Techniques to Suppress Invasive Oriental Bittersweet (*Celastrus orbiculatus*) on Presque Isle State Park in Erie, Pennsylvania

By

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ABSTRACT

Oriental bittersweet (*Celastrus orbiculatus*) is a deciduous, woody vine native to Southeast Asia. Currently this invasive is considered a major threat to native forests in the eastern United States. Some characteristics associated with its' competitive ability include shade tolerance, ability to colonize a wide range of suitable environmental conditions, and prolific seed production, viability and germination. These factors contribute to difficulties related to the suppression and containment of this species. In order to preserve native plant communities at Presque Isle State Park in Erie, PA, a total of 5 treatments, each having 4 replicates was established to test various procedures to suppress this invasive species and restore native plant communities. Two control treatments involved either making cuts of all stems at chest height and ground level (window cut) with no subsequent treatment or no action at all. Additional treatments consisted of a basal stump herbicide application of a 100% solution of either triclopyr or glyphosate to every cut stem immediately after window cuts were made. The last treatment method consisted of making window cuts followed by a foliar herbicide application 5 weeks post cut with a backpack sprayer containing a solution of 6% glyphosate and 3% triclopyr. Data analyses show that the most effective method to suppress *C. orbiculatus* is by making a window cut of all stems followed by a foliar herbicide application 5 weeks post cut. Plots with this treatment had significantly fewer regrowth stems and these stems had a trend towards shorter length as opposed to other treatments. This knowledge has the potential to assist not only Presque Isle State Park but many other locations afflicted with the presence of this invasive species.

INTRODUCTION

Invading non-native species within the United States have resulted in environmental losses and damages totaling nearly $120 billion per year (Pimentel et al. 2005). This destructive nature is due to the introduction of approximately 50,000 non-native species within the United States. Predation and competition between native and non-native species is directly linked to 42% of the native species that have been listed as Threatened or Endangered under the Endangered Species Act (Wilcove et al. 1998). Understanding the complexities associated with invading non-native species can allow for the preservation of our natural resources through prevention and suppression of these species.

Non-native invasive plant species pose a major threat to the ecosystems they inhabit. They are commonly associated with modifications in population densities of native species and a decline in habitat and resource availability. Often, eradication of an invasive is desirable; however, the feasibility of this process declines as invaded areas increase. Invasive plants have cumulatively cost the United States tens of billions of dollars in damages to industry and agriculture and have considerable negative impacts to natural ecosystems and native species (Mack 2000; Pimentel 2005). Therefore, determining the most effective measure to suppress an invasive species will allow for the most efficient allocation of resources to preserve native communities.

Celastrus orbiculatus is an aggressive invasive plant species that is considered a major threat to natural habitats throughout the eastern United States. This species has the potential to outcompete native plants in a diverse range of conditions. Currently, this species has the capacity to establish in open fields, along coastal areas, disturbed roadside habitats, and closed canopy forests. Some characteristics associated with this species' competitive ability include shade tolerance, ability to thrive in wide range of suitable environmental conditions, prolific seed production, and high seed viability and germination (Dreyer et al. 1987). These factors contribute to difficulties related to the suppression and containment of this species. Alterations in succession occur through inhibition of understory seedlings by the prevention of photosynthesis due to shading. The presence of this invasive species has been linked to significantly higher soil pH, calcium, magnesium, and potassium levels. A trend has also been seen in relation to higher nitrogen mineralization and litter decomposition rates when *C. orbiculatus* is established (Leicht-Young et al. 2009). The combination of these characteristics substantiated the ability of *C. orbiculatus* to alter existing environmental conditions and potentially result in native species inhibition.

A major concern associated with the invasion of *C. orbiculatus* is the suppression of native species, especially American bittersweet (*Celastrus scandens*). *Celastrus scandens* is native to eastern North America and is common in thickets and along roadsides (Gleason and Cronquist 1963; Seymour 1982). Despite similar growth characteristics among *Celastrus*, the native is less aggressive. They both utilize their root suckering capabilities to spread vegetatively resulting in vigorous clonal expansion (Dreyer et al. 1987). However, *C. scandens* requires open or patchy light conditions to expand while *C. orbiculatus* rootsuckers proliferate under a wider variety of conditions quite rapidly (Patterson 1974; Dreyer 1984; McNab 1987).

Celastrus orbiculatus was first introduced in the northeastern United States around 1860 as an ornamental. Since its original introduction, this species is reported as established in 33 states and deemed an invasive in 21 states (Lynch 2009). A common characteristic that continues to make this species a valued ornamental is its colorful and often abundant fruiting bodies.

Following establishment, *C. orbiculatus* is exceptionally difficult to eradicate. Each fruiting body contains anywhere from 3-9 seeds and is dispersed via wind, small mammals, and birds. These fruits mature in late September and can remain on the vine throughout the winter season (Ellsworth et al. 2004). A greenhouse experiment lasting two years ascertained that *C. orbiculatus* seeds do not persist in the seed bank. This was deduced by the lack of germination after one year (Kostel-Hughes et al. 1998). Conversely, field research has shown that seeds contain enough metabolic reserves to remain viable for up to several years (Dreyer 1994). Differences in these results can possibly be explained by dissimilarities among experimental conditions. Consequently, any method to suppress or eradicate this species should be implemented for several years to ensure sufficient measures have been taken.

Once *C. orbiculatus* has successfully established, it can girdle or overtop native shrubs and trees in forest gaps, along roads, and in clearings (Dreyer et al. 1987; McNab and Meeker 1987; Patterson 1974). *Celastrus orbiculatus* either grows in a sprawling manner overtopping shrubs or twines up tree trunks. These two growth forms increase invasion efficacy by targeting disturbed locations that have greater resource availability (Hobbs and Huenneke 1992; Greenbery et al. 2001). By utilizing existing trees, *C. orbiculatus* can reach maximum heights of 20 m ultimately resulting in host mortality due to girdling of the trunk. Both natural and human-caused disturbances tend to result in a greater amount of germination sites, water, and light availability. However, *C. orbiculatus* seedlings have been observed surviving within intact forest understories that contain little light availability (Ellsworth et al. 2013). This further complicates the preservation of natural habitats since disturbances are not essential for successful establishment.

Despite an extensive amount of background knowledge on this species, the most efficient treatment for containing this invasive is unknown. The uses of herbicides, such as glyphosate and triclopyr, have displayed some success but the most effective herbicide application method is unknown. Glyphosate has been utilized over the past three decades as a non-selective, post-emergent herbicide that is readily translocated throughout the plant system (Nandula et al. 2003). The biosynthesis of the aromatic amino acids phenylalanine, tyrosine, and tryptophan are inhibited by this herbicide resulting in disturbances to metabolic processes. In order to effectively target species, it must be applied to actively growing plants to allow for successful translocation. Triclopyr acts systemically as a synthetic auxin causing an overdose of roughly 1000 times natural levels in a plant (Netherland and Getsinger 1992). This causes severe hormonal imbalances which ultimately interfere with plant growth. This herbicide is used to control broadleaf weeds and woody plant while leaving conifers and grasses unaffected (Netherland and Getsinger 1992).

The most effective herbicide application technique for treating *C. orbiculatus* has a long history of debate in the scientific literature (Dreyer et al. 1988; Hutchinson 1992; McNab 1987). The two most common techniques involve either a foliar herbicide application with a backpack sprayer or stump application of herbicide on freshly cut stems with a handheld sprayer. These methods have displayed varying success rates and the optimum application is unknown. The objective of this study is to determine the most effective treatment method to suppress *C. orbiculatus*. Cut stems of this invasive were utilized to ascertain whether herbicide plays a crucial role in stifling regrowth and if so, which herbicide mixture and application technique has the greatest suppression capabilities.

METHODS

Site Description

Presque Isle State Park (42^{o}16'N, 80^{o}1'W), located in Erie, Pennsylvania encompasses 1,259ha of unique habitats to form a peninsula extending into Lake Erie. This park is a large sandbar that has a gravel moraine formation instead of a bedrock formation. The combination of lake currents and westerly winds cause the sand to wash away from the western end to the eastern point of the peninsula. Manmade efforts consisting of yearly deposition of sand and maintenance of 50 breakwaters are utilized to prevent this landmass from moving eastward. There are seven different ecological zones located within the park ranging in a gradual progression from beach shoreline to mature forest (Ware, 2011). The seven ecological zones are Lake Erie, the bay and shoreline, sandy plain and new pond, sand dunes and ridges, marshes and old ponds, thicket and subclimax forest, and climax forest (Ware, 2011). These unique habitats harbor a plethora of rare and threatened species which make this park a high priority site for ecological protection and restoration.

Average maximum temperatures in Erie, PA range from 0.3^{o}C in January to 21.8^{o}C in July while the average minimum temperatures vary from -7.8^{o}C in February to 17.0^{o}C in July (CIA World Fact Book 2011). Annual average maximum temperature is 13.9^{o}C and annual average minimum temperature is 5.2^{o}C. Average precipitation is 1.05 m and annual snowfall 2.19 m. Soil composition at Beach 6 on Presque Isle State Park is composed of lamson silt loam (USDA 2012). This soil type is poorly drained and has a high frequency of ponding. The typical soil profile at this location is silt loam from 0-0.2 m with fine sandy loam beneath.

Plots were located based on two conditions; invasion of *C. orbiculatus* twining up a tree and clonally isolated establishment. Most invasions by this species are quite dense which make it difficult to determine if treatments are affecting the entirety of the plant or only portions. By focusing on a clonally isolated invasion centered on a host tree, accurate analysis of the treatment can be determined because the entire plant is being targeted and not just a few stems. Additionally, each plot was established in areas affected by the twining growth form instead of sprawling form to increase the control of each applied treatment. Areas affected with the sprawling growth form were less likely to be isolated and often sprawled over multiple bushes. Each plot had to be located at least 2 m from the nearest plot to ensure that treatments did not have an effect on any other location. For this specific experiment, all plots were established at Beach 6 on Presque Isle State Park. Plot locations are shown in Figure 1 and each plot treatment was chosen using a random number generator.

The forest overstory at Beach 6 was generally dominated by *Sassafras albidum* (sassafras), and *Acer rubrum* (red maple). Percent cover for each plot was estimated using a spherical densitometer with values ranging from 70-85% cover at each location. Having each plot with relatively consistent forest overstory in terms of percent cover and species composition increased uniformity among plot conditions.

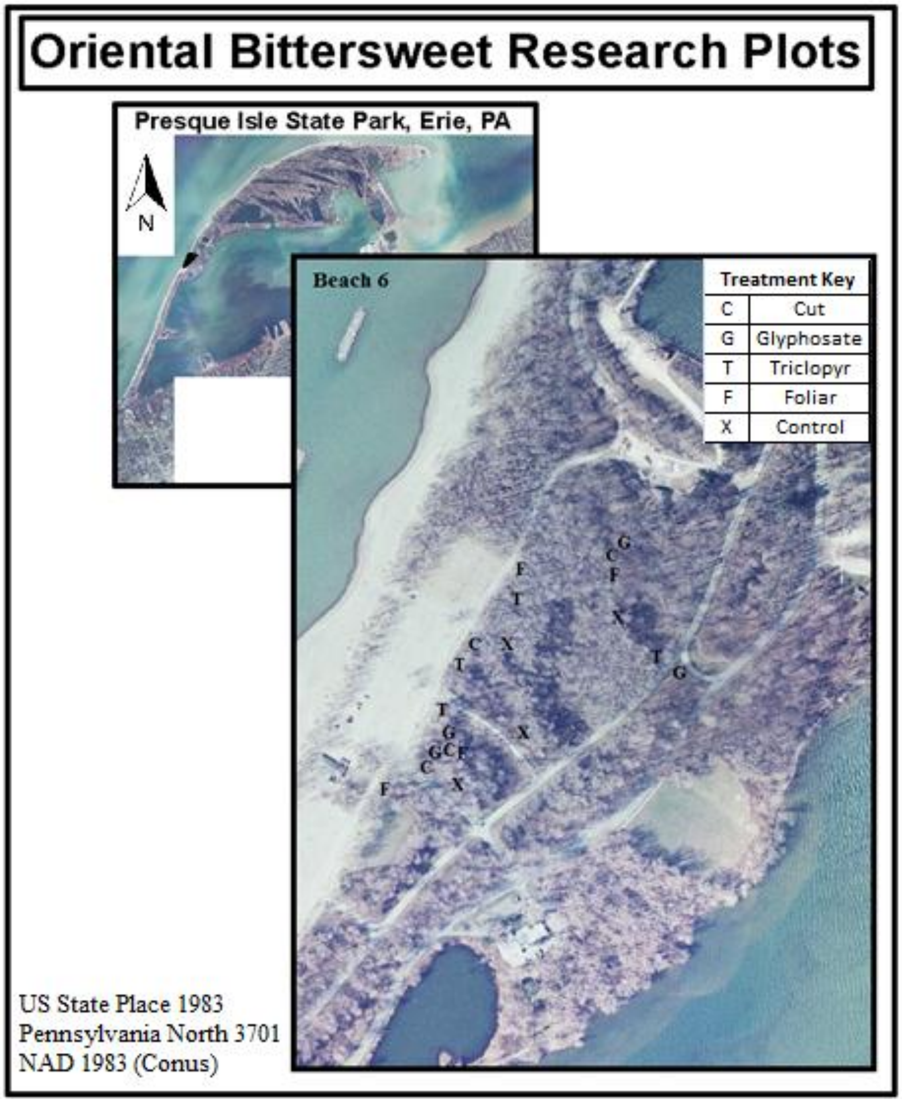

Fig. 1. Location of study area and plot locations at Beach 6 on Presque Isle State Park. Coordinate locations were collected using a Trimble Juno SB. Each plot location is indicated by a letter specifying the treatment applied: C = cut, G=glyphosate, T=triclopyr, F=foliar, X=control.

Experimental Design and Implementation

On 30 June 2012, twenty plots were established at Beach 6 on Presque Isle State Park. Five treatments consisting of four replicates each were randomly assigned using a random number generator to eliminate any potential biases. Treatment began on 7 July 2012. Two different control treatments were utilized that involved either no manipulation of *C. orbiculatus* stems in the plots or a window cut on all stems in the plots. A window cut is when each stem has two cuts applied, one at chest level and another at ground level. This process decreases the risk of leaving stems uncut by forming a gap of all cut stems surrounding the plot tree. Two additional treatments involved making a window cut of all stems and basal stump application using a spray bottle containing either 100% Garlon 3A # 62719-37 (triclopyr) or Glyphomate 41 # 2217-647 (glyphosate) within thirty seconds after each cut was made. The final treatment consisted of a window cut of each stem followed by a foliar herbicide application using a 4 Gallon EZ Clean Backpack Sprayer by SP Systems (SPS 507). The backpack sprayer contained a mixture of 3% Garlon 3A # 62719-37 and 6% Glyphomate 41 # 2217-647 on all regrowth stems five weeks post cut on August 11. When plots contained plant species other than *C. orbiculatus* they were mainly the non-native invasive species *Allaria petiolata* (garlic mustard), or *Lonicera maackii* (bush honeysuckle). Rare occurrences of native plants included *Vitis riparia* (river grape), *Parthenocissus quinquefolia* (Virginia creeper), and *Toxicodendron radicans* (poison ivy).

Plot monitoring was conducted biweekly to measure regrowth stems in each plot. At each plot, the total number of regrowth stems, the basal area of the stump each stem originated from, and the regrowth length was measured. Despite *C. orbiculatus* being known as a root suckering species (Dreyer et al. 1987), all regrowth stems originated from a stump and not from the root system. Measurements took place on: 21 July, 4 August, 18 August, 1 September, 15 September, 29 September, 13 October, and 27 October. The final data collection date was established when there were negligible differences between regrowth stem lengths from the prior measurement date which indicated the end of the growing season.

DATA ANALYSIS

Shapiro-Wilk and Levene Tests were conducted to assess data normality and variance distribution. The relationship of *C. orbiculatus* with each treatment was determined by performing a one-way ANOVA for each dependent variable with a Duncan post-hoc test in case of significance (SPSS 2009).

The Shapiro-Wilk test concluded that the data is normally distributed and the Levene Test determined that variances were not homogeneous for three of the treatments (triclopyr stump herbicide application had homogeneous variances). A log transformation reduced heterodascity but did not change ANOVA results. The results reported here are with log transformed data. The control treatment which was not cut grew vigorously over the summer and these plots were not analyzed.

RESULTS

Stem count before treatment varied from 4 to 57 stems per plot with a DBH range of 0.1 cm to 9 cm. Stem count and DBH did not yield a significant difference (Table 1). High variability in the stem count per plot occurred because of the inclusion of numerous stems of 0.1 cm in diameter. Regrowth stem length varied from 0.1 cm to 167 cm and the number of regrowth stems per plot ranged from 0 to 44 stems. Multiple regrowth stems often originated from a single stump left from a cut stem. A significant difference was revealed when comparing regrowth stem numbers between treatments but not regrowth stem length (Table 1).

Duncan post-hoc test showed that differences in regrowth stem number occurred between cutting and cutting foliar herbicide application and stump triclopyr application (Table 1). No significant differences were seen in regrowth length but a trend (p=0.081) was observed that the cutting and foliar treatment had less regrowth length than the other treatments. This trend was supported by the Duncan post-hoc test which detected a difference between the cutting treatment and the cutting foliar herbicide application and stump herbicide application of triclopyr.

DISCUSSION

On the initial day of cutting all stems of *C. orbiculatus*, measurements were taken to compare the homogeneity among plots before treatments were applied. The number of stems and the DBH of each stem were documented to ensure that there was not a significant difference among plots that would cause a bias in the results obtained. The ANOVA results indicated that all of the plots were relatively the same in relation to those two factors (Table 1). Thus, the differences that were present in stem number and DBH were not large enough to influence plot response to the treatments.

Original stem number in each plot varied from 4 to 57 stems per plot. The variability among stem number can be explained by the vast amount of stems with 0.1 cm DBH within plots containing large amounts of stems. These minute stems did not produce any regrowth. This can be explained by stems having a decrease in nutrient reserves that could be utilized to produce regrowth.

ANOVA found a significant difference in treatments in relation to regrowth stem number. A post-hoc Duncan test concluded that the significant difference in treatments was seen between cutting with many more regrowth stems and the significantly fewer regrowth stems of foliar herbicide application and stump herbicide application of triclopyr (Table 1). Regrowth stem lengths were not significantly different; however regrowth length was the smallest for the cut foliar application (Table 1).

The most effective treatment to suppress *C. orbiculatus* is by performing window cuts on all stems followed by a foliar herbicide treatment of 3% triclopyr and 6% glyphosate five weeks post cut. Plots with this treatment had significantly fewer regrowth stems and these stems had a trend towards shorter length. This treatment is beneficial because the herbicide concentration is much lower when compared to a 100% herbicide solution for a stump treatment. Lower herbicide concentrations decrease risks associated with non-target plant damage by accidental application. The lower the herbicide concentration the greater the probability the plant has to withstand the effects associated with the applied chemical.

Currently, the foliar herbicide application is the most widely utilized form of treatment on Presque Isle State Park to suppress invasive plant species. Not only does this increase the probability of this method being utilized on this park to treat *C. orbiculatus* but it is the most effective method to suppress this invasive species. This knowledge results in an enhanced allocation of resources to aid the park staff in their ongoing battle against invasive plant species. Furthermore, this information will be documented in future invasive plant species management plans for Presque Isle State Park to increase efficiency among treatment methods.

Celastrus orbiculatus response to herbicide techniques varied among plot treatments. Regrowth stem length ranged from 0.1 cm to 135 cm on the final data collection date. These sizeable differences resulted in high variability among the data collected for this experiment. Adding additional plots to the study potentially would have increased the power of the analysis and therefore increased the ability of ANOVA to detect significant differences. Finding plots with isolated colonies of *C. orbiculatus* was exceptionally difficult on Presque Isle State Park. Despite challenges associated with a small sample size and wide ranged data, a trend in regrowth length was seen relating the foliar herbicide application 5 weeks post cut as the most effective treatment in suppressing this invasive species.

The plots utilized in this study were mainly composed of invasive plant species. Therefore, off target herbicide application would have affected species that are not native to the region. The overall composition of these plots mainly included *A. petiolata* and *L. maackii* but on rare occasions *V. riparia*, *P. quinquefolia*, and *T. radicans* occurred at low densities and low cover. Fortunately, these natives are abundant throughout the park and if by chance herbicide was applied and damaged them they would have the opportunity to colonize the area once again. However, this may not be the case in all locations afflicted with *C. orbiculatus.* Therefore, the use of herbicide may not be plausible under all conditions. Determining the most effective method to suppress this invasive without the use of herbicides would be substantially more difficult. Frequent cutting and even mowing of regrowth stems could assist in preventing further range expansion but it is recommended to use herbicide to increase the likelihood of containment.

Despite documentation confirming *C. orbiculatus* as a root suckering species, regrowth stems originated on the cut stems. When a stem is cut, *C. orbiculatus* should respond by allocating resources to the root system where regrowth stems can be produced (Dreyer et. al. 1987). However, each regrowth stem originated from a stump that was left from the original cut stem instead of from the root system. There was no incidence of a regrowth stem originating from any location other than a cut stem. This was unexpected because the regrowth was expected to appear randomly throughout the plot ground where the root system was present. Most plots contained forest understory that was either bare, contained other invasive plant species, or rarely had a few native plant species. Therefore, obstructions on the ground level do not explain this phenomenon. Instead, further research should be conducted in relation to the growth system of *C. orbiculatus* in order to further understand the origination of regrowth stems after severe disturbances.

The future in suppressing this invasive species on Presque Isle State Park is quite probable. Having determined the most effective method to treat *C. orbiculatus* has allowed for proper allocation of resources and increase in efficiency. These results will be utilized in the development of future invasive plant species management plans that will be implemented on the park for many years to come. With a steady collection of volunteers, interns, and park staff to treat invasive species, there is hope for this park to preserve their natural environments.

CONCLUSION

Results indicate that the most effective treatment to suppress stem regrowth from *C. orbiculatus* is by applying a foliar herbicide application of 3% triclopyr and 6% glyphosate 5 weeks post cut. This treatment resulted in a significant difference in the number of regrowth stems and a trend in decreasing regrowth length. This is advantageous because the concentration of herbicide that is needed in these plots is much lower when compared to a 100% herbicide solution for a stump application treatment. Having a lower herbicide concentration decreases the risk of non-target plant damage by accidental application since they will be more likely to withstand the effects of a lower herbicide concentration than a high one. Also, for Presque Isle State Park, it is more efficient to utilize a backpack sprayer as opposed to a spray bottle. This is because the majority of the workers that apply herbicide on the park travel with this exact solution of herbicide in their backpack sprayer when treating invasive plants. With that in mind, this treatment method will not only assist Presque Isle State Park but all other locations that are afflicted with this invasive species. An enhanced allocation of resources can be utilized based on this knowledge obtained in understanding the suppression of *C. orbiculatus.*

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Table 1. Pre- and post-treatment measurements for *Celastrus orbiculatus* stems at Presque Isle State Park (n=4 plots, mean ± 1 s.d.). ANOVA conducted on the four variables measured found a significant difference across treatments for regrowth stem number. Different superscript letters mean significant differences between treatments using a post-hoc Duncan test. Averages given are based on non-transformed averages and standard errors.

Plant Attribute	Treatment				df	F	ANOVA p Value
	Cut	Foliar	Glyphosate	Triclopyr			
Pre-treatment Stem Number	21.8±13.2	21.5±24.1	19.8±6.0	22.3±11.9	3	0.035	0.991
Pre-treatment Stem DBH (cm)	1.2±0.3	1.5±0.6	1.3±1.0	1.5±0.8	3	0.508	0.684
Regrowth Number	28.0±17.2[a]	16.3±4.7[b]	23.0±12.5[ab]	4.8±4.3[b]	3	3.626	**0.045**
Regrowth Length (cm)	53±25.2	5.7±7.7	31.1±14.6	77.6±75.7	3	2.866	0.081

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