The Mapping of Nonnative Invasive Plants Leads to an Herbicide Trial of Autumn Olive in Lake Raleigh Woods Nature Preserve

By

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Abstract


A survey of nonnative invasive plants was conducted within the boundary of Lake Raleigh Woods Nature Preserve, a nature preserve on North Carolina State University’s Centennial Campus situated West of Lake Raleigh. This survey revealed that there was an abundance of undesired plants existing within the nature preserve. There were roughly ten acres of autumn olive (*Elaeagnus umbellata*) growing in the heart of Lake Raleigh Woods. Without intervention, this nonnative invasive plant could continue to spread and out-compete desired native plant species. To inform management practices, an herbicide trial was initiated to study the effectiveness of different herbicide and application method combinations for controlling autumn olive. The study was a 3 x 4 factorial design with three application methods and four herbicides. Herbicide treatments were: glyphosate, imazapyr, triclopyr and a mixture containing aminocyclopyrachlor, imazapyr, and metsulfuron. Application methods were: cut stump application, foliar application, and basal bark application. A ‘cultural control’ and nontreated check was included for comparison. Treatments were arranged in a randomized complete block design with four replications. Individual experimental units (plots) consist of three autumn olive subsamples. Visual ratings for control and stem count data was collected for statistical analysis. The cut stump treatment was the most effective application method across all herbicides for control of autumn olive, while triclopyr was the most effective herbicide across all application methods. The trial was repeated over two years with nearly the same results.
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Chapter 1: Mapping Nonnative Invasive Plants in Lake Raleigh Woods

Introduction

Lake Raleigh Woods is an area of approximately 96 acres situated West of Lake Raleigh on North Carolina State University’s Centennial Campus. Over the past six years there has been a push to preserve the land as a nature preserve and to maintain the property as a teaching resource. During the Fall of 2010, Dr. Gary Blank’s FOR 784 Environmental Impact Assessment class created a management plan to help guide decision making for Lake Raleigh Woods. I volunteered to conduct a mapping project to assess the occurrence of nonnative invasive plants within Lake Raleigh Woods. It was assumed that Lake Raleigh Woods would have some infestation of nonnative invasive plants considering the wooded area was surrounded by an urban environment. Nonnative Invasive plant species were mapped using a hand held Trimble GPS unit loaded with data dictionary created in Trimble’s GPS Pathfinder Office. The results of the survey showed that Lake Raleigh Woods did indeed have significant infestations of nonnative invasive plants.

Sources of Spatial Information Used

Most of the spatial information used as a background for this project was gathered from the Wake County Governments GIS website (http://www.wakegov.com/gis/download_data.htm). The following is a list of information that was downloaded from the Wake GIS website:

- City of Raleigh 2009 Orthophotography tiles 0793_009, 010, 011, 013, 014, 015, 017, 018, 019
• Raleigh Hydrology 2007
• Topo: Raleigh ETJ (2009) tile T07-0793

The Digital Elevation Model and Hillshade rasters used in the project were downloaded from NC Department of Transportation’s GIS website (http://www.ncdot.org/it/gis/DataDistribution/ContourElevationData/contourDataDownload.html). The boundary and trail shape files for LRW were created and donated, respectively, by fellow graduate students Charles Rudder and Christopher Kollar.

The orthophotography tiles were converted into a mosaic using the ARCGIS tool Mosaic (management), which can be found by showing the Arctoolbox Window and searching in the index for mosaic. After using the mosaic tool in ArcMap, the image had to be reduced to focus in on the area of interest. The resulting mosaic was used when conducting all land cover type classifications and when analyzing Lake Raleigh Woods in relation to the collected GPS data on invasive plant species.

Methods

A Trimble GeoExplorer, which is a mapping grade, handheld GPS unit, was used to map points, lines, and polygons around occurrences of invasive plant species within Lake Raleigh Woods. Before starting to collect data in Lake Raleigh Woods, a data dictionary was created to ensure that the points, lines, and polygons captured had relevant attribute information. Attribute information added to the dictionary included species type (tree/shrub/herb), species origin (US/foreign), maximum height, percent density, species name, and other comments. The data dictionary was created in GPS Pathfinder Office and had the extension *.dbf. It was then loaded onto the rover’s hard drive where it could be used in conjunction with data files, which ensured
that every time a new file was created for the invasive plant survey the data dictionary was utilized. A boundary shapefile for LRWs was also installed to ensure that all measurements were taken within, or in close proximity to, the boundaries of LRWs. The data was gathered over three visits to LRWs with a total approximate time of 10 hours in the field.

While collecting points, lines, and polygons on the rover, it was ensured that each point logged at least 30 positions at 1-second intervals. An average of these positions was taken in order to increase accuracy of the data collection. When logging vertices for line and polygon features, it was ensured that each vertex logged 20 to 30 positions. When the number of satellites available went below 4, the triangulation was lost and it was not possible to log points.

Another feature that was enabled in the GPS was SBAS Real-time correction. This ensured that the rover was constantly receiving data from satellites and correcting data as it was logged.

The areas targeted during the search were the boundaries of LRWs, three lines through the interior of LRWs, and a majority of the trails running throughout LRWs. The entire boundary was covered except for the area of LRWs extending east of the new Chancellor’s Residence and a section of the northern boundary. While collecting data, a bearing compass was used to walk lines through the forest. The first line walked through the interior of LRWs was walked along a bearing of south 5° west and began from the north, at the narrowest point of the property, at two chains (132 ft) east of the western boundary. The second line was walked along a bearing of north 5° east and began from the southern boundary line at four chains (264 ft) east of the western boundary. The third line was walked along a bearing of south 5° west and began from the north, just below the narrowest point in the property, at approximately 9 chains (594 ft) east of the western boundary. Lines were not walked through the northernmost point of the property,
due to its relatively small size and ease of visibility, but enough time was spent searching that area to get an idea of the invasive infestations. Many of the trails within the border of LRWs were surveyed for invasive plant species with particular attention paid to the trails running near the boundary of the nature preserve.

All invasive plants easily distinguished within line-of-sight near the paths walked during the survey were mapped as points, lines, or polygons. Points were taken at locations where there were between 1 to 30 invasive plants within a 30 foot radius. Lines were taken when the invasive plants were distributed in a linear fashion, such as the lespedeza (*Lespedeza cuneata*) and microstegium (*Microstegium viminimum*) that hugged the Southern border of Lake Raleigh Woods. Polygons were taken when there were greater than 30 invasive plant species clumped closely together and could easily be distinguished as being the dominant plant species covering the ground or understory.

In the Northern portion of LRWs, only the areas with the thickest portions of invasive plants were mapped, but it appeared that Chinese privet (*Ligustrum sinense*) and microstegium (*Microstegium vimineum*) was distributed throughout the entire floodplain area in varying degrees of density and height. Also in the Northern portion of LRWs, there was a creek that was not crossed due to its depth and a lack of obvious crossings. On the other side of this creek, there was a fairly thick stand of Chinese privet directly north of the large privet stand shown in the invasive species map (See appendix II) and what appeared to be dead clumps of microstegium blanketing the ground under the Chinese privet.

After collecting data with the rover, the program GPS Pathfinder Office was used on a PC to extract the data from the rover. Next the data was differentially corrected using the NC
CORS Raleigh base station. This corrected file was then exported to ArcMap where it was given projection information State Plane NAD 1983 North Carolina Feet. It was then possible to see invasive species data in its own ArcMap shapefile in relation to the Lake Raleigh Woods boundary shapefile and other useful data files.

**Results**

There were 85 points, 10 lines, and 4 polygons collected during the invasive plant survey. Below is a table describing the occurrences of the most prevalent invasive plant species observed during the survey:

<table>
<thead>
<tr>
<th></th>
<th><em>Elaeagnus umbellata</em></th>
<th><em>Ligustrum sinense</em></th>
<th><em>Microstegium viminimum</em></th>
<th><em>Lespedeza cuneata</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Points</td>
<td>67</td>
<td>12</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Trails</td>
<td>2</td>
<td>0</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Polygons</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Autumn olive (*Elaeagnus umbellata*) was by far the most prevalent nonnative invasive plant species observed in LRWs. A majority of the points and polygons taken were of autumn olive with 67 points, and 3 polygons being attributed to this plant. The total area covered by autumn olive polygons is a little more than 10 acres. The second most observed invasive plant was microstegium followed closely by Chinese privet. There was a 1.5 acre polygon of dense privet sheltering a ground completely covered by microstegium in the Northern flood plain portion of Lake Raleigh Woods with an unmapped area of similar size just north of the creek. Other species were also observed while conducting the survey but at much lower rates of occurrence than the invasive plants listed in Table 1. A list of these nonnative plants can be found in Appendix I.

There appeared to be several areas within Lake Raleigh Woods that had significant
infestations of nonnative invasive plants. The boundary area along Centennial Campus Drive had infestations of lespedeza, which was somewhat expected due to the occurrence of high light and disturbance. The Northern floodplain area of Lake Raleigh Woods was also highly infested with nonnative invasive plants. The problem plants in the floodplain were Chinese privet and microstegium. Chinese privet and microstegium occur quite frequently in the flood plains of Wake County and it is not very surprising that they also occurred in the flood plains of Lake Raleigh Woods. An unexpected find was the dense infestation of autumn olive in the heart of Lake Raleigh Woods. Autumn olive was found in a nearly 10 acre patch surrounding two of the interior intermittent stream beds that empty into Lake Raleigh (See Map 1). The autumn olive appeared to be most dense on gradual slopes (slopes of approximately 10-30°). It thinned out in the flat valleys of the stream beds, on the flat upland areas, and on very steep slopes.

It is likely that the nonnative invasive plant lists included in this study are not comprehensive. The data collection design could also be refined for future studies. One suggestion is to survey at different times throughout the year to get a more complete picture of the nonnative plants present in Lake Raleigh Woods.

**Conclusions**

Lake Raleigh Woods is heavily compromised by large populations of nonnative invasive plants. The survey of invasive plants revealed that there are over ten acres of dense autumn olive thickets in the heart of LRWs, at least 1.5 acres of dense Chinese privet and microstegium in the northern floodplain of LRWs, and a line of lespedeza mixed with microstegium along most of the southern border of LRWs. If Lake Raleigh Woods is intended to be used as a nature preserve and as a school teaching resource, there could be some merit in controlling the nonnative
invasive plant populations in the forest. The nonnative invasive plant populations can also provide an excellent opportunity for education. For example, students could conduct trials and experiments to determine optimal methods for control of undesired species.
Appendix I: Maps

Map 1: Displays Lake Raleigh Woods with an aerial photograph overlay.
Map 2: Displays Lake Raleigh Woods boundary on top of LIDAR data converted into a digital elevation model raster and a hillshade raster to highlight the topography within Lake Raleigh Woods.
Map 3: This map displays the extensive trail system that lies within Lake Raleigh Woods.
Map 4: This map displays the locations of nonnative plants located during the plant survey. The nonnative plants are mapped as points, lines, and polygons.
Appendix II: List of Nonnative Plant species Identified:

1. Lespedeza cuneata (lespedeza)
2. Elaeagnus umballata Thunbar. (autumn olive)
3. Pyrus calleryana (bradford pear)
4. Elaeagnus pungens (silverthorn)
5. Microstegium vimineum (microstegium, Japanese stiltgrass)
6. Ligustrum sinense (Chinese privet)
7. Nandina domestica (sacred bamboo, nandina)
8. Cortaderia selloana (true pampas grass)
Chapter II: Literature Review of Nonnative Invasive Species and Autumn Olive

Introduction to Nonnative Invasive Plants (NNIP)

As humans have spread across the globe, they, both wittingly and unwittingly, brought along a variety of passengers from nearly all kingdoms of life. Some of these passengers have been beneficial to humans while others have proven to be quite disastrous. All passengers have impacted the ecosystems they encountered to varying degrees. Several terms are available to describe these alien life forms, but for the purposes of this paper nonnative species will be used to describe all alien life forms that are introduced, intentionally or unintentionally, into a particular ecosystem. Nonnative invasive species (NNIS) shall be used to describe the more harmful nonnative species that have, or potentially will have, negative impacts on human economies and ecologies (Executive Order No. 13112, 1999).

Between 1906 and 1991, it is estimated that 79, only 14%, of nonnative species found in the U.S. resulted in $97 billion (U.S. dollars) lost to damages and control efforts. The losses are likely much higher but incomplete information concerning the remaining 86% of nonnative species doesn’t allow for accurate loss predictions (United States Congress Office of Technology Assessment, 1993). Pimentel, Morrison, and Zuniga (2005) estimated that there were approximately 50,000 nonnative species residing in the United States and that the small number of invasive ones cost the U.S. roughly $120 billion per year. Some nonnative species benefit humans by providing food crops and livestock, while the more aggressive species (e.g. kudzu (Pueraria montana var. lobata) cause wide-ranging problems to many facets of human interest, including forestry, agriculture and biodiversity (Pimentel et al. 2005).
Nonnative invasive species have had disastrous effects on biodiversity. Freeman et al. (2009) point out that invasive species “are the second leading cause of species extinctions after habitat loss”. Combined with habitat fragmentation and loss, invasive species are depleting the economic and aesthetic value of undeveloped open spaces throughout the United States. The ability of kudzu to completely blanket a landscape and smother the life out of towering trees provides a striking example of the destructive powers of invasive species. In response to the damaging effects of NNIS, the United States has created laws and tasked government agencies with finding solutions to the problems posed by the NNIS.

The United States government imposed the first law concerning invasive species management in 1912 with the Plant Quarantine Act (7 USC §§ 151-167). The Plant Quarantine Act authorized the U.S. Department of Agriculture (USDA) to monitor the movement of plants into and within the United States, in hopes that the USDA would limit or control the spread of harmful species. Since 1912, many other laws have been passed in response to the threat of invasive species. One of the latest federal laws passed concerning invasive species is the Noxious Weed Control and Eradication Act of 2004 (Public Law 108-412). This law allows the Secretary of Agriculture to create a grant program for entities, either governmental or private, who are attempting to control “noxious weeds” (Freeman, Albritton, Jose, and Alavalapati, 2009). Not only have laws been passed, but governmental agencies have been formed with the specific purpose of finding solutions to NNIS.

The Animal and Plant Health Inspection Service (APHIS), a branch of the USDA, was created in 1972 and has provisions outlining duties for the agency to deal with NNIS before and after they enter the United States. The introduction from APHIS’s Strategic Plan for 2007-2012 notes the following:
APHIS guards against the introduction, reemergence or spread of animal and plant pests and diseases that could limit production and/or damage export markets. As part of this protection focus, APHIS monitors for and responds to emergencies of varying types and scopes (APHIS, 2007).

The excerpt above highlights a commitment from the government to fighting and controlling the spread of harmful alien pests and diseases. APHIS also incorporates the National Environmental Policy Act of 1969 (Public Law 91-190, 42 U.S.C. 4321-4347) into their operations against NNIS through conducting environmental assessments on nonnative species before allowing them to be approved for entry into the United States.

Losses attributed to Nonnative invasive plants (NNIP) account for roughly 29% of the total costs that the United States loses each year to NNIS (Pimentel et al., 2005). This equals an astounding $35 billion a year going towards NNIP. Nonnative invasive plants are generally described as nonnative plants that have adverse impacts in a particular ecosystem by outcompeting native plants and altering the original makeup of the affected ecosystem (Moser et al., 2009; Dyer and Cowell, 2009). Nonnative invasive plants are capable of infesting disturbed areas swiftly, spreading to new sites, and being extremely difficult to remove once introduced (Dyer and Cowell, 2009).

While eradication of the worst NNIP is highly unlikely (Jenkins and Johnson, 2009), it is still important to take steps towards understanding the problems posed by specific invasive plants. There are numerous NNIP currently invading our forests. Moving forward it will be important to single out the most problematic and invasive pests and focus resources accordingly. In our region of North Carolina, a list of the worst forest pests would include invasive plants such as *Ligustrum sinense*, *Lonicera japonica*, and *Microstegium vimineum*. Another plant of
particular interest is *Elaeagnus umbellata* Thunb (autumn olive). This is a pest that appears to be well established in many of the forests in Wake County, North Carolina. A roughly ten acre patch was discovered in the heart of Lake Raleigh Woods Nature Preserve on North Carolina State University’s Centennial Campus. This invader provides a good choice for the focus of resources. Although it is highly invasive, it doesn’t produce a permanent seed bank and is fairly susceptible to control from herbicides (Kuhns, 1986).

**Autumn Olive Biology and Habit**

Native to eastern Asia, autumn olive is a tardily deciduous shrub that can grow up to 20 feet in height and is capable of forming dense stands on a wide variety of soil types, often favoring sites of disturbance and high light such as open fields, forest edges, or riparian gravel bars (Kohri, 2008). Autumn olive reproduces through the prolific production of tasty red drupes. This plant is capable of producing over 10,000 fruits in a single year (Kohri et al, 2002), and they are highly favored by a variety of wildlife (Engle, 1962; Fowler et al., 1982; and Kohri et al., 2002). Some researchers place the number of seeds produced by a single plant annually to be between 20,000 and 54,000 (Sather and Eckardt, 1987).

Autumn olive has many adaptations that assist in its ability to invade and take over disturbed sites, such as prolific fruiting, avian seed dispersal, tolerance for a broad range of soil types, ability to tolerate shaded conditions once established, and ability to fix nitrogen (Sather and Eckardt, 1987; Fowler and Fowler, 1987; and Fowler, Fowler, and Thomas, 1982). According to Kohri et al. (2002), autumn olive produces large amounts fruit toward the end of summer/beginning of fall that readily germinate during the following spring in Japan. However, I have noticed in Lake Raleigh Woods, over the previous three years, that autumn olive fruit has matured by early July and nearly all fruits are gone within two weeks. Research suggests that the
seeds of autumn olive do not persist in the seed bank for more than a year and any viable seeds found in the soil are from seeds produced during the previous fruiting event (Kohri, 2008).

Autumn olive responds to surface fires, animal browse, cutting, and mowing by sprouting vigorously from damaged stems or root crowns (Kuhns, 1986). In flood situations where autumn olive is uprooted or buried by debris, the buried or overturned plant is capable of rooting from stem tissue and shooting up new stems (Kohri, 2008). Overall, autumn olive is very adept at invading disturbed sites even if they are nutrient poor, owing to the nitrogen fixing capabilities of the shrub.

**Seed Germination**

Autumn olive is generally touted as a sunlight-loving (heliophytic) plant that grows in open areas such as old pastures, along forest edges, or within disturbed forest clearings (Sather and Eckardt, 1987; Kohri, 2002). In Wake County, North Carolina, autumn olive is generally found in partially shaded environments within forested areas. There is not much information available on how well autumn olive does under shaded conditions. Kohri (2002) notes that researchers in Japan have found that autumn olive have no particular light or temperature requirements for dormancy or seed germination.

There is information available, however, discussing autumn olive rate of seed germination when influenced by cold stratification and various temperature regimes (Fowler and Fowler, 1987). Fowler and Fowler (1987) found that autumn olive seeds germinated at higher rates after being placed in a temperature of 5˚ C for a period of at least 16 weeks than seeds exposed to cold temperatures for shorter periods. Temperature also played a role in that optimal temperature for autumn olive seed germination was day/night temperatures of 20/10˚ C. This information does not match up to the assertion in Kohri’s 2008 article. The cold dormancy
requirements of autumn olive have been noted by several other researchers (Hamilton and Carpenter, 1975; Sather and Eckardt, 1987). Not much else has been found concerning light requirements for autumn olive seed germination. It would be interesting to conduct a germination trial on autumn olive seeds under varying light conditions to further investigate this issue.

**Autumn Olive in the United States**

Autumn olive was introduced during the 1830s for wildlife forage and escape cover, eventually being used to reclaim abandoned strip mine sites due to its tolerance for a broad range of pH’s and ability to fix nitrogen. From the 1960s through the 1980s, autumn olive was planted widely in the eastern United States on surface mine sites and wildlife management areas, often being promoted by various private entities and government organizations (Fowler and Fowler, 1987). The Tennessee Valley Authority (TVA) appreciated autumn olive’s ability to stabilize soil banks on highly disturbed coal mine sites. The TVA liked the plant so much that they provided more than 122,000 of the invasive shrubs for planting throughout Tennessee, North Carolina, and Alabama for the reclamation of coal mine sites no longer in production (Fowler and Fowler, 1987).

Autumn olive does have some redeeming characteristics. Autumn olive varieties have also been planted in the understory of *Juglans nigra* (black walnut) plantations as a companion plant to increase black walnut productivity owing to the nitrogen fixing capabilities of autumn olive (Ponder, 1988). Not to forget, the facts reported previously in the paper that autumn olive was widely planted to recover mine spoil sites and for wildlife forage and cover. Black and Fordham (2005) point out that the fruit of autumn olive are edible by humans and have been a food source for humans in Southeast Asia and that they provide a potential food source for
people in the United States. Fordham, Clevidence, Wiley, and Zimmerman (2001) found that both naturalized and some cultivars of autumn olive drupes had much higher Lycopene contents than tomatoes. Despite these cited benefits, autumn olive poses a threat to native plant populations due to its aggressive growth behavior.

Owing to the widespread planting of autumn olive by a multitude of organizations, the plant can now be found in at least 37 states, including Hawaii, with populations spanning up and down the east coast from southern Canada to Florida. There are even populations in the western U.S. in Washington, Oregon and Montana (United States Department of Agriculture Forest Service, 2011). This widespread invasive plant is likely to cause problems for native flora, and work needs to be done to undo the mistakes of previous generations. To come up with a clear strategy for removing autumn olive it is important to utilize the most efficient methods available for locating and eradicating the plant.

**Effective Management Practices**

Mechanical treatment of autumn olive is not a viable option considering how autumn olive re-sprouts vigorously in response to mechanical damage. Therefore, herbicide control is a strategy that deserves some exploration. Larry Kuhns (1985) conducted an herbicide trial using a variety of available herbicides and herbicide combinations applied via foliar and thin line basal bark applications. He conducted three applications. The first was a basal bark application of 2 4-D/2 4-DP, 2 4-D/triclopyr, and triclopyr applied on May 25, 1984. The second was a foliar application of dicamba, 2 4-D/2 4-DP, 2 4-D/triclopyr, triclopyr, fosamine, and metsulfuron applied on July 10, 1984. The third was a basal bark application of 2 4-D/2 4-DP, 2 4-D/triclopyr, and triclopyr applied at varying concentrations on March 15, 1985. The foliar
treatments were mixed with DuPont’s surfactant WK, while the basal bark treatments were mixed with diesel fuel.

Kuhns found that the first basal bark treatment completely killed all plants treated within six weeks of treatment. The second basal bark treatment, which applied the same herbicides as the first at a range of concentrations from 100% to 1%, also provided total control for all plants, but in this treatment most of the 2 4-D/2 4-D/P treatments and the treatment of 1% concentration of triclopyr caused a much slower death of the plant. Kuhns points out that the plants treated with 2 4-D/2 4-DP and 1% concentration of triclopyr still appeared alive at the end of the trial but that upon close inspection of the bark at the base of the treated stems appeared dead. Kuhns concluded from this that the plants would likely not survive. It is important to note that all basal bark treatments were mixed with diesel fuel which is a practice no longer used in weed control. The only herbicide to provide total control out of the foliar applications was dicamba. All other foliar treatments did not provide adequate control at the rates applied.

Edgin and Ebinger (2001) studied the effects of removing autumn olive from the boundary of Beall Woods Nature Preserve in Illinois. They treated autumn olive shrubs in tree plantations near the nature preserve and along the forest edge of the nature preserve. The treatments were made in the spring of 1996 with follow up treatments conducted in the spring of 1997. The autumn olive plants were treated with a basal bark application method of Garlon 4 (active ingredient 61.6%) that was mixed with penevator oil (1 liter of Garlon/5 liters oil) and applied with a Solo backpack sprayer. In the summer of 1997, the researchers revisited the treated sites and found no live autumn olive plants.

In 2000, the researchers revisited the sites treated to assess the autumn olive populations. The autumn olive had been reestablished in the treated sites likely from animal dispersal and
from seeds produced the year before treatment. The researchers walked transects on the
plantations, along the nature preserve’s forest edge and in the interior of the nature preserve’s old
growth forest to assess autumn olive presence and stem density. The autumn olive populations
had greatest density on the tree plantations, low density along the nature preserve’s forested edge
and no presence on the transects walked in the interior of the forest. Indicating that for control of
autumn olive repeat applications would be needed to prevent the nature preserve from being
invaded.
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Chapter 3: Efficacy of Herbicide and Application Method on Autumn Olive (Elaeagnus umbellata) Control in Lake Raleigh Woods

Introduction

Lake Raleigh Woods is an approximately 96 acre nature preserve located on North Carolina State University’s Centennial Campus. There are roughly ten acres of *Elaeagnus umbellata* Thunbar. (autumn olive) growing in the heart of Lake Raleigh Woods. Without intervention, this nonnative invasive shrub has the potential to continue spreading and out-compete desired native plant species. The densest patches of autumn olive are located along two perennial stream banks of varying slope that empty into Lake Raleigh.

The objective of my research is to determine the most effective combination of herbicide and application method for controlling autumn olive in Lake Raleigh Woods.

Materials and Methods

Experimental Design

An herbicide trial was initiated to study the effectiveness of three application methods and four herbicides (3 x 4 factorial design) on treating autumn olive in Lake Raleigh Woods. Herbicide treatments were: glyphosate, imazapyr, triclopyr and a mixture similar to Dupont’s Viewpoint containing aminocyclopyrachlor (See Appendix B for information on herbicide brand and rate of application). A mistake was made in the calculations for the Viewpoint mixture. When calculating for the amount of active ingredient for imazapyr, it was calculated that there were 4lbs a.i. per gallon for the imazapyr formulation used (Habitat) when in fact there were only 2lbs a.i. per gallon. Application methods were: cut stump application, foliar application, and basal bark application. A ‘cultural control’ and nontreated check was included for
comparison. Treatments were arranged in a randomized complete block design with four replications. Individual experimental units (plots) consist of three autumn olive subsamples. Each autumn olive subsample was selected based on a visual estimation that the shrub was of similar size to the other subsamples. Each of the four replications was located in areas of gradual slope with a dense population of autumn olive containing at least 42 plants of similar size.

Two runs of this experiment were conducted over two years. The first run was initiated on August 11, 2011 on a hot, humid summer day with scant cloud cover though shade was provided by the forest canopy. The second run was initiated on August 14, 2012 under very similar conditions to the initial trial. Visual estimations for control and stem count data were collected for approximately one year after treatment. The visual estimates were collected one month after treatment, several times throughout the year, with the final visual estimate being collected during September the year after the treatment was applied. Stem Counts were collected twice (beginning and end) for each run of the experiment.

Data

Pre and post-trial stem counts were collected for each autumn olive subsample. All stems beginning at or below six inches were included in the counts. The pre-trial stem count was collected before the treatments were applied and the post-trial stem count was collected approximately one year after the treatments in the month of September.

The final stem count data were used to create a binary dataset called mortality. If the final stem count equaled 0, then the shrub was considered dead, but if the final stem count equaled any number greater than 0, then the shrub was considered alive. The Mortality dataset is binary with 0 indicating survival and 1 indicating mortality.
Visual estimations of damage were collected on a 0-100% scale with 0% indicating no observable damage and 100% indicating plant mortality. This is an inherently subjective measurement. To decrease subjectivity, I measured visual estimates for each plant in the same way each time. Visual estimates were only gathered during the growing season when the control autumn olive plants had full and vibrant foliage. The estimations were made by visually splitting the plant into four quadrants and estimating the amount of damage for each quadrant. The estimated damage for each quadrant was summed to attain the total estimation of damage for the target plant. This method was calibrated during the first data collection event by having a second person collect data at the same time as I collected the data. A comparison of the second person’s data to mine revealed very close approximations of plant damage. Visual estimations of damage were collected four times for each run of the experiment. Twice during the fall before leaves senesced and twice after the buds break in the year following treatment. The visual estimates were collected as close to the same date as possible for each run of the experiment with the final visual estimation of damage was collected with the final stem count.

**Statistical Analysis**

The mortality data was used for statistical analysis. Examination of the mortality data for errors and frequency counts revealed that all cut stump treatments regardless of herbicide resulted in 100% mortality. There is no need to analyze the cut stump method against the other application methods, because this treatment method provided complete control of autumn olive. Therefore, the cut stump variable was removed from the dataset to avoid quasi-complete separation of the data in a logistic regression model. For similar reasons, the control and cultural treatments were also removed from the data set before statistical analysis. The remaining data was analyzed to see if there were any significant differences between the remaining application
methods (basal bark and foliar) and if there were any differences between the herbicides (glyphosate, imazapyr, triclopyr and a mixture similar to Dupont’s Viewpoint containing aminocyclopyrachlor) applied via the remaining application methods.

A generalized linear mixed model described below was used to analyze the effects of treatment and herbicide on mortality of autumn olive shrubs.

\[ y_{ijk} = \log \left[ \frac{\pi}{1-\pi} \right] = \mu + A_i + H_j + e_{ijk} \]

Where;

- \( y_{ijk} \) is the k-th observation of the j-th herbicide and the i-th application method,
- \( \mu \) is the conditional mean,
- \( \pi \) is the proportion of incidence (mortality),
- \( A_i \) is the fixed effect of the i-th application method,
- \( H_j \) is the fixed effect of the j-th herbicide,
- \( e_{ijk} \) is the random error with \( N(0, \sigma_e^2) \).

The reference level for herbicides was set to triclopyr so that comparisons of all herbicide effectiveness were made against triclopyr. The reason for this being that previous research found triclopyr to be very effective in killing autumn olive (Kuhns, 1986; and Edgin and Ebinger, 2001). The LOGISTIC procedure of SAS software was used to estimate model parameters for application method and for herbicide (SAS Institute Inc. 2011).

**Results**

The model converged and was significant for both trials using the Likelihood Ratio test (\( \alpha = 0.05 \) and \( p < 0.0001 \)) providing evidence that at least one of the regression coefficients for herbicide or application method was not equal to zero. The null hypothesis that there was no
association between herbicide and application method was rejected. This suggests that the probability of mortality is different for herbicide and application method. Both models appear to be a good fit because the percentage of concordant pairs of observations (Trial 1: 82%, Trial 2: 84.1%) was considerably larger than the percentage of discordant pairs (Trial 1: 12.1%, Trial 2: 10.4%) and the model had a C statistic of 0.85 for the first trial and 0.87 for the second trial.

Inspection of the Analysis of Type 3 Error tables revealed that the basal bark and foliar application methods were not significantly different from each other (Trial 1: \( p = 0.3065 \), Trial 2: 0.4276). The cut stump application method provided 100 percent control, but caused a quasi-complete separation of the data so was not analyzed for comparison against the foliar and basal bark treatments. Whereas, the herbicide treatments were significantly different from each other (Trial 1: \( p = 0.0003 \), Trial 2: \( p < 0.0001 \)).

The Analysis of Maximum Likelihood Estimates tables (Appendix A, Tables 3a-b) provide greater detail on how the herbicide treatments (glyphosate, aminocyclopyrachlor, and imazapyr) compared to the reference herbicide (triclopyr) with regards to the probability of mortality. When using the Wald-Chi Square test at the 0.05 level, all herbicides compared to triclopyr were significantly less likely to experience mortality when applied by either the foliar or basal bark application method. Triclopyr was significantly more effective than the competing herbicides at killing autumn olive across the basal bark and foliar application methods (Appendix A, Tables 4a-b).

**Discussion**

It appears that the cut stump treatment provides the most effective means for autumn olive control. The four herbicides used in this study all provided 100% control of autumn olive when applied by the cut stump application method. With regards to herbicide, Garlon 4 Ultra
(triclopyr) proved very effective across all application methods while the other herbicides typically provided inadequate control via the foliar and basal bark application methods. Kuhns (1985) and Edgin and Ebinger (2001) both found triclopyr to be very effective at controlling autumn olive in their respective studies, though neither used the cut stump method in their research.

The cut stump application rates in this study were set based off of herbicide label minimum guidelines. These application rates proved to be extremely effective at killing autumn olive. It would be of great interest to conduct a study with each herbicide applied via the cut stump application methods at increasingly smaller rates to determine the minimal amount of active ingredient needed for total control of autumn olive. The benefits of such a study would be to ensure that herbicide was not being wasted and to save money.

Edgin and Ebinger (2001) note that autumn olive can be controlled using herbicide treatments but that without total eradication of nearby seed sources land managers will need to repeat treatments roughly every five years. Autumn olive is favored by many animals, birds in particular, that greatly assist the spread and potential reintroduction of autumn olive to previously treated areas. Kohri (2008) pointed out that, in Japan, autumn olive appears to be a favorite for birds because the fruit is typically eaten more quickly than the fruit of other fruiting trees. The fruit of autumn olive located in Lake Raleigh Woods also disappeared very quickly after maturation during the previous two summers. Each summer, ripe fruits were observed in early July but by August nearly all of the autumn olive fruits were removed. There are numerous autumn olive patches near Lake Raleigh Woods that provide seed banks for future invasions. It is likely that if autumn olive is removed from Lake Raleigh Woods that seeds from the nearby
seed banks will find their way back into the nature preserve making repeat herbicide applications a likely scenario for the management of autumn olive in Lake Raleigh Woods.

**Conclusion**

The implications of my study are that the cut stump method is the most effective application method for killing autumn olive and triclopyr is the most effective herbicide. The cut stump application method killed all autumn olive samples regardless of which herbicide was applied. The results of the cut stump application method are the most useful findings for the future management of the autumn olive invasion in Lake Raleigh Woods.

All herbicides were 100% effective at killing autumn olive when applied via the cut stump application method. Because of this, future managers of Lake Raleigh Woods will have at least four herbicide options to choose from when combatting the huge patches of autumn olive in the preserve. They can make their choices based on the prices and the environmental impacts of each herbicide and be sure that as long as they apply the herbicide at similar rates and via the cut stump application method they will have success in killing autumn olive.

Since all herbicides were effective when applied via the cut stump application method at the label suggested rates of active ingredient, further investigation into how low the herbicide application rates could be decreased and still be effective via the cut stump application method would be beneficial to any land managers with autumn olive infestations.
References


Appendix I: Results from statistical analysis

Figure 1a. The bar chart displays the average effects of herbicide treatments on autumn olive mortality across all application methods for the trial initiated in 2011.

Figure 1b. The bar chart displays the average effects of herbicide treatments on autumn olive mortality across all application methods for the trial initiated in 2012.
Figure 2a. The bar chart displays the average effects of application method on autumn olive mortality across all herbicide treatments for the trial initiated in 2011.

Figure 2b. The bar chart displays the average effects of application method on autumn olive mortality across all herbicide treatments for the trial initiated in 2012.
Tables 1a and 1b. These tables are two-way frequency tables displaying the frequency of survived versus died between the different herbicide treatments across all application methods. The herbicide triclopyr was by far the most effective herbicide killing 35 out of 36 autumn olive samples in the both the first and second trial.

**Table 1a: Trial initiated in 2011**

<table>
<thead>
<tr>
<th>Mortality</th>
<th>Control</th>
<th>Cultural</th>
<th>AMCP</th>
<th>Glyphosate</th>
<th>Imazapyr</th>
<th>Triclopyr</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survived</td>
<td>12</td>
<td>9</td>
<td>13</td>
<td>21</td>
<td>15</td>
<td>1</td>
<td>71</td>
</tr>
<tr>
<td>Died</td>
<td>0</td>
<td>3</td>
<td>23</td>
<td>15</td>
<td>21</td>
<td>35</td>
<td>97</td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
<td>12</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>168</td>
</tr>
</tbody>
</table>

**Table 1b: Trial initiated in 2012**

<table>
<thead>
<tr>
<th>Mortality</th>
<th>Control</th>
<th>Cultural</th>
<th>AMCP</th>
<th>Glyphosate</th>
<th>Imazapyr</th>
<th>Triclopyr</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survived</td>
<td>12</td>
<td>12</td>
<td>11</td>
<td>19</td>
<td>20</td>
<td>1</td>
<td>75</td>
</tr>
<tr>
<td>Died</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>17</td>
<td>16</td>
<td>35</td>
<td>93</td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
<td>12</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>168</td>
</tr>
</tbody>
</table>
Tables 2a and 2b. These tables are two-way frequency tables displaying the frequency of survived versus died between the different application methods treatments across all herbicide treatments. The cut stump application method was the most effective method for killing autumn olive regardless of which herbicide was used in treatment. The cut stump application method resulted in 100% mortality of autumn olive samples for both the first and second trial.

Table 2a: Trial initiated in 2011

<table>
<thead>
<tr>
<th>Mortality</th>
<th>Control</th>
<th>Cultural</th>
<th>Basal Bark</th>
<th>Cut Stump</th>
<th>Foliar</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survived</td>
<td>12</td>
<td>9</td>
<td>27</td>
<td>0</td>
<td>23</td>
<td>71</td>
</tr>
<tr>
<td>Died</td>
<td>0</td>
<td>3</td>
<td>21</td>
<td>48</td>
<td>25</td>
<td>97</td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
<td>12</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>168</td>
</tr>
</tbody>
</table>

Table 2b: Trial initiated in 2012

<table>
<thead>
<tr>
<th>Mortality</th>
<th>Control</th>
<th>Cultural</th>
<th>Basal Bark</th>
<th>Cut Stump</th>
<th>Foliar</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survived</td>
<td>12</td>
<td>12</td>
<td>24</td>
<td>0</td>
<td>27</td>
<td>75</td>
</tr>
<tr>
<td>Died</td>
<td>0</td>
<td>0</td>
<td>24</td>
<td>48</td>
<td>21</td>
<td>93</td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
<td>12</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>168</td>
</tr>
</tbody>
</table>
Tables 3a and 3b. The Analysis of Maximum Likelihood Estimates tables list the estimated model parameters, their standard errors, Wald Chi-Square tests, and the Wald Chi-Square tests’ associated p-values. The Wald chi-square, and its associated p-value, tests whether the parameter estimates are significantly different from 0. The p-values for AMCP, Glyphosate, and Imazapyr are significant at the 0.05 significance level. Indicating that each of the herbicides are significantly different from triclopyr since it was set as the reference level to which all herbicides are compared against.

Table 3a: Trial initiated in 2011

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DF</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>Wald Chi-Square</th>
<th>Pr &gt; ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>3.17</td>
<td>1.02</td>
<td>9.55</td>
<td>0.002</td>
</tr>
<tr>
<td>App. Method</td>
<td>Basal Bark</td>
<td>1</td>
<td>-0.27</td>
<td>0.26</td>
<td>1.05</td>
</tr>
<tr>
<td>Herbicide</td>
<td>AMCP</td>
<td>1</td>
<td>-3.34</td>
<td>1.11</td>
<td>9.12</td>
</tr>
<tr>
<td>Herbicide</td>
<td>Glyphosate</td>
<td>1</td>
<td>-5.14</td>
<td>1.20</td>
<td>18.31</td>
</tr>
<tr>
<td>Herbicide</td>
<td>Imazapyr</td>
<td>1</td>
<td>-3.69</td>
<td>1.11</td>
<td>11.02</td>
</tr>
</tbody>
</table>

Table 3b: Trial initiated in 2012

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DF</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>Wald Chi-Square</th>
<th>Pr &gt; ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>3.16</td>
<td>1.02</td>
<td>9.50</td>
<td>0.002</td>
</tr>
<tr>
<td>App. Method</td>
<td>Basal Bark</td>
<td>1</td>
<td>0.21</td>
<td>0.26</td>
<td>0.63</td>
</tr>
<tr>
<td>Herbicide</td>
<td>AMCP</td>
<td>1</td>
<td>-2.99</td>
<td>1.10</td>
<td>7.33</td>
</tr>
<tr>
<td>Herbicide</td>
<td>Glyphosate</td>
<td>1</td>
<td>-4.50</td>
<td>1.14</td>
<td>15.52</td>
</tr>
<tr>
<td>Herbicide</td>
<td>Imazapyr</td>
<td>1</td>
<td>-4.78</td>
<td>1.16</td>
<td>16.86</td>
</tr>
</tbody>
</table>
Tables 4a and 4b. The Odds Ratio Estimates and Profile-Likelihood Confidence Intervals shows that all odds ratios for herbicides (AMCP, glyphosate, and imazapyr) compared against triclopyr were significant at the 0.05 level because the 95% confidence limits did not include the value 1.00 within their limits. The odds ratios show that AMCP, glyphosate, and imazapyr had really low odds of causing mortality for autumn olive shrubs across the basal bark and foliar application methods compared to triclopyr. Basal bark versus foliar was not significant at the 0.05 level because the 95% confidence limits included 1.00.

Table 4a: Trial initiated in 2011

<table>
<thead>
<tr>
<th>Label</th>
<th>Estimate</th>
<th>95% Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMCP vs Triclopyr</td>
<td>0.036</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.214</td>
</tr>
<tr>
<td>Glyphosate vs Triclopyr</td>
<td>0.006</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.043</td>
</tr>
<tr>
<td>Imazapyr vs Triclopyr</td>
<td>0.025</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.152</td>
</tr>
<tr>
<td>Basal Bark vs Foliar</td>
<td>0.587</td>
<td>0.206</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.614</td>
</tr>
</tbody>
</table>

Table 4b: Trial initiated in 2012

<table>
<thead>
<tr>
<th>Label</th>
<th>Estimate</th>
<th>95% Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMCP vs Triclopyr</td>
<td>0.050</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.305</td>
</tr>
<tr>
<td>Glyphosate vs Triclopyr</td>
<td>0.011</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.072</td>
</tr>
<tr>
<td>Imazapyr vs Triclopyr</td>
<td>0.008</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.057</td>
</tr>
<tr>
<td>Basal Bark vs Foliar</td>
<td>1.530</td>
<td>0.539</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.500</td>
</tr>
</tbody>
</table>
Figure 3. The Odds Ratio plot provides a visual representation for profile-likelihood confidence limits listed in Table 4. The only confidence interval that crosses the equality reference line of 1 is for Treatment (Application Method) Basal Bark vs. Foliar. All other confidence intervals are significant at the 0.05 level. The figure above shows data for the first trial. The figure for the second trial is not included because the results are nearly identical.
Appendix II: Charts showing the final visual estimates for both trials

Figure 1: A bar graph representing the visual estimates for herbicide control on autumn olive shrubs for the initial herbicide trial. All replications and subsamples were averaged create the bar graph.
Figure 2: A bar graph representing the visual estimates for herbicide control on autumn olive shrubs for the second herbicide trial. All replications and subsamples were averaged to create the bar graph.
Appendix III: Information on herbicides and rates of application

Table 1: List of herbicides used in the study

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Brand Name</th>
<th>Manufacturer</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imazapyr</td>
<td>Habitat</td>
<td>BASF</td>
<td>2lbs a.i./gallon</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>Refuge</td>
<td>Syngenta</td>
<td>5lbs a.i./gallon</td>
</tr>
<tr>
<td>Triclopyr</td>
<td>Garlon 4 Ultra</td>
<td>Dow Agro Sciences</td>
<td>4lbs a.i./gallon</td>
</tr>
<tr>
<td>Aminocyclopyrachlor</td>
<td>Experimental</td>
<td>DuPont</td>
<td>2lbs a.i./gallon</td>
</tr>
<tr>
<td>Metsulfuron</td>
<td>Ally</td>
<td>DuPont</td>
<td>600 g/ kg</td>
</tr>
</tbody>
</table>

Table 2: Herbicide Application Rates. The cut stump treatments were mixed with water and 0.025% NIS then applied via sponge paint brush immediately after stem was cut. The basal bark treatment was mixed with basal oil (methylated seed oil) and applied with a sponge paint brush. The foliar application was mixed with water and 0.025% NIS in a 2 gallon tank and applied using pressurized backpack sprayer and a hand wand applicator.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Cut Stump</th>
<th>Basal Bark</th>
<th>Foliar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imazapyr</td>
<td>5%</td>
<td>5%</td>
<td>1%</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>25%</td>
<td>25%</td>
<td>2%</td>
</tr>
<tr>
<td>Triclopyr</td>
<td>25%</td>
<td>25%</td>
<td>6 qt / 100GPA</td>
</tr>
<tr>
<td>Viewpoint mixture</td>
<td>20 oz/acre</td>
<td>20 oz/acre</td>
<td>20 oz/acre</td>
</tr>
</tbody>
</table>

Table 3: Percent active ingredient for each herbicide used to make the Viewpoint mixture

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Percent Active Ingredient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aminocyclopyrachlor</td>
<td>22.8%</td>
</tr>
<tr>
<td>Imazapyr</td>
<td>*31.6%</td>
</tr>
<tr>
<td>Metsulfuron</td>
<td>7.3%</td>
</tr>
</tbody>
</table>

*Note: Due to calculation Imazapyr was mixed at half the amount needed. This was repeated in the second year to keep the application rates similar.
Appendix IV: Maps of Lake Raleigh Woods

Map 1: This map displays the nonnative plants found within Lake Raleigh Woods during a nonnative plant survey conducted in the Fall of 2010. The nonnative plants were mapped as points, lines, and polygons.
**Map 2:** This map displays the replication plots for both the first and second year herbicide trials.
Management Prescriptions for Autumn Olive (*Elaeagnus umbellata*) in Lake Raleigh Woods

The worst two nonnative invasive plant infestations in Lake Raleigh Woods are the autumn olive (*Elaeagnus umbellata* Thunbar.) infestation that covers over ten acres in the heart of the forest and the Chinese privet (*Ligustrum sinense*)/microstegium (*microstegium vimineum*) infestation found growing together in the northern floodplains of the property. Both infestations have seed sources nearby that lie outside of Lake Raleigh Wood’s boundary. The privet/microstegium areas are slightly harder to reach than the autumn olive patch and due to the nature of the floodplain, they will likely be re-invaded much quicker than the autumn olive patch after successful treatments. Therefore, it is proposed to focus more on the removal of autumn olive at first.

An herbicide trial, to investigate the optimal herbicide and application method for autumn olive control, was conducted from 2011-2013. The results of that herbicide trial showed that autumn olive was very susceptible to the cut stump application method (cut the shrub down with loppers and paint the stump immediately after) regardless of the applied herbicide (triclopyr, imazapyr, glyphosate, and a mixture roughly equivalent to DuPont’s Viewpoint containing aminocyclopyrachlor). All cut stump applications provide 100% control of autumn olive making this application method a great option to control the autumn olive in Lake Raleigh Woods.

There is not likely to be much funding for managing nonnative invasive plants in Lake Raleigh Woods. However, managing Lake Raleigh Woods can potentially provide excellent learning opportunities for students. Undergraduates from NC State’s Department of Forestry and Environmental Resources Introduction to Natural Resources (NR 100) conduct service learning
projects every Fall with the service learning projects often involving the removal of nonnative invasive plants from nearby parks and nature preserves. Lake Raleigh Woods would provide an excellent location to direct these industrious students in their effort to clean up local forest land. Volunteer effort could also provide some opportunities for accomplishing the removal of autumn olive.

Any student or volunteer labor will need to have some initial training so that they can properly identify autumn olive in the field and apply treatments correctly. It will also be important to have enough supervisors to ensure the workers are treating correctly and to act as a knowledge resource for the workers. At least one of the supervisors should have an herbicide applicators license. To remove autumn olive from Lake Raleigh Woods, it is suggested that the labor force (students or volunteers) be split into groups of two with one having a pair of lopper and the other having a spray bottle filled with the desired herbicide. The worker with the loppers would lop the autumn olive trees down and the worker with the spray bottle would spray immediately ensuring that all cut stumps were sprayed until wet but the herbicide should not be pooling on the ground. Applications made in August or September should provide control for autumn olive.

Table 1, shown below, displays suggested herbicides that have been found to be effective in treating autumn olive in Lake Raleigh Woods via the cut stump application method.
Table 1: Suggested list of herbicides with suggested application rates.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Trade Name</th>
<th>A.I./Gal</th>
<th>Suggested Rate</th>
<th>~Price/Gal ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glyphosate</td>
<td>Roundup PowerMax</td>
<td>5.5 lbs / gal</td>
<td>25%</td>
<td>18</td>
</tr>
<tr>
<td>Triclopyr</td>
<td>Garlon 4 Ultra</td>
<td>4 lbs / gal</td>
<td>25%</td>
<td>95</td>
</tr>
<tr>
<td>Imazapyr</td>
<td>Chopper</td>
<td>2 lbs / gal</td>
<td>6.25%</td>
<td>65</td>
</tr>
</tbody>
</table>

* Approximate prices for herbicides was taken from the University of Florida’s IFAS Extension website (http://edis.ifas.ufl.edu/wg056)

Table 1 also provides suggested application rates to provide complete control of autumn olive. The herbicides should be mixed with water plus 0.025% volume/volume of a nonionic surfactant (NIS). A sturdy handheld spray bottle should be sufficient to make applications.

It is likely that the application rates can be decreased and still complete provide control of autumn olive. There might be merit in conducting a small herbicide trial, using whichever herbicide is chosen, to determine how low the application rate can be decreased while still providing complete control. Money can be saved if the rate can be decreased significantly. Overall, it appears that with time and effort autumn olive can be managed in Lake Raleigh Woods with relative ease. The nonnative invasive shrub responds well to herbicide treatment especially when the herbicide is applied directly to the cambium of living plants.