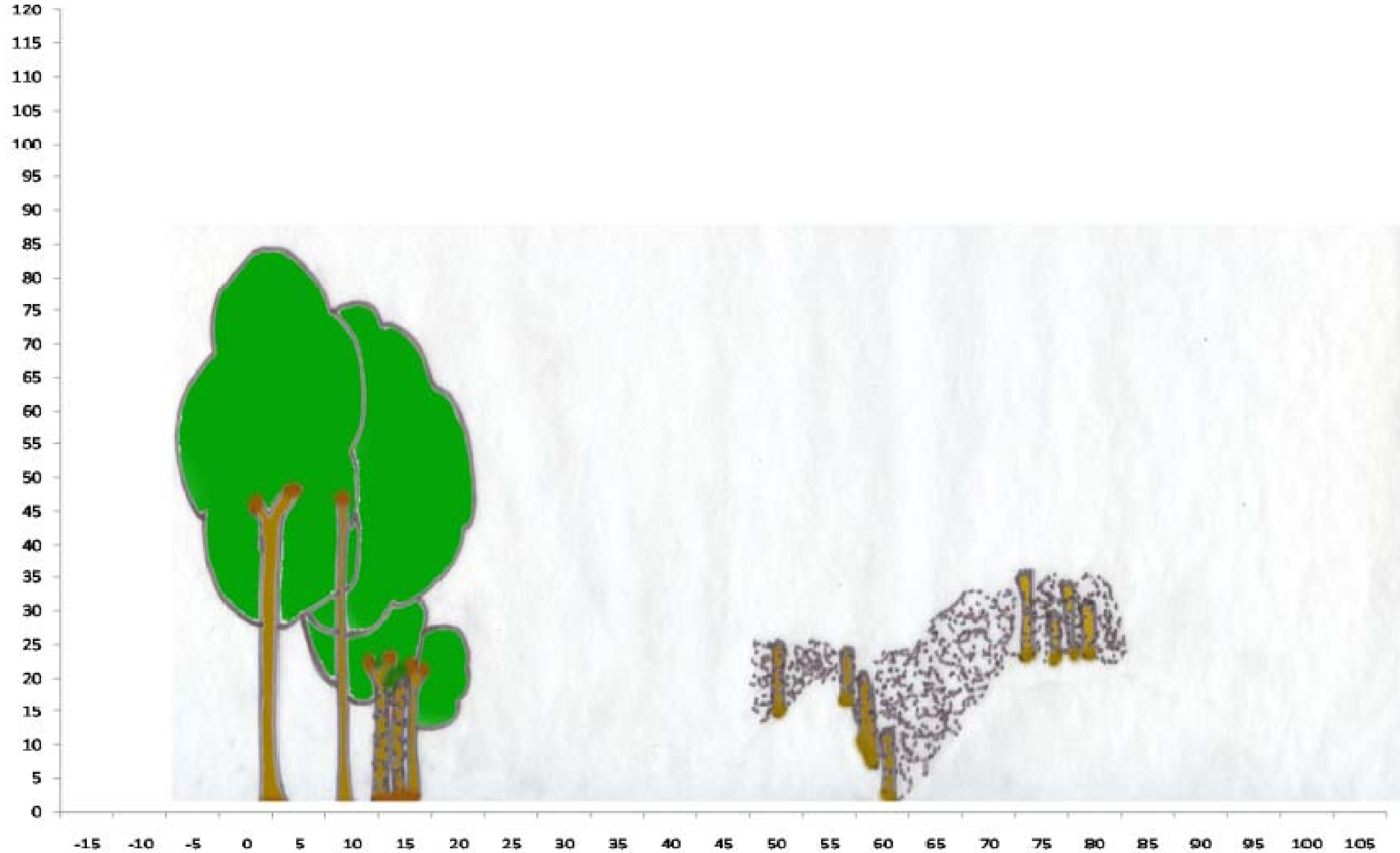

Figure 2.6 Transect 1 runs from the ROW into the interior of the forest. *Notes –represent *C. orbiculatus* and X represents *Vitis* L.

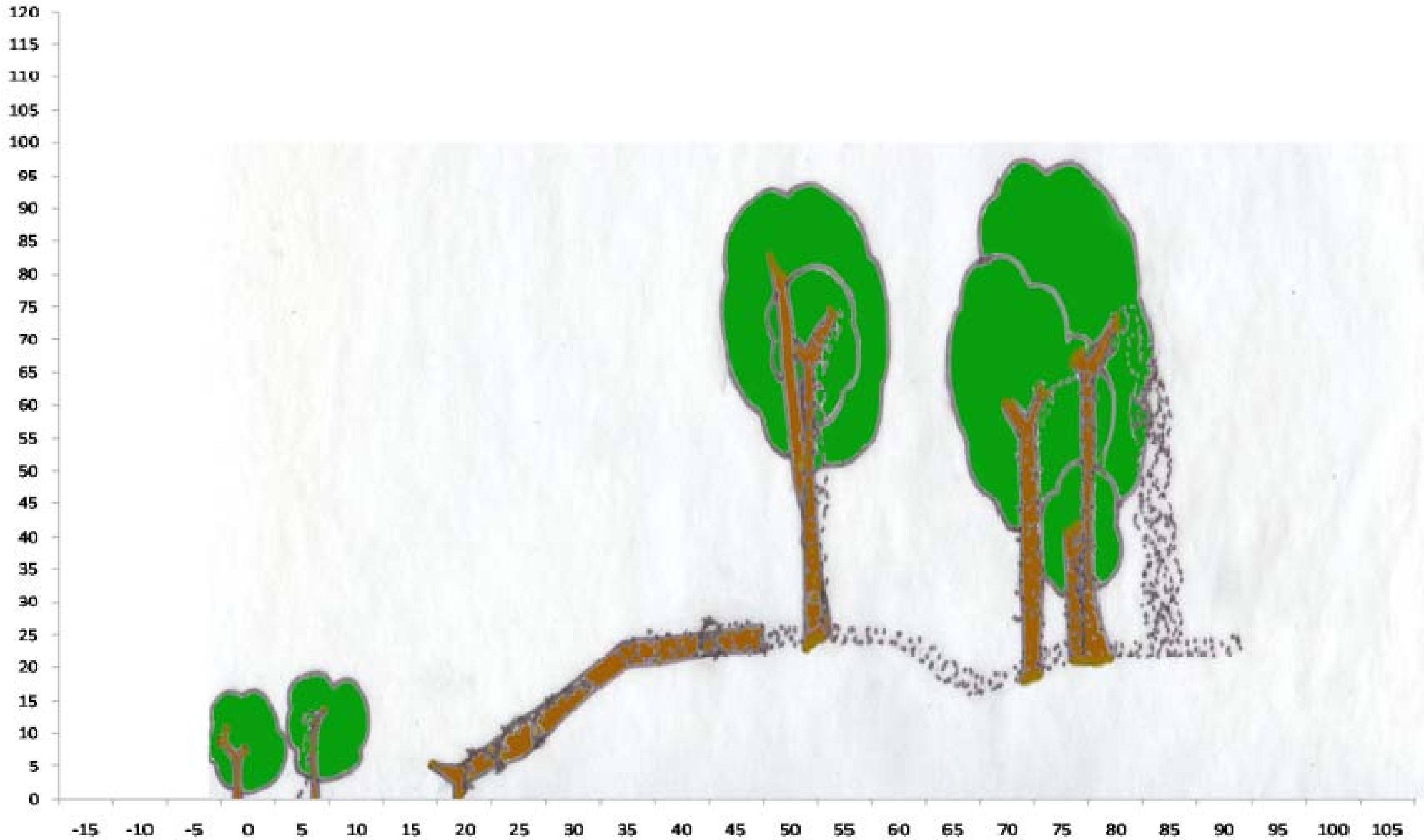

Figure 2.7. Transect 2 runs from the ROW into the interior of the forest. *Notes –represent *C. orbiculatus* and X represents *Vitis* L.

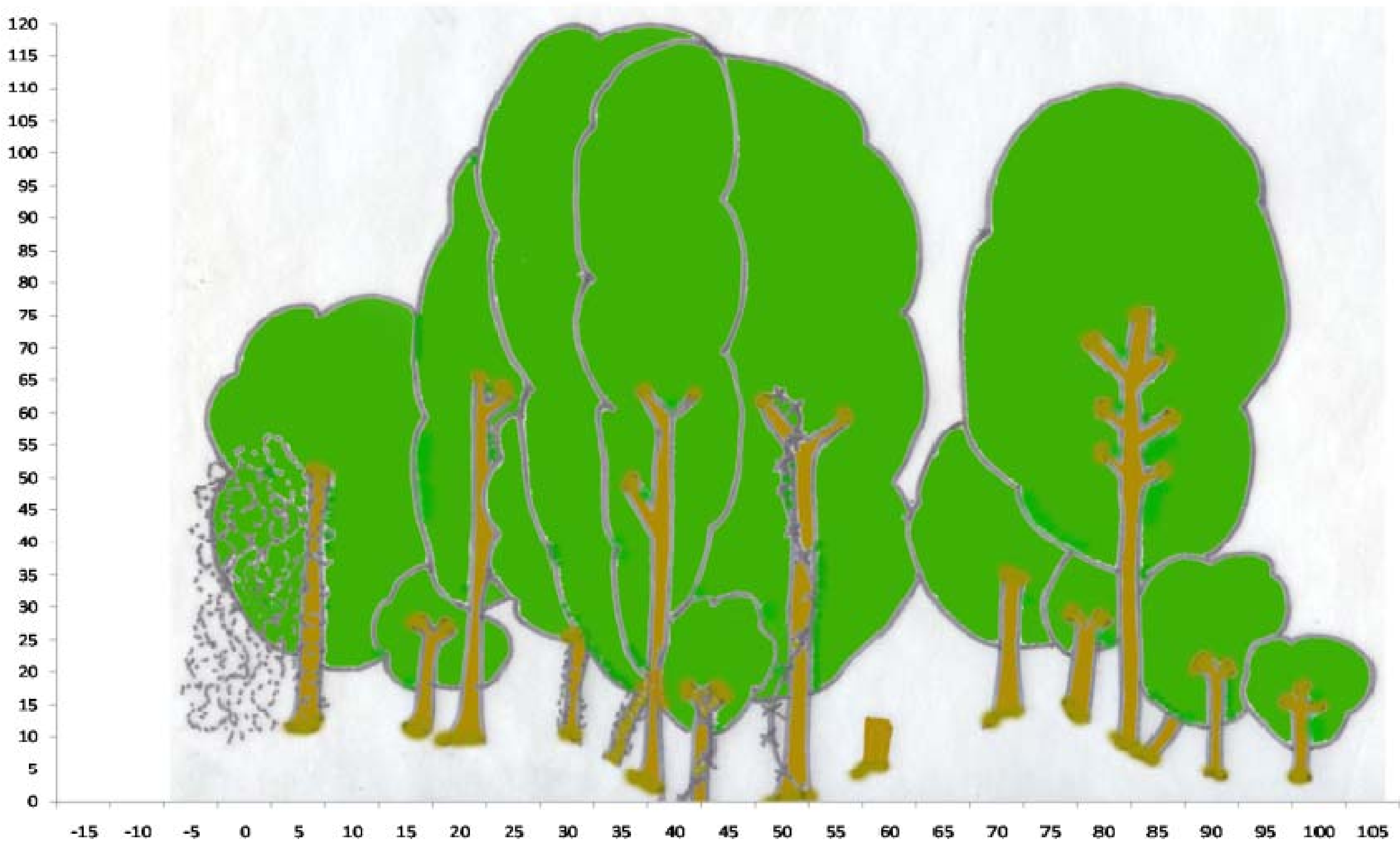

Figure 2.8. Transect 3 runs from the ROW into the interior of the forest. *Notes –represent *C. orbiculatus* and X represents *Vitis* L.

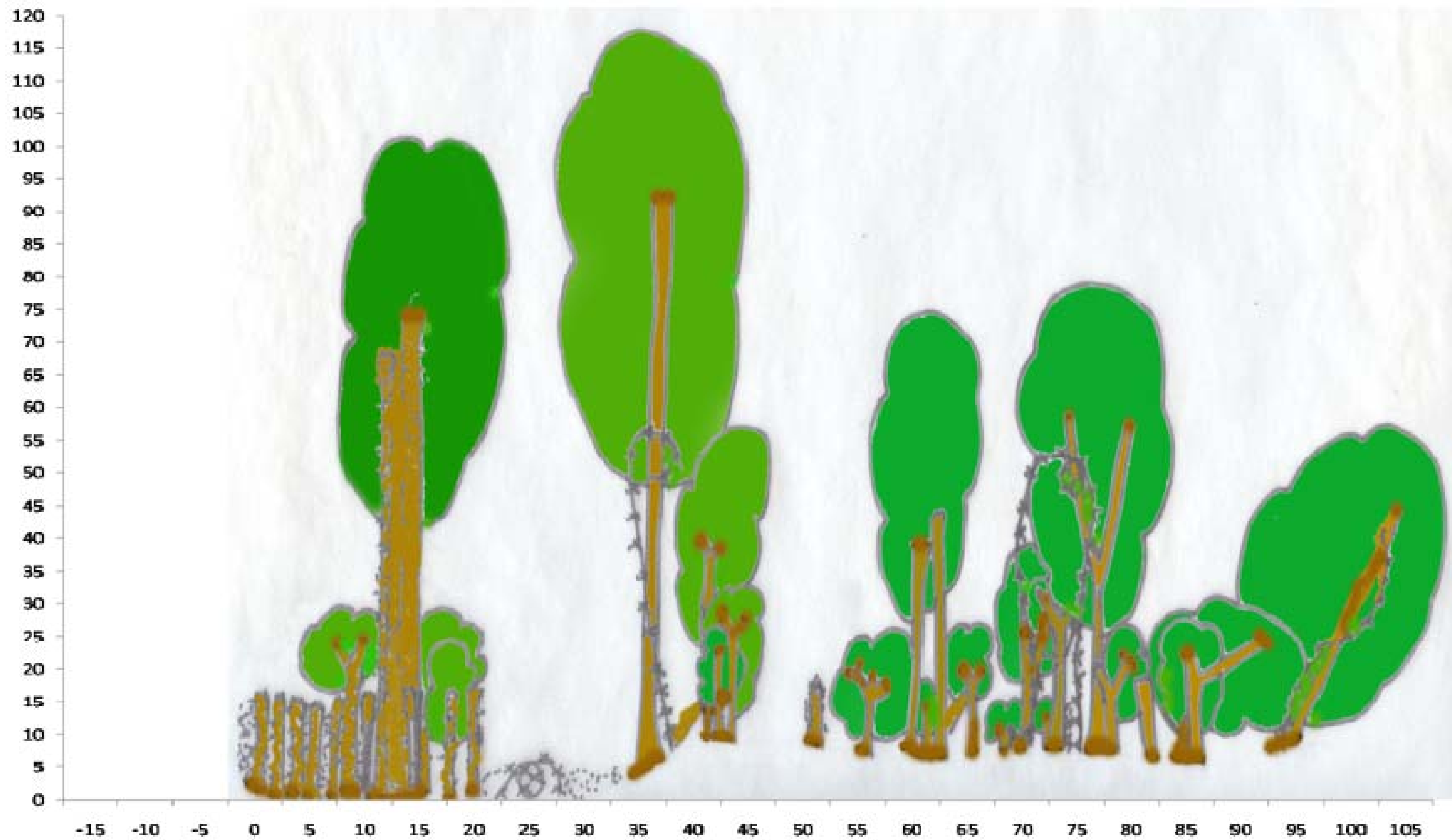

Figure 2.9. Transect 4 runs from the ROW into the interior of the forest. *Notes –represent *C. orbiculatus* and X represents *Vitis* L.

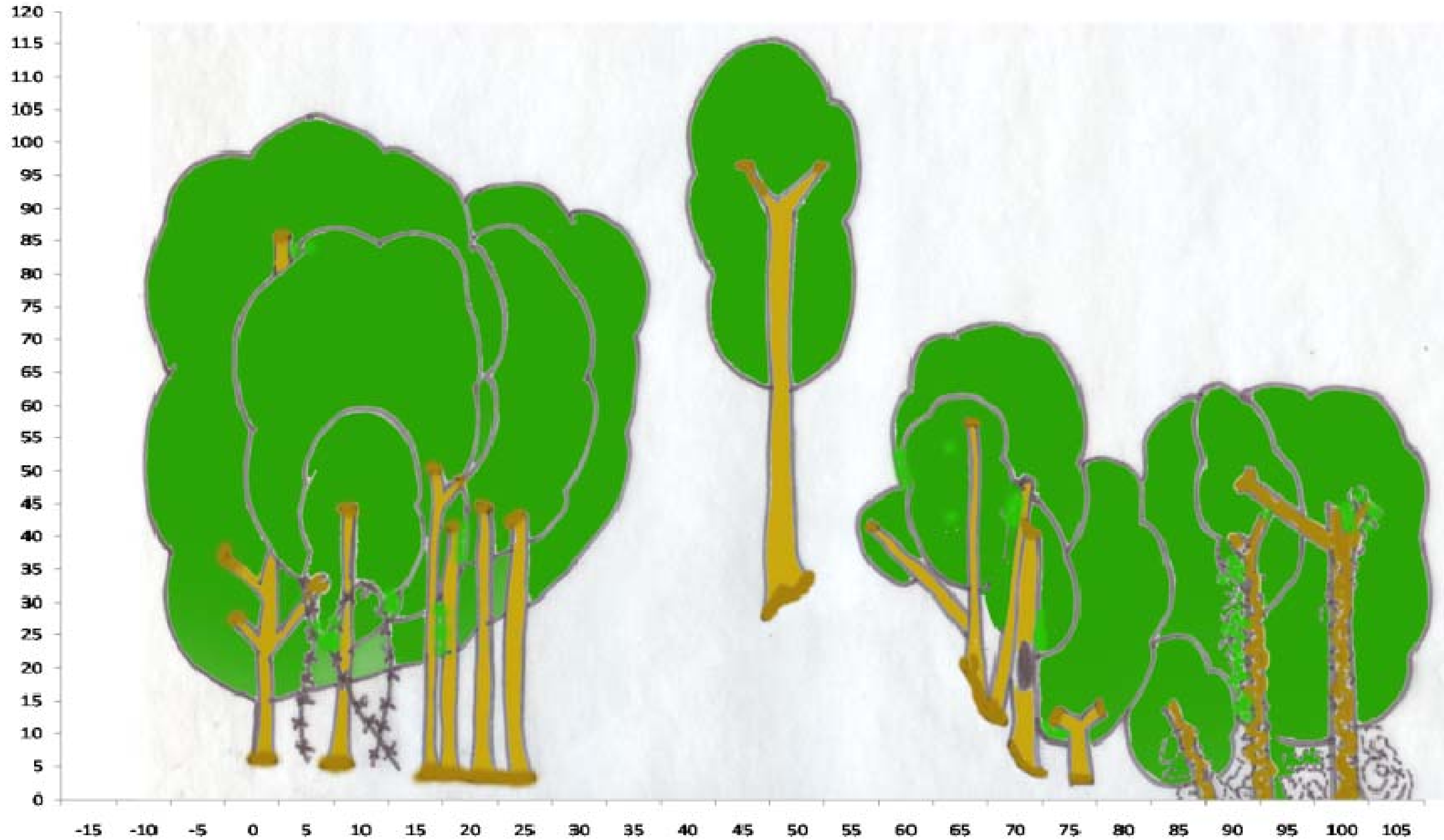

Figure 2.10. Transect 5 runs from the ROW into the interior of the forest. *Notes –represent *C. orbiculatus* and X represents *Vitis* L.

Figure 2.11. Transect 5 runs from the ROW into the interior of the forest. *Notes –represent *C. orbiculatus* and X represents *Vitis* L.

Discussion

Merriam (2003) compared *C. orbiculatus*, *L. japonica,* and *L. sinense* along railroad and electrical ROW's, finding *C. orbiculatus* occurred least commonly. Our results are consistent with those of Merriam (2003). Within our study *C. orbiculatus* was the second most abundant exotic-invasive species along electrical ROW's . Our results failed to discover statistical differences between the ROW (N or S) or the position (Edge or Interior) concerning the density of *C. orbiculatus* seedlings, which could be attributed to a number of factors. Our sites were selected based on high infestations of *C. orbiculatus,* along forest edges. These edges and canopy openings are densely covered by *C. orbiculatus* and other exotic-invasive shrub species, which may create "stepping stones" for an invasion into the interior of the forest (Goldblum and Beatty 1999). The age of the ROW may also have influenced our results. The ROW was placed on the property in the early 1950's, and nearly 60 years has passed allowing the ROW edges to grow back. Herbicide applications have been applied every ten years along ROW's, creating a continual distinct boundary, between forest edge and ROW's. These age/edge factors can be a contribution to the frequency of *C. orbiculatus* in the interior of the forest.

Merriam (2003) found that *C. orbiculatus* occurrence is low along streams and again our results are consistent. The interior points of the northern transects (200.19 m^2), which ran along Ice's Run Creek, had a lower abundance of *C. orbiculatus* seedling density than interior southern transects (373.56 m^2). The interior, closest to the creek, of these northern transects (200.19 m^2) had a higher abundance of *C. orbiculatus* seedlings compared to the forest edge of northern transects (104.41 m^2).

Matlack (1994) found that most edge oriented species were within 40 m of the forest edge and most were observed on north-south facing slopes. In contrast, Yates et al. (2003) noted that non-native species were found within 20 m of the forest edge. In our study, we established the first 20 m to be the edge and last 20 m to be the interior in a similar approach to the Honu and Gibson (2006) design. Honua and Gibson (2006) found that edge effects take place from 30 m to 50 m into the interior of the forest; they observed canopy openness to be an important microhabitat factor that affected the distribution of exotic-invasive species into the interior of the forest. Our six transects did not observed statistical differences between the side of the ROW (N or S) or the position (Edge or Interior) with respect to *C. orbiculatus* seedling densities. Total shrub crown cover was the only factor we found to be correlated with *C. orbiculatus* seedling densities. In contrast, our results show that as shrub crown cover increases, *C. orbiculatus* seedling densities decrease.

Flory and Clay (2006), Matlack (1994), and Yates et al. (2003) found that edge oriented species correlated closely with amount of light reaching the forest floor. Brothers and Spingarn (1992) speculated that low light is a limiting factor for invasions of exotic-invasive species in closed canopy forest. Matlack (1994) had a partial correlation with *Vitis spp.* and light levels (p = 0.003) show statistical differences. In contrast McNab and

Loftis (2002) found that light is not an important factor affecting the occurrence of *C. orbiculatus*. Similarly, we found no statistical differences in the amount of light reaching the edge of the forest compared to the interior forest ($p = 0.342$). *C. orbiculatus* does not appear to be limited by low light levels, although, it does have higher seedling densities in low light levels, however, low light levels do not appear to promote this species (Table 2.2).

Management Implications

Forest edge effects should also include other forms of disturbance, such as canopy openings. These canopy openings may act as pathways or "stepping stones" for exotic-invasive species into the interior of the forest (Goldblum and Beatty 1999). In contrast, Brothers and Spingarn (1992) found that exotic-invasive species were not more abundant in forest interior gaps created by a disturbance. Our results of *C. orbiculatus* seedling density do not show any correlation with the amount of light reaching the forest floor or with tree canopy crown cover. *C. orbiculatus* is negatively correlated with other exotic-invasive shrubs ($r = -.0689$; $p = 0.013$). *C. orbiculatus* seedlings were abundant in both forest edges and interiors. This suggest that *C. orbiculatus* is an extremely robust exotic-invasive species that can survive in a wide range of microhabitats. This transect study illustrates the abundance and presence of *C. orbiculatus* in timber harvested areas in north central West Virginia. Given the level of forest harvesting in the state over the past several decades, it is likely that forest managers will have to deal with already established invasions in many forest stands. There is very little understanding about the distribution and abundance of exotic-invasive species in West Virginia, since invasion patterns are unpredictable. Given the relationship between shrub cover and *C. orbiculatus* seedling density, managers that can control *C. orbiculatus* seedling densities and establish dense desirable hardwood regeneration will have fewer challenges controlling future infestation.

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CHAPTER 3
Testing efficacy of control Oriental bittersweet in the Appalachian Mountain Region

Introduction

Effective control of woody invasive-exotic vines is an expensive, long-term effort that usually requires a combination of mechanical treatments, targeted herbicide applications, and continuous monitoring. These vines are difficult to manage, since the vine grows into the upper canopy supported on the stems of shrubs and trees. These twining vines can shade, suppress, and ultimately kill native surrounding vegetation.

Exotic-invasive vine control is unique, since large amounts of the vine woody biomass are found in the upper canopy of a forest. Controlling vines from the forest floor still leaves large amounts of the vine woody biomass in the canopy. This left behind vine woody biomass can increase a tree's susceptibility to ice and wind damage (Webster et al. 2006).

One exotic-invasive species that has become a serious threat in eastern hardwood forests is oriental bittersweet (*Celastrus orbiculatus* Thunb.). *C. orbiculatus* is also known as Asiatic bittersweet. *C. orbiculatus* is native to Asia. In its native habitat, it is not a forest species. *C. orbiculatus* is a deciduous woody vine that was first introduced into the United States in 1860.

C. orbiculatus is a nuisance because it can easily overtop native trees and vegetation with rapid growth over stumps, saplings, and mature trees. This twining vine can shade, suppress, and ultimately kill native vegetation. Traits that contribute to *C. orbiculatus* invasiveness include efficient use of minerals and water (Webster et al. 2006), exclusion of other species (Dreyer et al. 1987), mammal dispersal of seeds (Bowers 1993), natural robustness (Dreyer et al. 1987), ability to form a seed bank (Dreyer et al. 1987), and ability to form thickets (Dreyer et al. 1987).

Recommended Control Methods

Recommendations for control of *C. orbiculatus* depends on the extent of invasion, the habitat in which it occurs, the resources available to land management agencies, and to some extent management philosophy. Many sources describing recommendations for controlling *C. orbiculatus* are in the form of information fact sheets and weed control guidebooks, such as, Bergman (1999), Dreyer (1994), Greenbuerg et al. (2001), Hutchinson (1992), Miller (2002), and Southeast Exotic Pest Plant Council Invasive Plant Manual (2003).

Mechanical means are recommended for small populations, in areas where herbicide cannot be used (Southeast Exotic Pest Plant Council Invasive Plant Manual 2003) or if labor resources are readily available (Hutchinson 1992). Mechanical methods include cutting (Southeast Exotic Pest Plant Council Invasive Plant Manual 2003), hand pulling (Hutchinson 1992), and mowing. In order to eliminate *C. orbiculatus*, the vines should be removed from the site once they are cut, mowed, or pulled to avoid re-rooting (Webster et al. 2006). Any portions of the root system not removed will potentially re-sprout. The general inefficiency of mechanical treatments indicates that herbicide may be a necessary part of a control program (Ding et al. 2006, Dreyer 1988, McNab and Meeker 1987, and Southeast Exotic Pest Plant Council Invasive Plant Manual 2003).

In areas of high infestation, cutting and treating the stump with glyphosate or triclopyr amine can kill *C. orbiculatus*. High infestation areas are areas that are densely covered with exotic-invasive vines. These areas cannot be easily treated with mechanical treatments, such as cutting, mowing, or pulling, since it is physically difficult to access these sites using manual methods. These areas are ideally suited for chemical control methods. 2, 4 - D (Hutchinson 1992), glyphosate, or triclopyr (Dreyer 1988) are commonly recommended herbicides for *C. orbiculatus* (Miller 2002, Southeast Exotic Pest Plant Council Invasive Plant Manual 2003, and Webster et al. 2001). Glyphosate is a non-selective herbicide that controls both woody and herbaceous broadleaf plants by inhibiting the shikimic acid pathway, a pathway that manufactures proteins for growth (Cox 1998). Glyphosate is water soluble, while triclopyr has two forms: amine (water soluble) and ester (oil soluble). Glyphosate amine is ideal to use with a surfactant. Surfactants allow for herbicide to adhere to noxious plants and lower the surface tension of water. This will increase plant uptake of the herbicide (Langeland 2003).

Triclopyr is a selective herbicide that controls woody and herbaceous broadleaf plants by mimicking the plant hormones, auxin. Plant auxins control the plant's growth functions. Triclopyr causes the uncontrolled cell division and cell growth of the plant leading to death (Tu et al. 2001). An advantage to using triclopyr, is that it does not kill monocots, such as grasses, sedges, and liliaceous plants. These species will continue to thrive and prevent soils from being completely exposed (Miller 2002). Exposed soil can create an microsite that can be susceptible to invasion by exotic-invasive species. These herbicides can be applied to plants using various methods: foliar, injected, applied to cut stems, and through the bark via oil-based carriers (Langland 2003). These methods are applied depending on local conditions, state of invasive plant development, and management objectives and philosophies.

Foliar applications are generally applied with spray nozzles from aerial or directed spray equipment. Herbicide labels (2009a and 2009b) recommend foliar applications for glyphosate or triclopyr ester a 2 % volume to volume mixture with water. Foliar application should thoroughly wet the foliage and stems, but should not drip off. Hutchinson (1992) found that foliar application of triclopyr effectively "reduce *C. orbiculatus"*.

Cut-stump or basal bark treatments are best for situations where foliage is inaccessible or difficult to treat without incidental damage to associated plants. Cut surface applications target the herbicide being applied to the cambium of a freshly cut surface. Cut surface application is used to treat vines that are growing within or around surrounding vegetation, or growing in the canopy of other tree species. Herbicide labels (Anonymous 2009a and Anonymous 2009b) recommend cut-stump applications of glyphosate or triclopyr with a 25 % volume to volume mixture with water to control *C. orbiculatus.*

Basal bark treatments can be used on stems of vines growing in dense patches or those with their foliage high in the canopy. Triclopyr ester combined with mineral oil or diesel oil can be sprayed directly on stems of undesirable plants. One common basal bark treatment is a 20 % triclopyr in oil to control *C. orbiculatus* (Anonymous 2009b). In basal bark applications, the lower 30 – 50 cm of the vine is sprayed with the oil soluble herbicide. Basal bark treatments can be sprayed with a backpack sprayer, a small spray bottle, or from large skidder-mounted mist blowers for commercial applications in pine plantations for hardwood control. It is practical for all vegetation smaller than 15 cm in diameter, and practical where dead vegetation can be left standing (Langeland 2003).

It is commonly recommended that treatments be applied to exotic-invasive plants prior to their producing fruit (Panda et al. 2007). Minimizing the production of fruits will minimize seed dispersal. In order to minimize damage to surrounding vegetation, timing the herbicide application in early spring, before plant nutrient uptake of native species, or in late fall when most native species are dormant, will selectively target *C. orbiculatus* (Southeast Exotic Pest Plant Council Invasive Plant Manual 2003). For *C. orbiculatus*, however, it is really meaningful at the outset of establishment because once plants are established and have developed into dense infestations, the amount of seed already existing in the local environment can be significant. Ellsworth et al. (2003) found that after two years *C. orbiculatus* seedling emergence from the seed bank averaged 0.9 seedling/m^2 in fifteen plots. Current recommendations for controlling *C. orbiculatus* specify that in order to reduce seed dispersal, herbicide applications should be applied before *C. orbiculatus* produces fruits.

Currently, there are no biological control treatments for *C. orbiculatus* (Dreyer 1994), however, other methods of control include mammal herbivory. Deer browsing appears to have no effect on the species diversity of exotic-invasive plants, but generally can reduce the occurrence *C. orbiculatus* (Bowers 1993). Blossey (1991) and Carpenter and Cappuccion (2005) suggest that herbivore browse can contribute to the control of exotic-invasive species, thus further preventing the spread. Exotic-invasive species tend to be more tolerant of herbivory than native plant species. In greenhouse studies with simulated herbivory (clippings), *C. orbiculatus* had higher growth rates after damage (Aston and Lerdau 2008).

The objective of this project is to further document the efficacy of the herbicide triclopyr and glyphosate in controlling *C. orbiculatus*. Basal bark, cut-stump, mechanical cut, and deer fencing were used to test the *C. orbiculatus* vines ability to re-sprout, and evaluate deer browse pressure. Little research has been formalized in peer reviewed journals. These peer-reviewed journals are considered to be 'grey literature'. Grey literature is literature that is not published by a commercial publisher, such as, technical reports, conference proceeding, and academic institution literature (ACRL 2008). Much of what is available concerning *C. orbiculatus* is found in outreach information, such as, Hutchinson (1992), Dreyer (1994), Langland (2003), Miller (2002), and Southeast exotic pest plant council invasive plant manual (2003).

Methods

Site Selection and History

The study was set up on a private forest property in Marion County, West Virginia (39º 45´ N, 80º 16´ W). The property is located north of Fairmont State College and south of US Route 250, near the old Fairmont State College soccer field (Figure 3.1).

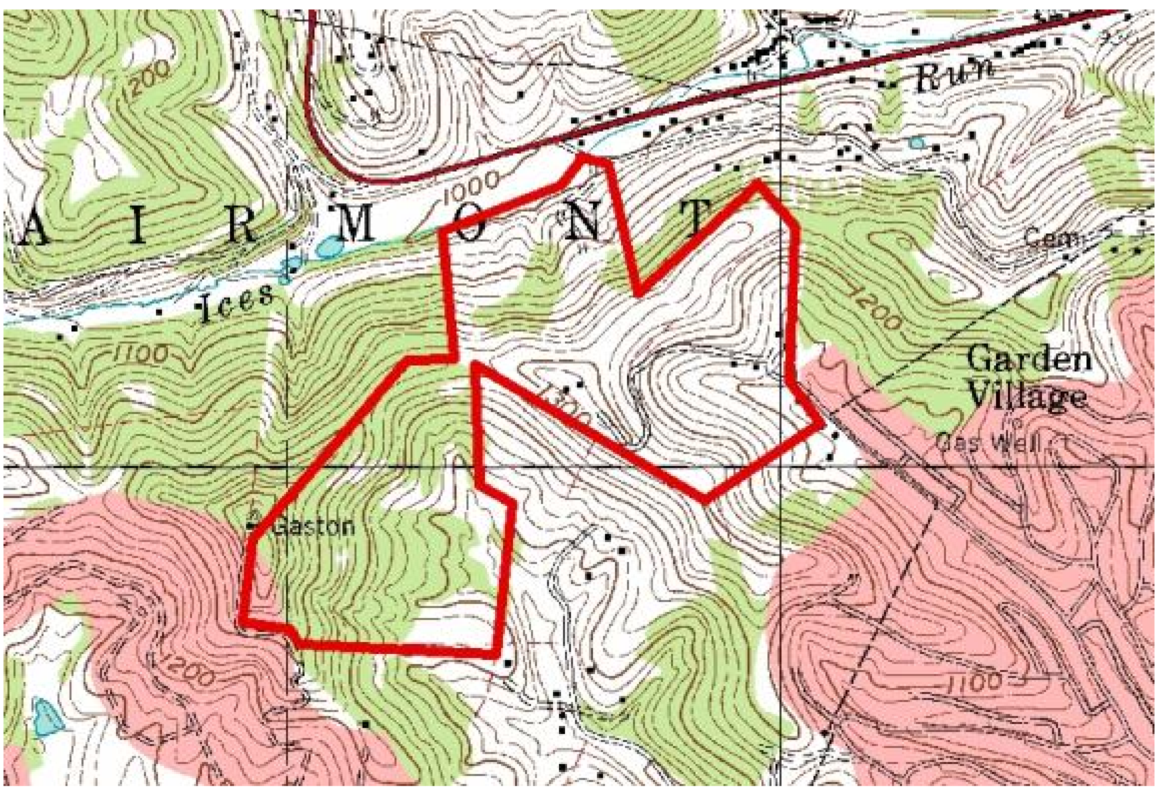

Figure 3.1. Study site located in Fairmont, West Virginia.

The property is approximately 35 ha and has an elevation of 457.2 m above mean sea level. The average temperature is 11.2 ºC and the average precipitation is 99 cm (USDA 2008). The slopes are generally north or east-southeast facing. The major forest cover is composed of two types; cove hardwoods and yellow poplar-red maple. Based on 40, 0.02 ha plots systematically distributed on a 92 m X 92 m spacing, the most abundant overstory species (trees $\geq$ 10 cm diameter at breast height (DBH)) include northern red oak (*Quercus rubra* L.), red maple (*Acer rubrum* L.), yellow-poplar (*Liriodendron tulipifera* L.), and elm (*Ulmus spp*.) (Figure 3.2 and Table 3.1). The most abundant dead standing trees were black cherry (*Prunus serotina* Ehrh.), black walnut (*Juglans nigra* L.), and elm (*Ulmus sp.* L.).

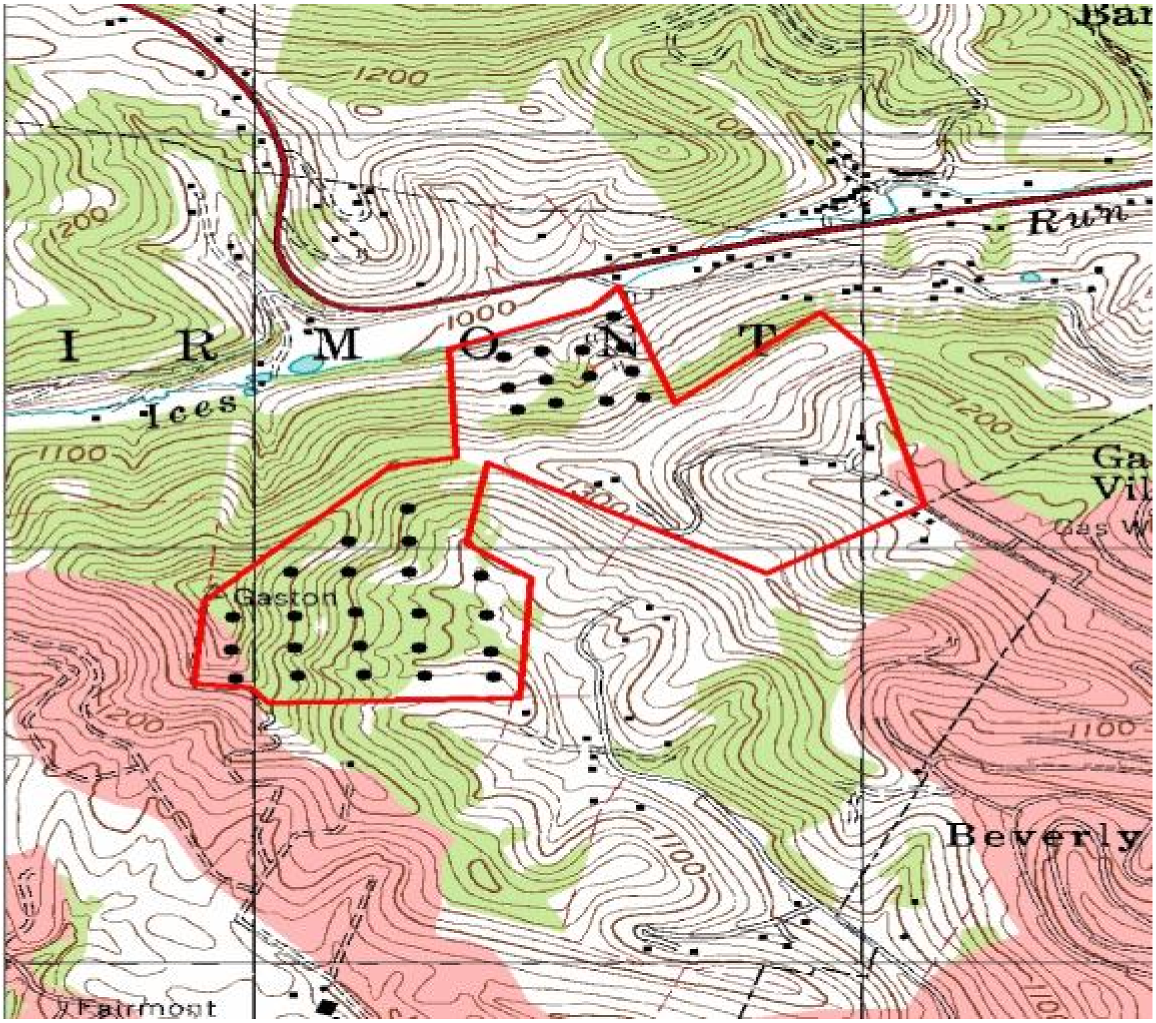

Figure 3.2. The 40 systematic points placed on the Study site to describe surrounding habitats.

Table 3.1 Mean overstory composition values (IV = 0.5*(relative density + relative basal area)) of live tree species.

Species	Relative Basal Area %	Relative Species Density%	Importance Value (IV)
Quercus rubra	36.15	20.49	22.7
Acer rubrum	9.96	18.94	21.65
Liriodendron tulipifera	17.36	16.99	18.15
Ulmus spp.	18.75	3.44	14.35
Prunus serotina	7.53	0.8	8.05
Fraxinus spp.	3.44	20.11	5.42
Sassafras albidum	1	0.62	2.12
Ulmus americana	0.8	9.96	2.02
Quercus alba	1.95	1.95	1.23
Crataegus spp.	1.27	0.45	1.21
Caya ovata	0.45	0.28	1.03
Juglans nigra	0.42	7.53	0.67
Robinia pseudoacacia	0.28	18.75	0.49
Carya glabra	0.49	0.1	0.48
Ulmus rubra	0.1	0.05	0.28
Acer saccharum	0.05	0.03	0.14
Total	100	100	100

Forest soils on the property are comprised of Westmoreland silt loam (63 %), Culleoka - Westmoreland silt loams (30 %), and Clarksburg silt loam (7 %). Westmoreland soils are generally found on uplands and are deep well-drained soils with a 5.6 pH. These soils are loam – silty loam clays. Culleoka - Westmoreland soils are not as deep as Westmoreland soils and found on uplands with a 5.6 pH. These soils are loam – silty loam clays. Lastly, Clarksburg soils are generally deep soils found on foot slopes and are well drained with a pH of 5.8. These soils are silt loam and are heavily influenced by colluviation (NRCS 2008, USDA 1982).

A dot grid was used with aerial photos dating back to 1938 to estimate changes in tree and shrub cover. Photos for 1938 and 1967 were taken in October, the 1953 photos were taken in May, and the 1981 and 2007 photos were taken in November. Due to the low resolution of these photos, particularly the earlier photos, land cover percents may not be fully accurate, since some were taken in late fall/early winter. In 1938, woody plants covered 83 percent of the study site and most of the woody vegetation is present on the southern side of the property. Evidence on the 1952 aerial photos suggests that a timber harvest or other clearing operation took place sometime in the early 1950's (18 % woody cover). Also, in the 1952 photos, a power line right-of-way (ROW) is present. In 1967, the woody vegetation cover was 30 percent, and most of the woody vegetation is above the southern side of the ROW. By 1981, forest cover had grown to 55 percent and woody vegetation was present on both sides of the ROW. As of 2007, woody vegetation cover is 83 percent. Field observations indicate that this forest is an old growth forest with large standing alive and dead trees, which is represented by the clearing operations in the 1952 aerial photos.

As mentioned above, in 1951, a Chesapeake Emerson ROW was established on the property. The ROW runs-east west along the north side of the property, near route 250. The ROW is approximately 26 m wide. Currently, the Allegheny Power Company maintains the ROW. Only trees that are considered dangerous or will be potentially dangerous to the ROW are cut every four to eight years. The ROW is mowed and treated with herbicides every ten years regardless of condition (*Personal communication*, D. Delaney Allegheny Power Company 2008).

Forest management operations over time have included grapevine removal to reduce damage to regeneration in 1994, 1995, 1997, and 2001 (Wildman 2001). The property had 108,361 board feet in international 1/4 Inch scale of timber harvested during the dry season (winter months) of 2001. The forester for the research property administered a timber harvest in 2001. During the timber cruise, the forester noticed an unidentified vine on neighboring properties that was later identified to be *C. orbiculatus (Personal communication*, J. Wildman, WV Division of Forestry; 2008).

Herbicide Treatments

Forty vines less than 5 cm in diameter were selected for use in the control methods treatments. Diameter of the vines were taken at 10 cm from the base of each stem. Each of the forty treatment vines were marked with a corresponding number 1 – 40, and were randomly assigned in one of the four treatments.

Glyphosate and triclopyr were the herbicides selected for this experiment because of the availability of these chemicals, their frequent use in forestry operations, and recommended uses for control of *C. orbiculatus*. These are commonly used in forestry to control woody plants along rights-of-way (ROW), and in forest settings (Heiligmann

1997). Four treatments were randomly applied to forty individual *C. orbiculatus* vines (Figure 3.3). These treatments were:

- Mechanical Cut
    - In this treatment vines were cut 10 cm from the ground and no herbicides were applied. This treatment, in combination with the following cut-fence treatment was designed to evaluate deer pressure. This treatment had stems exposed to deer pressure. Deer browse was noted during the growing season as broken tips and missing vegetation on new sprouts.
- Mechanical Cut-Fence
    - As in the mechanical cut treatment, stems in this treatment were cut 10 cm from the ground, but these were protected by a woven-wire fence around the individual vine. The fence was 1.2 m high and provided a 0.61 m buffer on either side of the vine to prevent deer browsing. This treatment was used to assess the effects of a mechanical cut and application to compare the effects of deer browse on *C. orbiculatus*.
- Basal Bark
    - Vines were sprayed with Garlon® 4 (triclopyr ester) herbicide in oil around the lower 30 cm of the vine. The basal bark mixture was 20 % Garlon® 4 (20 ml of Garlon® 4 and 80 ml of water).
- Cut-stump
    - Cut-stump vines were cut at 10 cm above the ground and two squirts of 50 % Accord® (Glyphosate) were applied to the stump of the vine. Accord®

(Glyphosate) was mixed in a spray bottle with a 1:1 ratio of herbicide: water.

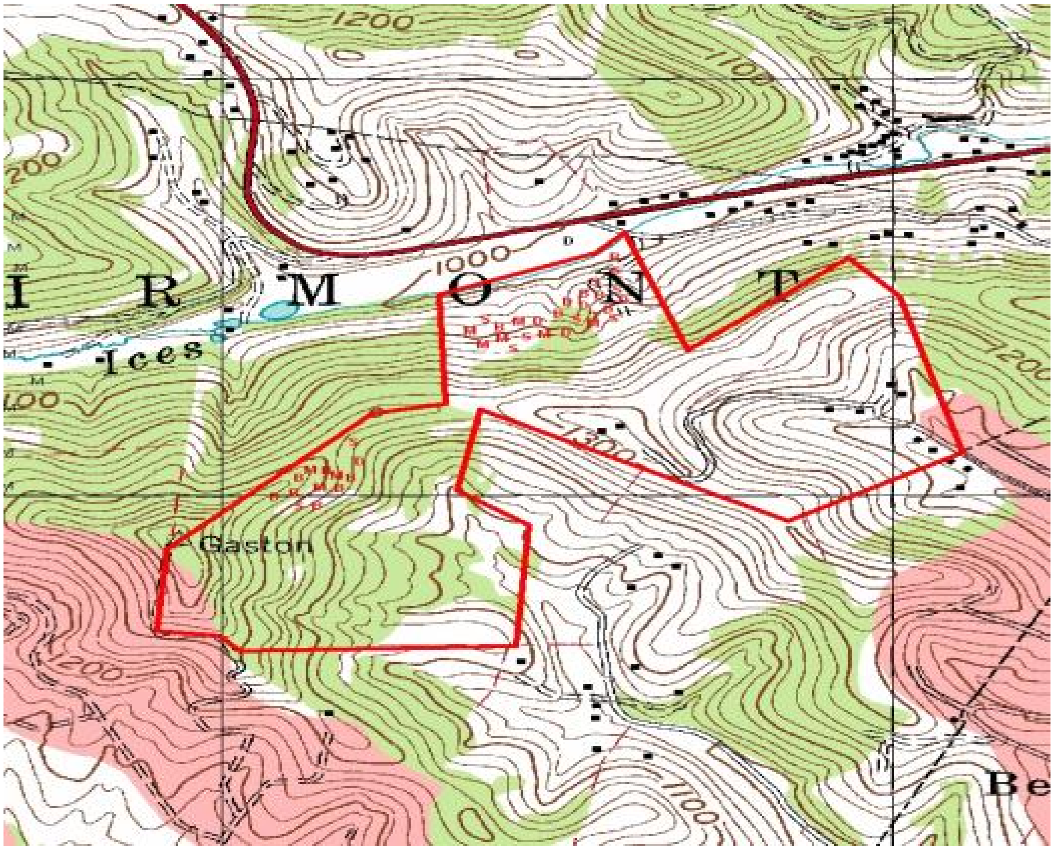

Figure 3.3. Study site map with selected of *C. orbiculatus* vines for each treatment. Note: B = Basal Bark, D = Mechanical Cut-Fence, M = Mechanical Cut, and S = Cut-stump

To assess the amount of spray per squirt, one liter spray bottles were calibrated in the lab. Six squirts were measured and averaged in the laboratory with bottles being sprayed only once into a 10 ml graduated cylinder. Each spray delivers approximately 1.3 ml.

During January 2008, the 40 vines were identified, mapped, and measured. Fencing was set up in January 2008. Herbicide treatments were applied in July 2008. Site visits were made on bi-weekly basis after all treatments were applied to monitor effects. The number of stump sprouts, root sprouts, length of longest stump sprout, and length of longest root sprouts were measured on each occasion. In January 2009, *C. orbiculatus* stumps were dug up to confirm whether sprouts were of stump or root origin. Stump sprouts were identified as vegetative growth originating directly from the stump of the vine. Root sprouts were distinguished as vegetative growth originating from the soil adjacent to the cut or otherwise treated stems (Figure 3.4).

Figure 3.4. Identification of a stump sprout on *C. orbiculatus.*

Analytical methods

Analysis of Variance (ANOVA) was used to compare the number and length of stump and root sprouts within each treatment. The ANOVA test were performed using SAS 9.1 software (SAS Institute, 2003) using the General Linear Model (GLM) procedure. The significance level for the test was set at alpha = 0.05.

Results

Sprouting potential of C. orbiculatus

Sixteen weeks following treatments, *C. orbiculatus* stems treated with a basal bark application of triclopyr ester had no stump or root sprouts. Sprouts were not observed on these stems at any time during the 16-week period. In contrast, the cut-stump, cut-fence, and mechanical cut treatments had 30, 50, and 80 percent, respectively, sprouts from either roots or stumps recorded at least once during the observation period. Many of the sprouts that appeared following treatments, however, died during the 16-week observation period. Most sprouts originated at the stump, although the proportions of individuals with sprouts varied by treatment. Stems in the mechanical cut treatment had the highest proportion of sprouts originating only from the stump (50 %). An additional 30 % of the mechanical-cut treatment stems sprouted from both the stump and roots (Table 3.2).

Table 3.2. Proportion of *C. orbiculatus* stems with stump sprouts or both stump and root sprouts observed at some point during the 16-week observation period.

Treatment	Stump only (%)	Stump and root (%)	Total sprouts (%)
Basal Bark	0	0	0
Cut fence	30	20	50
Cut Stump	20	10	30
Mech Cut	50	30	80

The number of sprouts per stem are not statistically different between treatments ($p = 0.15$). The maximum number of sprouts for cut-fence, cut-stump, and mechanical cut are

9, 8, and 20, respectively. Length of longest sprouts was statistically different between treatments (p = 0.01). The maximum length of sprouts for cut-fence, cut-stump, and mechanical cut are 152 cm, 40 cm, and 90 cm, respectively. Least significant difference tests (LSD) for maximum number of sprouts and lengths for cut-fence and cut-stump treatments are statistically different. Vines in the cut-fence treatment have the longest average sprouts, while the smallest average sprouts are in the cut-stump treatment. Vines in the cut-fence treatment had the second largest number of sprouts, while cut-stump had the fewest sprouts.

Vines in the cut-fence treatment had the average longest sprout length (115.87 cm), closely followed by mechanical cut treatment (99.03 cm). Vines in the cut-stump treatment had the average shortest sprout lengths (27.75 cm). Similarly, average length of stump and root sprouts were found in the cut-stump and mechanical cut treatments. Protection from deer browse was represented by longer root sprouts in the cut-fence treatments (Table 3.3).

Table 3.3. Mean length of surviving *C. orbiculatus* sprouts after sixteen weeks of observation following treatments in mixed deciduous forest in north central West Virginia. Average values with different letters within columns are statistically different (α=0.05).

Treatment	Stump Sprout (cm)	Root Sprout (cm)	Combined Sprouts (cm)
Basal Bark	0.00b	0.00b	0.00b
Cut Fence	30.27a	85.60a	56.62a
Cut Stump	11.75b	10.00b	11.50b
Mech Cut	42.59a	56.44a	45.63a

Fate of *C. orbiculatus* sprouts through time

The largest number of stump sprouts came from mechanical cut treatments and the greatest number ofroot sprouts came from cut-fence treatments. These sprouts were present throughout the observation period. The greatest number of sprouts that sprouted and died throughout the observation period was found in mechanical cut treatments. Within treatments, stump sprouts are in greater abundance than root sprouts (Table 3.4).

Table 3.4. Number of *C. orbiculatus* stems sprouting following mechanical and chemical control treatments. (Maximum number of sprouts p = 0.15)

Treatment	Never sprouted	Sprouted and died	Sprouted and lived	Total sprouted
		------*Stump Sprouts*------		
Basal Bark	10	0	0	0
Cut-Fence	5	2	3	5
Cut Stump	7	2	1	3
Mechanical Cut	2	4	4	8
		------*Root Sprouts*------		
Basal Bark	10	0	0	0
Cut-Fence	8	0	3	3
Cut Stump	9	1	0	1
Mechanical Cut	7	0	2	2
		-----*Total*-----		
Basal Bark	10	0	0	0
Cut-Fence	8	2	3	5
Cut Stump	9	2	1	3
Mechanical Cut	7	4	6	8

Figure 3.5. ***C. orbiculatus*** **vine outside of deer fence missing leaves and terminal bud broken off.**

In the field, we observed evidence that indicate that vines of *C. orbiculatus* were stripped of leaves and terminal bud was broken off if the sprouts are not protected within the deer fence (Figure 3.5). Week ten was the first week that observed deer browse. Mechanical cut had 4 vines browsed, cut fence had 2 vines, and cut stump had 1 vine (Table 3.5).

Table 3.5. The number of stems with field observation of deer browse at week ten of monitoring.

Treatment	Stump Sprouts	Root Sprouts	Total
Basal Bark	0	0	0
Cut Fence	2	0	2
Cut Stump	0	1	1
Mech Cut	4	0	4

Discussion

Miller (2002) states that triclopyr or glyphosate as basal bark in 20 % solution can control *C. orbiculatus.* Similarly, in our study, 20 % Garlon® 4 (Triclopyr) proved to be 100% effective in killing *C. orbiculatus.* Similarly, this treatment did not have any stump or root sprouts during the monitoring period.

In greenhouse studies with simulated herbivory (clippings), *C. orbiculatus* had higher growth rate after damage (Aston and Lerdau 2008). Ashton and Lerdau (2008) found that *C. orbiculatus* may be more tolerant of herbivory, since mechanical damage stimulates the vines growth response causing it to produce more stump and root sprouts. In our study, most of the sprouts were produced by cut-fence and mechanical cut treatments. The number of combined stump and root sprouts were statistically different in cut-fence treatments and were also statically different from cut-stump. Root sprouts in the cut-fence treatments were well protected from deer browse, since most of the root sprouts survived through the monitoring period.

Hutchinson (1992) found that cut-stump and mechanical removal application with glyphosate or triclopyr was able to control *C. orbiculatus,* but provided no data on how effective. Miller (2002) states that cut-stump application of glyphosate or triclopyr can control *C. orbiculatus.* In our study, cut-stump had 30 % to sprout, but only 10 % remained throughout the entire monitoring period, and had fewer total sprouts compared to other treatments. The number of sprouts and lengths of cut-stump sprouts were the smallest among all treatments, indicating that 50 % Accord® (Glyphosate) was effective in reducing the length and number of sprouts.

Dreyer (1994) and Dreyer et al. (1987) found that *C. orbiculatus* produces root suckers after the main vine is damaged or cut, especially with low amounts of mowing; that is, two to three times a year. In contrast, if the vine is continually mowed enough to exhaust the root storage, this mechanical method can control *C. orbiculatus.* In our study, the largest number of sprouts was produced by mechanical cut and cut-fence treatments. We concur that *C. orbiculatus* produces an abundant number of root sprouts, since cut-fence and mechanical cut treatments only had root sprouts present at the end of the monitoring period.

Management Implications

The only treatment to prove 100 % effective in controlling *C. orbiculatus* stump and root sprouts was basal bark treatments of 20 % Garlon® 4 (Triclopyr). However, none of the treatments were significantly different, but sprout lengths were significantly different. This indicated that sprout lengths are inhibited by herbicide and mechanical removal treatments. Mechanical treatments stimulates stump and root sprouts of *C. orbiculatus*, but the majority of the vines in mechanical removal treatments (cut-fence, cut-stump, and mechanical cut) did not sprouts back; of the few that did spout in mechanical removal methods, 67 % lived though the monitoring period. For maximum control of *C.*

orbiculatus, it is recommended that mechanical removal methods, herbicide applications, and continual monitoring all be used.

Rossell et al. (2007) found that deer browsing reduced the frequency of *C. orbiculatus* and reduced the spread into the interiors of the forest when it occurred in low patches. Our research suggests that deer browse may be present, since cut-fence treatments produced the maximum lengths of sprouts and 40 % of sprouts were present throughout the entire monitoring period.

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