HERBICIDE USAGE ON ENGLISH IVY IN THE MARYVILLE COLLEGE WOODS

A Report of a Senior Study

by

Sarah Holland

Major: Biology

Maryville College

Spring, 2023

Date approved ____________________, by ______________________________________

Faculty Supervisor

Date approved ____________________, by ______________________________________

Division Chair

ABSTRACT

Hendra Helix, English Ivy, is one of the many invasive species inhabiting the Maryville College (MC) Woods (located within the Maryville College Campus) in Maryville, Tennessee. The purpose of this study was to determine a way to get rid of English Ivy, as an invasive species, and allow for more native Tennessee plant populations to return to the MC Woods. Research was performed in the MC Woods behind the Ruby Tuesday Lodge. The research area was split into 21, 1m x 1m plots that were observed to determine percent coverage with English Ivy and were either treated with Triclopyr™ herbicide, treated with Escort™ herbicide, or were non-treated plots (control). It was hypothesized that herbicide application on English Ivy would kill 70% or more of the green English Ivy dominating the plots observed. An ANOVA test was performed along with a Tukey Post-Hoc to compare the percent reduction of English Ivy coverage between the groups and determine significance between them. The Escort™ herbicide overall showed a lower percent reduction and p-value (38.99%, 1.0×10^{-6}) than Triclopyr™ herbicide (61.77%, 3.70×10^{-6}), showing a greater amount of success with Triclopyr™ herbicide. However, it is imperative to test herbicides in an environment capable of producing a consistent amount of sunlight, humidity, and temperature to distinguish which herbicide is the best use for English Ivy.

ACKNOWLEDGEMENTS

I would like to give a big thanks to my advisor Dr. Brigati and professor Dr. Clark in helping me with this senior project. This project would not have been possible without Dr. Brigati’s extensive help with completing this research and reviewing my paper copious amounts of times. Many thanks to Dr. Clark for helping me perform this research and dive into a deep background on why English Ivy is such a threat to MC and what is being done in neighboring areas and parks to combat this invasive.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Hendra Helix, English Ivy, is an invasive species inhabiting the southeastern United States causing death to vegetation and elimination of native species. English Ivy is one of the many invasive species inhabiting the Maryville College (MC) Woods in Maryville, Tennessee. Numerous methods have been used to attempt to eradicate this invasive species, but none have proven successful thus far. These methods include herbicides, grazing, controlled fire, and manual removal. The purpose of this study is to determine a way to get rid of English Ivy, as an invasive species, and allow for more native Tennessee plant populations to return to the MC Woods. The hypothesis for this study is that herbicide application on English Ivy will kill 70% the green English Ivy dominating the plots observed.

Background:

English Ivy is a plant native to England, Ireland, Northern Europe, and the Mediterranean region (Okerman 2000). In the late 1500's, before English Ivy was brought to the United States, Queen Elizabeth I set up groups called "Ivy Squads" (Okerman 2000). The purpose of these squads was to strip trees from any walls of English Ivy to protect the trees and any possible destruction that may have occurred from the vines (Okerman 2000). Although native to Europe, English Ivy was introduced into the United States in the colonial era and was originally used as an ornamental plant or as ground cover (Yang et al. 2013, Okerman 2000). As of 2013 English Ivy has been identified as being endemic in at least 31 of the 50 states in the United States and has migrated up into Canada (Yang et al. 2013). This spread was largely aided by the extensive logging that occurred in the United States in the 1600's (Biggerstaff and Beck 2007).

<u>Characteristics:</u>

In areas where English Ivy is present or has previously been planted as a means of ornament/ groundcover, an "ivy desert" can be seen (Okerman 2000). An "ivy desert" refers to a forested area that has a limited amount of canopy species, a thick area of ivy groundcover, and includes English Ivy vines entangling tree trunks (Okerman 2000).

This "ivy desert" can be seen because English Ivy is labeled as an invasive species. Labeling of organisms can be done one of two ways but is based on dispersal – invasive and expansive. An invasive species is an organism that goes past natural native limits, colonize non-native areas, and affect biodiversity, while expansive species are organisms that exploit new environments within their natural range and typically have high dispersal potential (Kucharski et al. 2019). Invasive species, such as English Ivy, have no natural predators to compete against in the United States (Miller 1998). English Ivy then can outcompete many plant communities and create a competition with native species for light, nutrients, and soil (Okerman 2000).

Once an invasive has entered a native area, changes in community structure occur by invasives due to introduced species outcompeting native species, modifying habitats, or altering key ecosystem processes (Biggerstaff and Beck 2007). English Ivy begins by forming a dense ground cover that prevents the emergence of almost all herbs and dramatically reduces light levels (Biggerstaff and Beck 2007). Once the Ivy has consumed a tree, there is a higher probability that during a weather event, the tree will end up snapping and dying (Okerman 2000). Overall, English Ivy grows very quickly and can dominate a secondary woodland completely in around 30 years' time (Biggerstaff and Beck 2007).

English Ivy is a green woody climbing vine that produces a sticky substance to adhere to a multitude of surfaces (Swearingen and Diedrich 2006). English Ivy can grow to heights of 270 meters and can grow anywhere under 914 meters altitude (Okerman 2000). It is most likely to occur in areas where there is some form of development (ex: human habitation) (Okerman 2000). It is also most found in woodland, forest edges, fields, marches, and coastal areas, but does not grow well in areas where extreme moisture or floods are common (Swearingen and Diedrich 2006). Although English Ivy cannot withstand extreme amounts of moisture, it does have the ability to withstand a wide range of soil pH's with a preference of slightly acidic soil at 6.5 (Swearingen and Diedrich 2006).

Life Stages:

There are two distinct life forms of English Ivy, which alters the appearance of the vine – juvenile and adult. The juvenile form is thin and consist of 3-5 dark green lobed leaves with white veins (Okerman 2000). This form is typically found as ground cover but produces rootlets to allow it to climb trees and other structures due to less light required to grow (Okerman 2000). The juvenile form is non-reproductive (Okerman 2000).

The adult life stage is a thick, lighter green color and ovate to rhombic in shape (Okerman 2000). The veins are not as prominently white as the juvenile form but does produce both clusters of fruit and flowers (Okerman 2000). The flowers may take up to 10 years to be produced and are white and/or green in color and are pollinated by wasps, bees, flies, and other organisms (Okerman 2000). In the spring, a purple fruit is produced to aid in the adult reproductive capabilities (Okerman 2000). The adult form requires a greater amount of light than the juvenile form resulting in growing closer to the top of the canopy, edges of forests, and areas where human interaction is present (Kucharski et al. 2019).

The fruit of English Ivy contain 1-3 hard, stone-like seeds that may live through the winter months if not consumed by another organism but contain toxins (Swearingen and Diedrich 2006). These toxins, called glycoside hederin, are found on both the leaves and berries and if consumed may cause difficulty breathing, coma, fever, and lack of coordination (Swearingen and Diedrich 2006). This toxin ensures that there is effective seed dispersal by birds and other organisms and is not dispersed by the incorrect carrier (Swearingen and Diedrich 2006). Although fruiting occurs in the springtime, English Ivy has the ability to photosynthesize during the winter months while other vegetation is dormant (Swearingen and Diedrich 2006, Okerman 2000). This quality allows the plant to grow more rapidly upwards with an abundance of sunlight due to the hibernation of other species (Okerman 2000).

As mentioned previously, the juveniles produce rootlets which allow them to climb trees and other rough structures (Okerman 2000). English Ivy has 4 distinct phases which allow for a permanent attachment to surfaces: contact formation (1), forming closure of root with substrate (2), chemical adhesion by excreting glue from root hairs which densely cover attachment roots (3), and passive shape of root hairs (4) (Melzer et al. 2011). These four steps give English Ivy the ability to climb surfaces such as wood and cork, but do not allow it to attach to smooth surfaces such as glass and aluminum (Melzer et al. 2011).

Genetics play a large role in any species, but especially those considered to be invasive species due to the importance of understanding their dispersal and reproduction.

Polyploidy is when a normal diploid cell, or organism, has more than 2 homologous sets of chromosomes. It is common in flower plants and may be connected to invading species and natural habitats (Green et al. 2013). Unlike diploid organisms, these organisms are more likely to survive bottlenecks and live in disturbed habitats and may exhibit adaptation due to recombination and epigenetic processes (Green et al. 2013). A bottleneck occurs when there is a great reduction in the size of a population due to natural events such as fires and floods. Polyploidy played a large, indirect, role in facilitating English Ivy as an invasive species in the United States by adapting to occupy habitats more like their native habitat in Europe (Green et al. 2013).

Environmental Factors:

Climate change and global warming are directly responsible for changing the natural ranges of both plants and animals around the world (Kucharski et al. 2019). Changes in the natural environment are also due to human interaction impacting dispersal of organisms (Kucharski et al. 2019). Global warming that was observed in recent decades significantly impacted the life of organisms primarily due to the lengthening of the growing season (Kucharski et al. 2019). For English Ivy, global warming allows the plant to travel more into the Northern United States with success due to longer growing seasons and more sunlight readily available (Kucharski et al. 2019).

In 2012, English Ivy was listed as 1 of the 135 non-native plant species by the Tennessee Exotic Pest Plant Council (TNEPPC) (Pfenningwerth and Kuebbing 2012). It was then considered to be a “lesser threat” and they considered English Ivy to only need special monitoring to ensure it did not become highly invasive (Pfenningwerth and Kuebbing 2012). However, it was predicted that English Ivy caused the United States upwards of $25 billion worth of damages in the United States (Pfenningwerth and Kuebbing 2012). Furthermore, it was discovered that California alone was paying nearly $82 million annually in attempt to get rid of the invasive species (Pfenningwerth and Kuebbing 2012). Removal of English Ivy is costly, takes a lot of time, and a lot of effort, but there are many ways to remove the invasive.

Removal of English Ivy:

Although removal of English Ivy and other invasive species may be costly, it is imperative to restoring natural ecosystems and native plants. There are many ways English Ivy can be successfully removed from an area allowing native vegetation to return. Of the many methods, targeted grazing is when a species of livestock is applied over a particular season, time period, and intensity to accomplish vegetation or landscape goals (Launchbaugh and Walker 2006). The difference between targeted grazing and use of vegetation for feeding purposes is that targeted grazing focuses on vegetation and landscape enhancement versus livestock production (Launchbaugh and Walker 2006). Targeted grazing alone does not eradicate a weed or invasive species so it should be performed with a combination of burning, herbicide application, and other forms of biological control (Launchbaugh and Walker 2006). It should also be noted that targeted grazing cannot only occur once for it to be an effective means of control; it must occur repetitively over a long time period (Launchbaugh and Walker 2006).

Allowing animals to consume English Ivy as a form of weed control and management could help to restore a balance in the ecosystem leading to native plants being able to thrive (Launchbaugh and Walker 2006). Animals that are used in biological controls of English Ivy range from insects to ruminants, which allows farmers to use English Ivy as a diet supplement and to diminish an infestation of English Ivy (Gulizia and Downs 2019). Using livestock as a method to eliminate English Ivy is a cost-effective method for famers but is a slow process that occurs over a period of years.

Other methods to eradicate English Ivy, such as chemical applications, are generally ineffective unless applied over the course of multiple years or are combined with other methods of control (Frye et al. 2017). Herbicides vary on English Ivy control depending on soil type, weather conditions, formulation, application, characteristics of the ivy, and frequency of application (Berisford et al. 2006). Evapotranspiration can also play a role because it can increase or decrease the amount of water leaching below the root zone which determines the amount of potential herbicide movement to groundwater (Berisford et al. 2006). Although there are a variety of herbicides available (glyphosate, Triclopyr™, Escort™) most of them do not perform well when used as a control method for English Ivy. Another approach to eradicate English Ivy is to combine herbicide(s) with grazing, controlled fire, or other biological control. Herbicide treatment can be combined with competition from another aggressive plant species, or a "smother crop" (Harrington et al. 2003).

Biological control can occur in many different forms – burning, manual removal, and management by another organism. The most ineffective form of biological control is manual removal, but in cases where English Ivy is dense or if herbicide-control methods are not preferable, it can be utilized. Manual removal is considered the most ineffective tool for removal due to the possibility of aggravating soil surface erosion and promoting invasion by other weeds (Yang et al. 2013). Manual removal begins by cutting vines at the base of trees; pulling them down is futile because the vines will die above the cut and eventually fall off on their own (Manning and Miller 2011). Next, vines are followed to the ground where the nodes are cut using scissors (if small enough) or a handsaw (Manning and Miller 2011). If herbicide usage is the intended goal, herbicide is applied to the stem within 5-10 minutes of the initial cut (Manning and Miller 2011). Failure to spray within the initial 5–10-minute frame results in the stem drying up and making herbicide application void (Manning and Miller 2011). If herbicide application is not preferable, the nodes can be dug up and cut. (Manning and Miller 2011).

Common tools that can be used for manual removal include a mattock and a mechanical root raking and disking machine. A mattock is a tool that has an ax on one end and a digging tool on the other end (Manning and Miller 2011). This tool is efficient in manual removal of English Ivy because it is easier to remove any rooted vine nodules that have grown underground (Manning and Miller 2011). Mechanical root raking and disking machines should be used only in extreme cases where there is dense infestation of English Ivy, and it is the only way to start control (Manning and Miller 2011). This tool has runners that chop invasive plants into segments, but this tool must be followed by another form of control to avoid intensification due to the transportation of segments (Manning and Miller 2011).

Although manual removal is not the most effective tool for English Ivy removal, prescribed burning is a more effective option for management. Prescribed burning is the premeditated use of fire under a specific and very controlled condition (Manning and Miller 2011). Sprouts and seeds of English Ivy that are top killed by burning can be more easily treated with herbicides and this method is often the most cost effective for herbicide application and success (Manning and Miller 2011). Herbicide application also becomes more successful because prescribed burning prepares a site by clearing debris and any hazards that may have been covered by English Ivy, such as holes in the ground (Manning and Miller 2011). It is best for prescribed burning to occur in the late winter or early spring to minimize periods of bare soil and to most effectively kill any sprouting or seeds that may have begun growth (Manning and Miller 2011).

After English Ivy is removed from an area via manual removal, herbicides, prescribed burning, or other forms of control native plants should be able to restore themselves naturally (Biggerstaff and Beck 2007). English Ivy does not negatively impact the formation of a seed bank or the germination of those seeds (Biggerstaff and Beck 2007). It is encouraged to plant native plants following English Ivy removal to ensure it cannot return to an empty forest floor.

Experimental Background:

The Maryville College Woods (MC Woods) are a 140-acre designated area located within Maryville College campus in Maryville, Tennessee. English Ivy growth increases drastically every year resulting in a decrease in native Tennessee vegetation. English Ivy, however, is not the only threat; the most common invasive species found within the MC Woods include English Ivy (*Hedera helix*), kudzu (*Pueraria montana var. lobata*), Chinese privet (*Ligustrum sinense*), and honeysuckle (*Lonicera japonica*). Within the last few years, many efforts have been made to eliminate the English Ivy that has invaded the MC Woods including grazing, controlled burning, manual removal, and herbicide application, but none have been completely effective. In this study, English Ivy eradication is being studied after herbicide application has occurred. After herbicide application occurs on the 14 of 21 plots new growth will be observed.

Although herbicide application will occur, there are two possible herbicides that are being used for this study – Triclopyr™ and Escort™. Triclopyr™ is a broad leaf herbicide most used in forestry, pastures, rangelands, home lawns and gardens that mainly targets broad leaf weeds and brush (United States Environmental Protection Agency 1998). Labelling of Triclopyr™ states that it should only be applied when there is little to no drift to adjacent or sensitive areas such as threatened or endangered habitats, non-target crops, and residential areas (Antunes-Kenyon and Kennedy 2004). This is due to the fact that Triclopyr™ is classified as a systematic pyridine carboxylic acid herbicide that kills entire plants, including roots (Antunes-Kenyon and Kennedy 2004). Triclopyr™ shows greater efficiency than other herbicides which allow vegetation to regrow from the roots (Antunes-Kenyon and Kennedy 2004). Triclopyr™ is also an ideal herbicide for usage in the MC Woods due to little lateral movement in soil during the dryer months, which in Tennessee occurs in late October due to this being the driest month (Berisford et al. 2006).

Escort™ (Metsulfuron-methyl) is also a broadleaf herbicide used in forestry (Klotzbach and Durkin 2004). Due to its use in many forests, it has a low toxicity level to birds, insects, and aquatic organisms (Klotzbach and Durkin 2004). It is a selective pre- and post-emergence herbicide and works rapidly after being taken up by the plant it is sprayed on (Klotzbach and Durkin 2004). It works by stopping cell division in both the shoots and the roots and kills the plant (Klotzbach and Durkin 2004). After being taken up by the plant, it remains in the soil for a varying amount of time. If the herbicide is in slightly acidic conditions, it will break down quicker than in soils with high moisture, more basic pH, and higher temperature (Klotzbach and Durkin 2004). Optimal temperature for Escort™ to be effective is 65°F-75°F, during the spring before other vegetation comes out of dormancy (Klotzbach and Durkin 2004). Escort™ would be an ideal herbicide for usage in the MC

Woods due to its environmentally friendly side-effects. Few-to-no organisms would be harmed if ingested or leached into aquatic systems.

Herbicide will be applied in the late winter months and English Ivy growth will be reevaluated in the spring. Aside from herbicide application, 7 of the 21 plots will not have herbicide applied to them and will be the control plots. Spring observations will occur to determine if herbicide usage alone is an effective way to eradicate English Ivy in the MC Woods. The purpose of this study is to determine a way to get rid of English Ivy, as an invasive species, and allow for more native Tennessee plant populations to return to the MC Woods. The hypothesis for this study is that herbicide application on English Ivy will kill 70% of the green English Ivy dominating the plots observed.

CHAPTER II

MATERIALS AND METHODS

Research was performed in the MC Woods behind the Ruby Tuesday Lodge, located within the Maryville College Campus in Maryville, Tennessee. This area of the woods features heavy growth of English Ivy and other non-native species to Tennessee. Before research began, an area with flat land was established to get the best herbicide results and lessen the possibility of runoff. After the general area was determined for research, a total of 21 plots (1m x 1m) were laid out in a random fashion on January 11, 2023.

Each of the plots were marked with an orange flag in each corner and a number was assigned to each. Marking the plots with numbers and flags allowed for easier identification of the plots, especially if one of the flags were to be knocked out of its original spot. Along with marking the plots with flags, the coordinates of each plot were recorded using a Garmin GPS 73, as well as the average distance between each plot (4.15 meters) using a Keson 30-meter measuring tape.

Table 1. The GPS coordinates of the 21 plots.

plot	coordinate
1	0232474 3959743
2	0232460 3959746
3	0232453 3959749
4	0232451 3959749
5	0232449 3959751
6	0232443 3959753
7	0232440 3959753
8	0232438 3959747
9	0232442 3959743
10	0232450 3959741
11	0232458 3959741
12	0232463 3959740
13	0232466 3959739
14	0232471 3959741
15	0232481 3959743
16	0232472 3959749
17	0232467 3959752
18	0232460 3959755
19	0232458 3959756
20	0232454 3959760
21	0232486 3959748

After each plot was marked, data collection began on each of the 21 plots before herbicide was applied to determine the original coverage of the English Ivy. A 1x1 square meter was made from PVC pipe and fishing line. The fishing line was used to create 25 smaller 0.20 x 0.20-meter squares inside of the 1x1 square meter. Data collection was made in the same sequence and direction each time the 1x1 square meter was used to ensure the research would be repeatable. For this research, data was collected facing Southeast and began at the bottom left of the 1x1 square meter and ended at the top right.

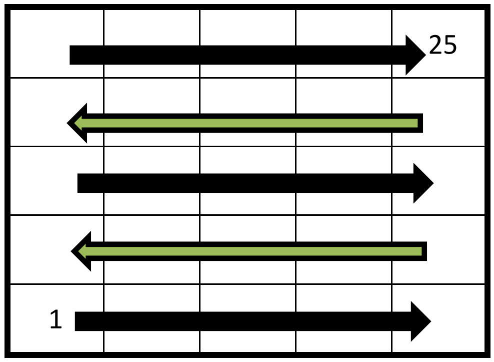

Figure 1. The direction in which data was collected for each of the 0.20 x 0.20-meter squares, starting at the bottom left and ending at the top right.

On January 24, 2023, the percent coverage was measured for each plot and pictures were used to record the initial coverage. Only English Ivy with some green in the leaves was considered alive in this study. For example, if a cell within the plot contained a leaf that was 50% brown and 50% green, it would still be counted as live for the percent coverage data. All 21 plots were randomly assigned to either be sprayed with Escort™ herbicide, Triclopyr™ herbicide, or nothing (control plots). Plots 2, 3, 10, 11, 17, 20, and 21 were the control plots; plots 1, 4, 9, 12, 14, 18, and 19 were the Escort™ plots; plots 5, 6, 7, 8, 13, 15, and 16 were the Triclopyr™ plots. For the plots to be sprayed it was necessary that the temperature stayed above 50°F and there was no rainfall 36-48 hours beforehand. It was also necessary to ensure that there would be no rainfall on the plots 36-48 hours after spraying to guarentee the herbicide did not run off of the English Ivy.

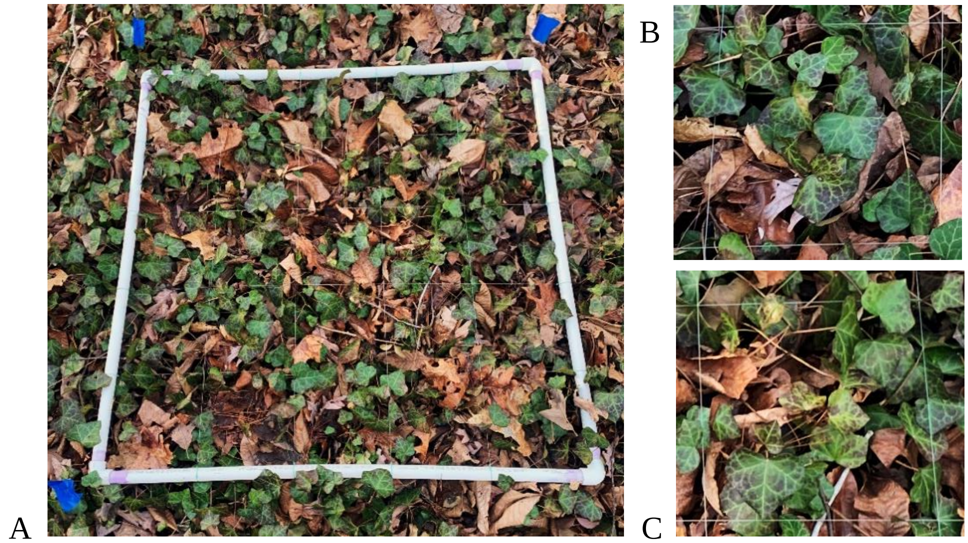

Figure 2. (A) The 1x1 square meter being used to determine the percent coverage on plot 11 out of 21. (B) Cell 9 and (C) Cell 14 on plot 11 determined to have a percent coverage of 8/10 and 7/10, respectively.

Two backpack sprayers were used to ensure even and thorough coverage of all English Ivy that was sprayed. In the one backpack sprayer, 6.4 oz of Triclopyr™ 4% was added per gallon of water, for a total of 25.6 oz used. In the other backpack sprayer, 0.5 oz of granulated Escort™ herbicide was added into 4 gallons of water. Lastly, 2 oz of Spray-Slick surfactant was added to each backpack sprayer to ensure better adhesion of herbicide to the English Ivy leaves. Surfactant is soluable in water and works as an enhancment to herbicides allowing them to stick to the leaves of plants better.

Then, using the backpack sprayers, each plot was oversprayed by a minimum of 12" outside of the perimeter of the plot to ensure thorough coverage of all English Ivy. During overspraying of the plots, the leaves were being sprayed not the roots of the plant. It was also imperative that each plot that was sprayed had runoff on the leaves to make sure there was full coverage on all of the leaves. Post-herbicide application, 6 days passed before another rainfall occurred, ensuring no possible loss of herbicide or leaching into the soil occurred.

Figure 3. Runoff of Escort™ herbicide on English Ivy.

On February 25, 2023, each plot had data on percent coverage collected to use in comparison to the amount of English Ivy present in the data collected on January 24, 2023. The same technique used when collecting the initial data was repeated for this data collection.

After all observations were made and data was collected, statistical analysis was performed in Microsoft Excel. The average percent coverage was calculated for all plots before and after treatment, then separated based on either being treated with Escort™ herbicide, treated with Triclopyr™ herbicide, or not treated (control) and averages were calculated again. Comparisons were then made between standard deviation and p-values using a paired t-test before herbicide was applied to the plots and after to determine the effectiveness on the English Ivy. Percent reduciton was then calculated for each 1 m^2 plot and used to perform ANOVA to determine if there was a significant difference between the two treatments and the control. A Tukey Post-Hoc test was used to determine if there a statistically significant difference between each group tested.

CHAPTER III

RESULTS

The weather in Maryville ranged between a low of 22°F-49°F and a high of 49°F-68°F during the experiment period. There was no precipitation for data collection and herbicide spraying on January 24, 2023, and February 6, 2023. However, there was a total of 0.53” of precipitation during post-herbicide data collection on February 25, 2023. The temperature averaged above 50°F 24 hours prior to herbicide application and over 48 hours after application. No precipitation occurred during the 48-hour window post-herbicide application.

	High (°F)	Low (°F)	Precipitation (“)
01/24/23	50	24	0.00
02/04/23	49	22	0.00
02/05/23	59	27	0.00
02/06/23	61	32	0.00
02/07/23	68	33	0.00
02/08/23	57	44	0.00
02/25/23	54	49	0.53

Table 2. Measurement of temperature and precipitation during the days of observation (01/24/23, 02/25/23), 2 days prior to herbicide application (02/04/23, 02/05/23), the day of herbicide application (02/06/23), and 2 days post herbicide application (02/07/23, 02/08/23).

When observed, plots treated with Triclopyr™ herbicide showed a larger amount of death amongst the English Ivy. The leaves became limp and wilted, but there was some green still left. Although the plants treated with Triclopyr™ showed wilting and drooping, the plants treated with Escort™ began to show leaves turning brown. There was a greater amount of green left on the English Ivy within the Escort™ herbicide plots in comparison to the Triclopyr™ herbicide plots.

A 

B 

Figure 4. Plots treated with (**A**) Triclopyr™ and (**B**) Escort™ when observed two weeks after herbicide application.

The plots treated with Escort™ herbicide caused an average percent reduction of green English Ivy 38.99%. The average percent cover pre-herbicide had a lower standard deviation at 3.75 compared to the average percent cover post-herbicide at 6.92. A paired t-test confirmed that there was a significant reduction in percent cover by English Ivy after treatment with Escort™ ($p = 1.0 \times 10^{-6}$).

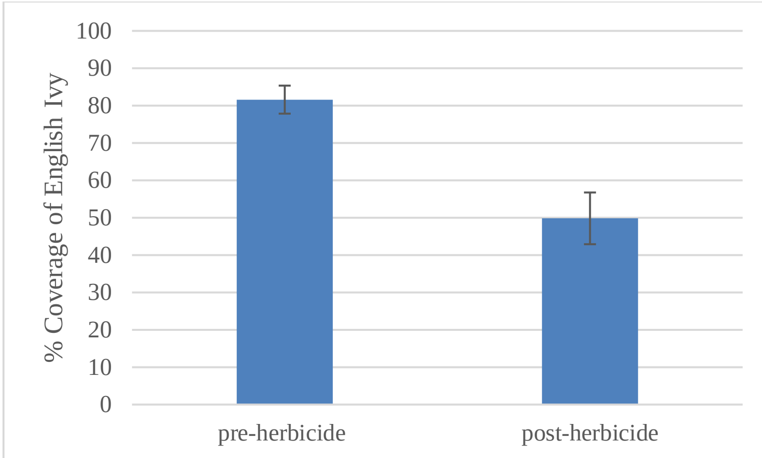

Figure 5. The percent coverage of English Ivy before and 19 days after Escort™ herbicide was applied to the plots ($p = 1 \times 10^{-6}$, paired t-test).

The plots treated with Triclopyr™ herbicide caused a greater percent reduction of green English Ivy when compared to the plots treated with Escort™ herbicide and the control at 61.77%. The standard deviation for the plots treated with Triclopyr™ also varied largely between the standard deviation of average percent cover pre-herbicide at 4.68 and an average percent cover post-herbicide of 12.24. A paired t-test confirmed that there was a significant reduction in percent cover by English Ivy after treatment with Triclopyr™ ($p = 3.70 \times 10^{-6}$).

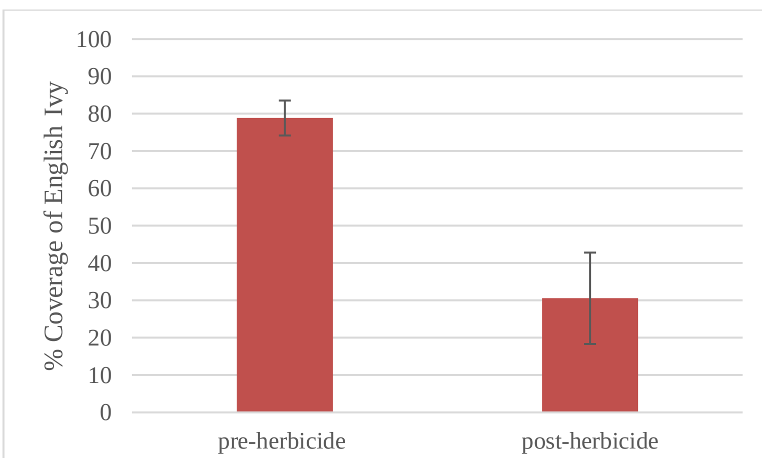

Figure 6. The percent coverage of English Ivy before and after Triclopyr™ herbicide was applied to the plots ($p = 3.70 \times 10^{-6}$, paired t-test).

The control plots did not vary much between pre- and post-herbicide application with an average percent reduction of green English Ivy of 2.78%. The standard deviation for average percent cover pre-herbicide was 6.93 and for average percent cover post-herbicide was 6.51. A paired t-test confirmed that there was no significant reduction in percent cover by English Ivy ($p = 0.26$).

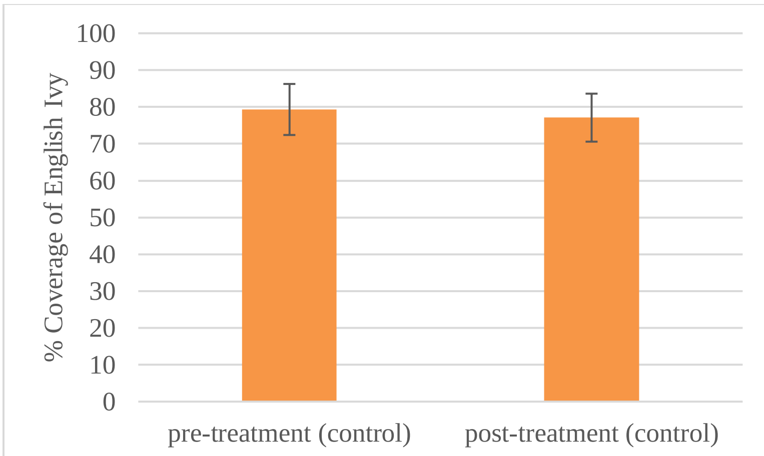

Figure 7. The percent coverage of the control English Ivy plot before and after herbicide was applied ($p = 0.26$, paired t-test).

Overall, the pre- and post-herbicide application on the plots caused an ANOVA average percent reduction of green English Ivy 34.52%. The standard deviation was wide in the overall difference with average percent cover pre-herbicide application being at only 5.17 and average percent cover post-herbicide application being at 21.32. A paired t-test confirmed that there was a significant reduction in percent cover by English Ivy after treatment with Triclopyr™ and Escort™ ($p = 1.80 \times 10^{-6}$).

Figure 8. The overall percent coverage of English Ivy before and after herbicide was applied to 14 of 21 plots ($p = 1.80 \times 10^{-6}$, paired t-test).

An ANOVA with Tukey Post-Hoc was used to compare each treatment (Escort™, Triclopyr™, and the control) to the others to determine if there was a statistical difference in the percent reduction of green English Ivy. The absolute mean values were 22.78, 58.98, and 36.21 respectively. The critical Q value was 6.52. All absolute mean values were greater than the critical Q value. The p-value of ANOVA was 2.46×10^{-9}, showing a statistically significant difference from each other.

CHAPTER IV

DISCUSSION

English Ivy, or *Hedera helix*, is a green climbing vine that was introduced into America in colonial times and was first used as an ornamental plant (Okerman 2000). At first, English Ivy was used as a landscape plant in the Pacific Northwest because it had a higher rate of survival, grew quickly, and was adapted to sub-tropical zones (Okerman 2000). Since then, it has been thought to invade more forests and reach the Southeastern United States due to the help of extensive logging and human habitation in the area (Biggerstaff and Beck 2007). The advantage logging gave to English Ivy came from increased light and less root competition due to the trees being cleared out of their way (Biggerstaff and Beck 2007).

English Ivy has spread across the United States, growing rapidly in deciduous forests, and forming a green carpet across the forest floor, blanketing out other trees and vegetation (Okerman 2000). It forms a dense ground cover that prevents almost all other vegetation from emerging and drastically reduces light levels (Biggerstaff and Beck 2007). Not only does English Ivy block other plants from emerging, but it also climbs and engulfs trees by blocking out any light the leaves of the tree may receive (Swearingen and Diedrich 2006).

As a result, English Ivy drastically changes the forest ecosystem and outcompetes many plants that may surround it, even natives. English Ivy is one of the many invasive species inhabiting the Maryville College (MC) Woods in Maryville, Tennessee. Numerous methods have been attempted to eradicate this invasive species, but none have proven successful thus far. The purpose of this study was to determine a way to get rid of English Ivy, as an invasive species, and allow for more native Tennessee plant populations to return to the Maryville College Woods. The hypothesis for this study is that herbicide application on English Ivy will kill 70% of the green English Ivy dominating the plots observed.

Escort™ herbicide was applied to plots 1, 4, 9, 12, 14, and 18. Within these plots, there was a percent reduction of living English Ivy 38.99%. This showed that 38.99% of the English Ivy was killed off in comparison to the data that was collected in the initial pre-herbicide application of data. There was a higher standard deviation in post-herbicide application (6.92) in comparison to pre-herbicide application (3.75) due to variation in the amount of live English Ivy on the 7 plots. A paired t-test was used to determine if there was any significance within the data that was collected. From this test it was determined that the p-value of Escort™ herbicide ($p = 1.0 \times 10^{-6}$) showed significance. Significance being shown means that the hypothesis is confirmed and Escort™ herbicide was effective in killing the green English Ivy.

In 1991 and 1992, experiments were performed to determine the effectiveness of herbicides, including Escort™, on woody plants, vines, and other vegetation along roadways in eastern Texas (Meyer et al. 1993). Herbicides, such as kernite and arsenal were found to be more effective at killing woody vegetation in comparison to Escort™ (Meyer et al. 1993). Escort™ was not found to enhance any woody plant control at the research sites (Meyer et al. 1993). Herbicides combined with Escort™ had a greater amount of death, but little in comparison to when they were combined with herbicides other than Escort™ (Meyer et al.

1993). The current study indicates that despite its ineffectiveness on other woody plants, it is effective at killing English Ivy. However, in agreement with prior work, it was found that other herbicides are more effective.

Triclopyr™ herbicide was applied to plots 5, 6, 7, 8, 13, and 15. Within these plots, there was a percent reduction of living English Ivy 61.77%. This showed that 61.77%% of the English Ivy was killed off in comparison to the data that was collected in the initial pre-herbicide application of data. There was a much higher standard deviation in post-herbicide application (12.24) in comparison to pre-herbicide application (4.68) due to variation in the amount of live English Ivy on the 7 plots. A paired t-test was used to determine if there was any significance within the data that was collected. From this test it was determined that the p-value of Triclopyr™ herbicide ($p = 3.70 \times 10^{-6}$) showed significance. Significance being shown means that the hypothesis is confirmed and Triclopyr™ herbicide was effective in killing the green English Ivy.

These results are similar to those from a study on English Ivy that was conducted in British Columbia, Canada by Prasad in 2005. In this experiment herbicides and manual removal were tested to determine the best way to rid of English Ivy. They found that Triclopyr™ was best in stopping growth and resprouting of English Ivy (Prasad 2005). Triclopyr™ was applied to 10 English Ivy plants using a plastic bottle sprayer and results were monitored for 2 years to see if any regrowth or changes arose (Prasad 2005). Other herbicides, like glyphosate, were attempted to be used on field English Ivy but were found to be less successful in comparison to Triclopyr™ (Prasad 2005). However, more success was found when combining Triclopyr™ herbicide with manual removal, such as cutting, to ensure no regrowth would occur (Prasad 2005). Although Triclopyr™ was more effective and economical, concerns were raised on the long-term side-effects of Triclopyr™ on neighboring plants and animals (Prasad 2005).

There was little variation in the control plots at only a 2.78% reduction in live growth. However, some difference in readings at two different points was expected due to the research taking place outdoors. Various conditions could have attributed to any differences seen in the control plots such as weather, human traffic through the area, or animals. Along with this, a paired t-test was conducted to determine that the p-value ($p = 0.26$) showed no significance, but no herbicide was applied to these plots, so no significance was expected.

For the overall data of the before/after of the two herbicides combined, a paired t-test was used to determine if there was any significance within the data that was collected. From this test it was determined that the p-value of both Escort™ and Triclopyr™ herbicides ($p = 1.80 \times 10^{-6}$) showed significance. Significance being shown means that the hypothesis is confirmed, and Escort™ herbicide was effective in killing the green English Ivy. The herbicides used in this research killed a total of 34.52% of the English Ivy that was documented at the beginning of this study.

The standard deviation for green English Ivy varied between Escort™ and Triclopyr™. Pre-herbicide application of Triclopyr™, there was a standard deviation of 4.68 and after herbicide application the standard deviation was 12.24. Pre-herbicide application of Escort™ showed a standard deviation of 3.75 and 6.92 post-herbicide application. Triclopyr™ had a larger range of standard deviation due to the effectiveness of the herbicide and the reaction of English Ivy. This was due to the herbicide killing live English Ivy on some of the plots, but not all of them. This difference may have been due to a varying amount of sun exposure, canopy coverage, or varying amounts of precipitation. There was a greater variance post-herbicide application for both Triclopyr™ and Escort™ due to the death of the plant.

The Escort™ herbicide overall showed a lower percent reduction and p-value (38.99%, 1.0×10^{-6}) than Triclopyr™ herbicide (61.77%, 3.70×10^{-6}). When the plots with Escort™ were compared to the plots treated with Triclopyr™ and the non-treated plots (control) by an ANOVA with Tukey Post-Hoc analysis, significance was seen between all groups. All absolute mean differences were larger than the critical Q value (6.52). Each group showing statistical differences explains that there is a high degree of confidence that the herbicides caused the death of live English Ivy and that one herbicide (Triclopyr™) killed more English Ivy than the other (Escort™).

When comparing the plots treated with Escort™ to the non-treated plots (control), an absolute mean difference of 36.21 was seen. When the plots treated with Triclopyr™ were compared to the non-treated plots (control), an absolute mean difference of 58.98 was seen. The difference is values explains a higher degree of effect between the plots treated with Triclopyr™ and the plots treated with Escort™. This variation may show that Triclopyr™ herbicide had a greater effect on English Ivy than Escort™ did, but both herbicides were successful in killing off live English Ivy.

Although Triclopyr™ herbicide had a greater success rate, external factors must be considered for both herbicides such as: amount of sunlight reaching each plot, amount of rainfall on each plot, and herbicide temperature dependencies. Some plots may have received more sunlight or rain than other plots due to any breakup of the tree canopy. This may also be true due to the random position each had – some plots were placed closer to trees, forest liter, or pathways than others causing variation within the data.

Each herbicide has a specific temperature range that they are most likely to work within. The range of Triclopyr™ is between 50°F to 80°F and the temperature range for Escort™ is smaller at 65°F - 75°F (Klotzbach and Durkin 2004). Triclopyr™ has a larger range of temperatures it is likely to work within, but it does have greater side-effects in comparison to Escort™. Triclopyr™ may cause permanent damage when ingested by humans and other mammals via food or water (loss of vision, difficulty breathing), but is low in toxicity for aquatic organisms (Strid et al. 2018, Antunes-Kenyon and Kennedy 2004). Although it may be toxic if consumed, it does not leach deep into the soil, is dissolved within a minimum of 1 day, and is specific to broadleaf plants (Strid et al. 2018, Antunes-Kenyon and Kennedy 2004). Escort™ has a smaller range for successful herbicide usage, but it is more environmentally friendly. Escort™ is very low in toxicity and is only known to cause issues in birds, bees, or insects if ingested at a high volume (Klotzbach and Durkin 2004). There is little to no risk to fish or other aquatic organisms, but other vegetation may be impacted by runoff if rainfall occurs too close to application (Klotzbach and Durkin 2004).

Through this research it is evident that Triclopyr™ is more effective than Escort™, but risks should be considered. Triclopyr™ has more success within the MC Woods due to less possibility of a large animal interfering with the vegetation. It is also a more ideal candidate to use for herbicide due to the limited staff and volunteers Maryville College has available to eradicate English Ivy as an invasive in the woods, in comparison to a national park. Escort™ would be more suited for a National Park environment due to the protection of animals and plants. Although Escort™ may not be as quick as Triclopyr™ for eradicating an invasive, national parks such as the Great Smoky Mountains National Park must focus on the welfare of the organisms they house.

More research should be conducted to further validate this research such as testing the herbicides within a controlled environment. Testing herbicides in an environment capable of producing a consistent amount of sunlight, humidity, and temperature would be imperative to distinguish which herbicide is the best use for English Ivy. Other experiments should be conducted in warmer weather to determine efficiency of herbicide usage on English Ivy when other vegetation is beginning to come out of dormancy or compete with the English Ivy.

APPENDIX 1: RAW DATA

	1/24/2023 plot pre-herbicide application																				
cell	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	8	8	9	7	8	9	9	9	9	7	8	9	10	9	9	7	7	9	9	9	5
2	7	7	9	8	8	9	9	9	9	5	5	9	8	8	9	9	8	9	8	7	4
3	7	8	8	9	7	4	9	10	10	8	8	9	9	5	8	4	9	8	10	8	4
4	8	9	7	9	9	9	7	7	9	9	7	7	7	8	8	9	9	9	8	8	6
5	7	9	9	5	9	8	8	4	9	9	8	8	8	9	9	9	8	9	9	9	6
6	7	10	7	9	9	8	9	9	8	9	9	9	9	8	9	10	9	7	9	9	7
7	8	7	9	7	10	9	7	8	10	9	5	9	5	9	8	5	9	8	10	9	5
8	9	10	8	9	9	9	10	9	8	9	8	9	5	7	9	9	9	8	5	9	8
9	9	9	9	9	7	7	9	9	4	7	9	10	8	9	9	9	8	9	5	9	7
10	8	10	8	7	4	9	8	7	4	9	8	7	8	8	10	8	7	9	8	7	3
11	4	9	10	5	9	9	9	8	8	10	9	5	7	8	10	9	8	8	9	9	10
12	9	9	9	9	9	7	9	10	10	7	9	10	10	9	10	8	5	9	8	10	10
13	9	9	7	8	5	9	10	8	9	4	8	5	9	9	9	7	5	9	9	10	8
14	9	10	5	9	9	9	7	8	9	4	9	5	7	9	9	8	7	2	10	7	7
15	9	9	4	8	8	9	9	5	10	8	9	7	5	7	8	10	9	10	10	9	9
16	8	9	10	8	9	7	9	8	10	8	9	8	9	9	8	9	9	10	10	9	4
17	8	9	10	8	9	8	4	7	10	9	9	9	9	9	9	5	9	9	9	8	7
18	9	9	7	9	9	9	8	8	9	8	5	9	8	9	10	10	4	9	9	9	8
19	8	8	7	7	5	5	7	5	9	9	9	7	4	9	9	9	5	8	8	9	9
20	10	5	10	4	10	7	7	4	9	7	5	9	2	9	9	8	9	9	9	10	8
21	9	9	8	5	9	10	9	5	9	4	9	9	7	9	5	5	8	5	8	10	6
22	7	9	10	9	9	10	2	5	10	4	8	8	5	7	5	9	8	5	9	8	10
23	4	10	10	9	7	5	9	8	9	10	7	10	4	7	8	10	10	8	9	9	8
24	9	9	8	8	9	7	10	7	9	5	8	7	8	9	8	8	10	9	5	9	7
25	4	9	8	8	9	7	9	7	10	9	5	7	8	10	7	4	7	8	5	7	4

Pre-herbicide application of raw data based on observations made with the $1m^2$ plot. The different types of plots are designated based on color: Triclopyr™ (orange), Escort™ (blue), control (white). 1 = 10% coverage, 10 = 100% coverage.

	2/25/2023																				
	plot post-herbicide application																				
cell	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	5	8	9	3	1	4	6	3	4	7	8	6	2	5	2	2	7	6	3	9	5
2	4	6	9	4	2	5	6	3	5	5	5	8	4	4	5	2	8	5	1	7	3
3	5	8	8	5	2	3	6	4	8	8	8	9	1	4	1	1	9	4	4	8	4
4	3	9	7	5	4	3	3	2	7	9	7	5	1	5	3	1	9	8	4	6	6
5	3	8	9	3	6	2	2	1	5	9	8	5	2	5	3	4	8	4	3	9	6
6	2	10	7	6	3	2	1	0	4	9	9	6	1	4	2	2	7	5	5	8	7
7	3	7	8	5	5	7	4	1	6	8	5	6	0	3	4	2	8	5	6	7	5
8	4	10	8	10	4	6	9	4	4	9	8	8	4	2	6	4	9	4	3	8	8
9	5	9	9	3	2	3	3	2	2	7	9	10	2	6	7	3	8	4	3	9	7
10	4	10	8	2	3	8	2	1	5	9	7	4	0	4	4	2	7	4	6	7	3
11	4	9	10	5	6	8	3	1	2	10	8	4	0	5	3	1	8	5	3	9	8
12	6	9	9	4	6	5	2	3	5	7	9	6	1	7	8	4	5	5	3	10	10
13	7	9	7	4	3	8	5	2	6	4	8	4	1	6	7	2	4	5	3	10	8
14	7	10	5	6	4	9	4	4	7	3	9	3	3	6	5	3	7	2	7	7	7
15	7	9	6	4	1	5	2	2	9	7	8	3	1	3	3	3	9	4	10	9	9
16	4	9	4	3	5	4	2	1	10	8	8	7	1	8	4	5	8	6	5	8	4
17	4	9	10	6	3	4	4	2	9	9	7	6	1	4	4	3	9	6	4	8	7
18	5	9	10	6	5	3	0	2	10	8	5	6	0	5	5	6	4	8	3	9	8
19	5	8	7	4	4	3	0	2	8	9	9	4	0	7	5	3	5	3	3	7	9
20	9	4	6	2	1	4	2	1	4	7	4	5	0	8	0	4	9	7	5	10	8
21	4	9	10	2	3	8	4	0	6	3	9	5	0	4	1	2	7	4	4	10	6
22	3	9	8	7	3	8	1	3	7	4	8	5	1	3	1	3	8	2	5	8	10
23	2	10	10	9	5	4	1	1	4	10	7	5	0	4	6	3	10	4	5	9	8
24	2	9	10	7	3	3	1	3	6	5	8	10	2	5	7	4	10	3	3	9	7
25	3	8	6	4	4	2	2	2	8	9	5	5	2	9	5	1	7	2	5	7	4

post-herbicide application of raw data based on observations made with the $1m^2$ plot. The different types of plots are designated based on color: Triclopyr™ (orange), Escort™ (blue), control (white). 1 = 10% coverage, 10 = 100% coverage.

WORKS CITED

Antunes-Kenyon SE, Kennedy G. 2004. A Review of the Toxicity and Environmental Fate of Triclopyr™ [Internet]. Massachusetts Department of Agricultural Resources; [cited 2023 April 10]. Accessed from: https://massnrc.org/ipm/contact-us.html

Berisford YC, Bush PB, Taylor JW. 2006. Leaching and persistence of herbicides for kudzu (*Pueraria montana*) control on pine regeneration sites. Weed Science. 54:391-400.

Biggerstaff MS, Beck CW. 2007. Effects of Method of English Ivy (Hedera Helix) on Seed Bank Formation and Germination. The American Midland Naturalist. 157(2):250-257.

Biggerstaff MS, Beck CW. 2007. Effects of Method of English Ivy Removal and Seed Addition on Regeneration of Vegetation in a Southeastern Piedmont Forest. The American Midland Naturalist. 158(1):206-220.

Frye MJ, Hough-Goldstein J, Sun JH. 2007. Biology and Preliminary Host Range Assessment of Two Potential Kudzu Biological Control Agents. Environmental Entomology. 36(6):1430-1440.

Green AF, Ramsey TS, Ramsey J. 2013. Polyploidy and Invasion of English Ivy (Hedera spp., Araliaceae) in North American forests [Internet]. Springer; [cited 2023 April 10]. Available from: https://static1.squarespace.com/static/548475cde4b0982d899e8797/t/54a81c8fe4b09c6fe40876fc/1420303503013/Green+et+al+2013.pdf

Gulizia JP, Downs KM. 2019. A Review of Kudzu's Use and Characteristics as Potential Feedstock. Agriculture. 9(220):1-15.

Harrington TB, Rader-Dixon LT, Taylor JW. Kudzu (Pueraria montana) Community Responses to Herbicides, Burning, and High-Density Loblolly Pine. Weed Science Society of America. 51(6):965-974.

Klotzbach J, Durkin P. 2004. Metsulfuron Methyl – Human Health and Ecological Risk Assessment – Final Report. USDA, Forest Service. 1-152.

Launchbaugh K, Walker J. 2006. Targeted grazing: a natural approach to vegetation management and landscape enhancement. Centennial (CO): American Sheep Industry Association. 2-8.

Manning S, Miller J. 2011. Manual, Mechanical, and Cultural Control Methods and Tools [Internet]. American Chemical Society; [cited 2023 April 10]. Available from: https://www.usda.gov/

Melzer B, Seidel R, Steinbrecher T, Speck T. 2011. Structure, attachment properties, and ecological importance of the attachment system of English Ivy (Hedera Helix). Journal of Experimental Botany. 63(1):191-201.

Meyer RE, Motteram ES, Evans SG, McCully WG. 1993. Controlling Forest Encroachment Along East Texas Roadways. Texas Transportation Institute. 1-43.

Miller J. 1998. Exotic Invasive Plants in Southeastern Forests' [Internet]. Exotic Pests of Eastern Forests; [cited 2023 April 10]. Available from: https://www.usda.gov/

Kucharski L, Kloss M, Sienkiewicz J, Liszewska M, Kieltyk P. 2019. Impact of climate change on ivy (Hedera helix L.) expansion in forests of Central Poland. Sciendo. 61(3):211-221.

Okerman A. 2000. Combating the “Ivy Desert”: The Invasion of Hedera helix (English Ivy) in the Pacific Northwest United States. Restoration and Reclamation Review. 6(4):1-10.

Pfenningwerth AA, Kuebbing SE. 2012. Direct Costs Associated with Invasive Non-Native Plants in Tennessee [Internet]. Wildland Weeds; [cited 2023 April 10]. Available from: https://www.se-eppc.org/

Prasad R. 2005. Status and management options of exotic and invasive weeds of forestry in coastal British Columbia, Canada [Internet]. Invasive Weeds in Forests; [cited 2023 April 10]. Available from: https://cfs.nrcan.gc.ca/pubwarehouse/pdfs/25961.pdf#:~:text=CURRENT%20STATUS%20AND%20MANAGEMENT%20OPTIONS%20OF%20EXOTIC%20AND,Forestry%20Centre%2C%20Natural%20Resources%20Canada%2C%20Victoria%2C%20B.C.%20rprasad%40nrcan.gc.ca

Strid A, Hanson W, Cross A, Jenkins J. 2018. Triclopyr™ General Fact Sheet [Internet]. National Pesticide Information Center; [cited 18 March 2023]. Available from: http://npic.orst.edu/factsheets/Triclopyr™gen.html.

Swearingen JM, Diedrich S. 2006. Fact Sheet: English Ivy [Internet]. Plant Conservation Alliance’s Alien Plant Working Group; [cited 2023 April 10]. Available from: https://monte riocentral.com/assets/community/ivyFactSheetNPS.pdf.com)

United States Environmental Protection Agency. 1998. Reregistration Eligibility Decision (RED) Triclopyr™.

Yang Q, Wehtje G, Gilliam CH, McElroy JS, Sibley JL. 2013. English Ivy (Hedera helix) Control with Postemergence-Applied Herbicides. Weed Science Society of America. 6:411-41