Large Oriental Bittersweet Vines Can Be Killed By Cutting Alone

Final Report

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16. Abstract: Oriental bittersweet (*Celastrus orbiculatus* Thunb.) is an invasive, exotic, woody vine introduced to North America in the mid- to late 1800s from East Asia. The New York State Department of Transportation considers oriental bittersweet a problem because it can kill roadside trees through competition and mechanical stress. These hazardous and dangerous trees then need to be removed before they cause harm. Two manipulative field experiments were conducted across the Hudson Valley by the State University of New York College of Environmental Science and Forestry to test timing of cutting and glyphosate herbicide concentration effects on large vine mortality. While results from the first year indicated that herbicides were needed to achieve high mortality rates, this was not true with second year results. Cutting vines without herbicides produce the same, high rate of mortality of oriental bittersweet vines after the second year (>90% kill) as cut stump treatments with herbicides. It may be important that high kill rates of cut vines is related to the large vine size and that stumps were in forest shade. We concluded that it may not be necessary to apply herbicide via cut stump methods to kill oriental bittersweet vines that have a minimum stem diameter > 1-inch and are growing in areas were the invaded trees and forest systems are not significantly disturbed with vine treatment.			
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1 EXECUTIVE SUMMARY

Overall Project: Integrated Vegetation Management Program Enhancements

Five research tasks related to roadside right-of-way (ROW) vegetation management are being conducted by the State University of New York College of Environmental Science and Forestry (SUNY-ESF) for the New York State Department of Transportation (NYSDOT).

General objectives for the research are as follows (as presented in the problem statement provided by the NYSDOT / University Transportation Research Center [UTRC] RFP [RFP Number: C-06-24; dated April 2, 2009] [shortened from original text]).

• Objective No. 1: Update the Department's Integrated Vegetation Management Plan to reflect changes in work practices.

• Objective No. 2: Develop simple decision support tools that NYSDOT roadside vegetation managers can use to decide which vegetation management treatments are most suitable for their roadsides/transportation assets and to help schedule treatments for maximum effectiveness.

• Objective No. 3: Undertake field research on the effectiveness of alternatives to herbicides in controlling unwanted roadside vegetation on a sample of highways in NYSDOT's Poughkeepsie Region.

• Objective No. 4: Undertake research on whether cut stump applications of glyphosate-based herbicides, such as Rodeo and Round-Up, control Oriental bittersweet (*Celastrus orbiculatus*) in a manner that is efficacious, consistent with regulations and safe to workers and the environment.

SUNY-ESF began meeting these objectives in 2010 by working on five tasks, each with a sequence of sub-tasks and associated deliverables. The current report is the Final Report associated with Objective No. 3.

Task 4: Efficacy of Using Glyphosate on Cut Vines to Control Oriental Bittersweet

Non-native, invasive (NNI) plants are of high concern for vegetation managers because of their environmental and socioeconomic impact. On roadside ROWs, NNI plants can produce a broad spectrum of problems.

A NNI of special concern for NYSDOT is oriental bittersweet (*Celastrus orbiculatus* Thunb.). It is a liana (vine) introduced to the United States in the mid- to late-1800s from East Asia as an ornamental plant. For the roadside ROWs manager, bittersweet can grow into the crowns of roadside trees, killing them by girdling tree trunks and increasing weight on the tree's canopy. A tree besieged by oriental bittersweet causes a danger to motorists due to increased risk of branches and stems breaking and falling.

Study Objective

Determine the efficacy of herbicide treatment (glyphosate) for controlling oriental bittersweet using cut stump application methods.

Study Benefits

Continued cost-effective vegetation management; continued safe, efficient and effective road travel; informed vegetation managers and other practitioners; improved interactions with publics and regulators.

Study Hypotheses

At the end of the treatment cycle (1-year to 2 years post-treatment), glyphosate herbicide treatments of Oriental bittersweet will significantly control resprouting of vines. Rate of herbicide application (amount of active ingredient) needed to kill bittersweet will vary as a function of time of year of application. It was expected that percent kill would be highest in fall, and lowest in early summer.

Rationale

Oriental bittersweet is a problem plant that is being managed by NYSDOT. Most problem vines are large and twined to the top of hardwood trees, making foliar spray of herbicide on climbing vines impossible without damaging or killing the tree. Cut stump application of herbicides – where the vine is cut near groundline and herbicides applied at high concentration to the cut surface – is commonly recommended, but its efficacy is unknown. Efficient and effective use of herbicide treatment methods to control large oriental bittersweet can only be achieved with a rigorous research and development project, such as reported herein.

Methods

Two manipulative field experiments were conducted across the Hudson Valley of New York State in 2011-2013 to test relative effectiveness of:

- controlling the vines with cutting alone or cutting with an application of herbicides to the cut surface; and
- different herbicide application dates and herbicide amounts used in cut stump applications.

These two studies were established along field/forest and roadside right-of-way edges. A randomized block factorial design was used to test treatment effects on survival and growth of oriental bittersweet at the Vanderbilt National Historic Site in Hyde Park, New York, with control by cutting alone and cutting and cut stump herbicide treatments, varying application date (June, August and October) and varying herbicide concentrations (26 and 53 percent of glyphosate as the active ingredient via Accord herbicide) as the tested factors.

A randomized complete block design was used to test the same herbicide treatments applied in October across the Hudson Valley. Treatment sites (blocks; n=3) were located near Lake George, Hyde Park and Stony Point/East Fishkill. All treatments were applied to sets of 10, large Oriental bittersweet vines (average diameter ranged from 1.2 to 2.0 inches) per treatment plot, for a total of 360 vines treated. Treated vines were evaluated in mid-Summer 2012 (1-year after treatment) for survival and sprouting, and again in Fall 2013 (2 years post-treatment) for survival. Treatment effects were evaluated using standard analysis of variance techniques.

Outcome

After the first year of the factorial experiment at Hyde Park, the herbicide treated vines had higher mortality (86 percent) than vines that were cut only (44 percent). The randomized completed block experiment across the Hudson Valley produced similar results after the first year – the herbicide treated vines had higher mortality (67 percent) than vines that were cut only (13 percent). By the end of the second year after treatment, nearly all of treated vines were dead – regardless if they were cut only or cut and treated with herbicides.

Future Work

Results of this study are ready for operational application. NYSDOT could begin to operationally treat large (> 1-inch vine diameter near groundline) oriental bittersweet vines growing in fully stocked forest (shaded cut stumps) with cutting alone – no herbicides are recommended for use in killing these vines.

Operational treatments of cutting vines without herbicide treatment should be monitored to affirm study results – that > 95 percent kill is expected with cut treatment alone. Monitoring of treatment effectiveness should occur for at least 2 years, as it took that long for the development of full treatment effects in the current study.

In the course of conducting this study, the researchers discovered that oriental bittersweet is also widespread at the study sites as smaller diameter vines or shrubby growth. Because of their size, they are not amenable to cut stump herbicide treatment. While these small vines may take decades to produce problems similar to large vines, future study is recommended to determine how great a threat to trees Oriental bittersweet is in these forms and what are the best control methods.

2 INTRODUCTION

Oriental bittersweet (*Celastrus orbiculatus* Thunb.) is an invasive, exotic vine. This liana, or woody, vine has been historically prized for the ornamental value of its bright red berries and for its usefulness in landscaping and controlling roadside erosion (Patterson 1974; Dreyer et al. 1987). It was introduced to North America in the mid- to late-1800s from East Asia, where it is native to Japan, Korea and China north of the Yangtze River (Hou 1955). The woody vine (a liana) was first observed in New York City in 1897 (Steward et al. 2003). Naturalized populations were first recognized sometime between 1910 and 1920, and it was found in 21 of the United States by 1970 (Patterson 1974). In New York State, oriental bittersweet is today present across the state, but is found in problematic high densities and advanced growth and development in the Hudson and Mohawk Valleys (C. Nowak and C. Peck, personal observations). This is likely due to radial spread along roadside edges from introduction centers, as encouraged by valley climates.

Woody vines in general have long been recognized as a potential threat to the normal or desired development of trees and forest stands (Lutz 1943; Siccama et al. 1976; Trimble and Tyron 1979; McNab and Meeker 1987; Schnitzer and Bongers 2002). Specific problems with vines include changes in forest ecosystem regeneration and successional processes, competition for sunlight (see Figure 1), and mechanical damage to individual trees. Oriental bittersweet produces high levels of all these problems. Unlike native Virginia creeper (*Parthenocissus quincefolia* L.), poison ivy (*Toxicodendron radicans* L.), and wild grapevine (*Vitis* spp.), common liana vines in the eastern United States which attach to trees and other supports using tendrils and rootlets, twiners like bittersweet constrictively wrap vine sections around tree stems up through to the top of the forest canopy (see Figures 2 and 3). These twined vines can girdle stems and increase crown canopy weight load. Both effects together or separately can cause trees to become hazardous due to increased risk of breakage and total collapse. Trees that have imminent risk of collapse require arborists, foresters, and other tree care managers to remove them before they degrade to danger trees and cause property damage or personal injury.

Controlling oriental bittersweet before it can cause trees to become dangerous has become an important part of tree management in natural and human-built environments (Dreyer 1994; Williams and Timmins 2003). New York State's Department of Transportation (NYSDOT) has been cutting problematic oriental bittersweet stems near groundline in their roadside right-of-way environs when it appears the vine will cause a problem with trees that could fall into a road. NYSDOT recently questioned if cutting alone is effective in controlling oriental bittersweet in the long-term, and wanted to know if using a cut surface herbicide treatment would increase kill of vines (J. Rowen, NYSDOT, personal communication) – these questions were the impetus for the current study.

There are few published studies on the use of mechanical and chemical control of oriental bittersweet vines (see non-refereed Master of Science theses: Lynch 2009; Wooten 2013). Since root suckering and stump sprouting after cutting has been reported for oriental bittersweet (Dreyer 1988; Williams and Timmins 2003), recommendations for using herbicides and cut stump methods are common in the form of information sheets and weed control handbooks (e.g., Dreyer 1994; Williams and Timmins 2003). In general, various herbicides, and especially those with glyphosate as the active ingredient, can be used to readily kill woody plants applied via cut stump methods, particularly with later season treatments (Ballard and Nowak 2006). Using herbicides with stem cutting is well understood as a way to control stump sprouts and root suckers of trees (Abrahamson 1983; Zedaker et al. 1987; Kochenderfer et al. 2004; Ballard and Nowak 2006; Petrice and Haack 2011). Since oriental bittersweet is a woody plant, it was assumed that herbicides would be needed to kill the vines so as to control suckering and sprouting, and the questions would be: how much herbicide and at what time of year to optimize treatment efficacy. NYSDOT expressed an interest in learning specifically how effective the addition of a glyphosate-based herbicide would be to their cut vine treatment of oriental bittersweet. At present, oriental bittersweet is not commonly listed on herbicide labels as a species of known control with treatment, including Accord herbicide (active ingredient, or a.i.: glyphosate) as used in the current study. A special 2ee exemption was needed to test and then possibly operationally apply the herbicide on oriental bittersweet in New York .Other states with a less stringent state-level interpretation of herbicide labeling may not require such an exemption.

Two replicated field experiments were established in New York State’s Hudson Valley to determine the effects of cutting and cut surface herbicide treatments on mortality of large oriental bittersweet vines. Based on work with trees (e.g., see Ballard and Nowak 2006), it was hypothesized that Accord herbicide (a.i.: glyphosate) applied to freshly cut bittersweet stumps would result in significant mortality of treated vines, and that percent kill would be greatest with the highest concentration of glyphosate applied late in the season, as compared to no herbicide or low concentrations applied earlier in the growing season. A randomized block factorial experiment at one site, and a randomized block experiment across three sites, were established during the growing season of 2011 and treatment effects measured in summer 2012 and fall 2013. Patterns of mortality and sprouting the first year following treatment supported the hypothesis that glyphosate herbicide can increase the amount of kill and reduce sprouting number and growth, but surprisingly, early summer treatments with herbicides were more efficacious and effective than fall treatments. At the end of the second growing season after treatment, differential treatment effects disappeared – vine mortality was high regardless of treatment method, leading to a conclusion that herbicides may not be needed to achieve a high degree of control of large, cut, oriental bittersweet vines.

Figure 1. Photo showing oriental bittersweet vines and how they completely cover trees on the Hyde Park site.

Figure 2. Photo showing large oriental bittersweet vines on the Hyde Park site.

Figure 3. Photo of an oriental bittersweet vine wrapped around a yellow poplar (tulip tree) on the Hyde Park site.

3 MATERIALS AND METHODS

Study Areas

Study plots were laid out as follows:

- along field/forest edges on the National Park Service's Vanderbilt National Historic Site in Hyde Park, NY (Study 1, and one block of Study 2) (41°47′35" N 73°56′35"W);
- along roadside rights-of-way near the village of Lake George (43°25'45" N, 73°43'15"W); and
- along roadside rights-of-way just outside New York City near the towns of Stony Point (41°16'55" N, 73°57'41"W for one treatment plot) and East Fishkill (41°34'23" N, 73°46'48"W for two treatment plots) (Figure 5).

Field/forest edges are where damage to trees from oriental bittersweet are of most concern to roadside vegetation managers, and it is known that bittersweet is commonly abundant along these forest edge sites (Robertson et al. 1994; Merriam 2003; Londré and Schnitzer 2006).

The study areas were located entirely within the Hudson Valley Section of the Eastern Broadleaf Forest Province and Hot Continental Division (Section 221B) (McNabb and Avers 1994). Across the Hudson Valley, average annual precipitation is 40 inches, average annual temperature ranges from 45 to 50°F, and the growing season lasts from 160 to 180 days (McNab and Avers 1994). These environmental conditions are conducive to the spread, growth and persistence of oriental bittersweet (Dukes et al. 2009). The northern site (Lake George) is apparently near the current northern distribution of oriental bittersweet in New York State, and the southern sites (East Fishkill and Stony Point) are near to where oriental bittersweet may have entered into New York (just north of New York City).

Soils associated with the study sites included Dystrochrepts and Fragiachrepts with udic moisture regime and mesic temperature regimes in the southern and middle areas of the Section, and Hapludalfs with udic moisture and mesic temperature regimes in the north. Soil series were all excessively well-drained and apparently included (from www.websoilsurvey.com): Hinkley soils in the Lake George block, a Nassau-Cardigan complex of soils in the Hyde Park blocks, and unidentified Udortent associated with a pit-quarry operation on one south block plot (Stony Point) and Hossic soils in the other two south plots (East Fishkill). Soils in the Lake George and the Stony Brook plots appeared to be anthropic as the landforms have apparently have been reworked with heavy machinery during highway construction and maintenance.

Experimental blocks associated with both studies were fully-stocked forests that ranged in age from 40-80 years (C. Nowak, personal observation). The forest types were as expected for the

Hudson Valley – various combinations of northern hardwoods and Appalachian oaks. The most important tree species across the study areas were sugar maple (*Acer saccharum*), tree-of-heaven (*Ailanthus altissima*), black locust (*Robinia pseudoacacia*) and red oak (*Quercus rubra*) for the Hyde Park site, and flowering dogwood (*Cornus florida*), green ash (*Fraxinus pennsylvanica*), black cherry (*Prunus serotina*), and red oak (*Quercus rubra*) and for the East Fishkill and Stony Point plots (Peck 2014). The Lake George site was occupied by 40-year-old white pine (*Pinus strobus*).

Experimental Design and Vine Treatments

Study plots, which are the "experimental units", were established in 2011 along forest edges that contained at least 10 large, (> 0.5 inch diameter) twining (climbing to near the top of trees) vines per 900 square feet area. All plots extended 30 feet into the forests and were 30 feet wide for Study 1, and 90 feet wide for Study 2. Experimental design for Study 1 was a randomized complete block 3x3 factorial on one site (Hyde Park) with herbicide concentration as one factor, and month of treatment application the second factor; for Study 2 the study followed a randomized complete block design to test herbicide concentration on three sites (blocks) across the Hudson Valley.

Treatments were based on cutting vines within 6 to 18 inches of groundline (depending on vine form and access due to neighboring vines and other plants) with a hand saw to produce a horizontal surface (to maximize retention of herbicide on the cut surface) (Figure 6). Ten randomly selected and tagged (numbered) large vines within each treatment plot were cut within each plot (numbering allowed us to find the treated vines over time). A total of 360 vines were treated across the two studies. One third of the vines were cut, but did not receive a herbicide treatment (cut only treatment). The remainder of cut vines had herbicide treatments applied to the freshly cut surface of the stump using a syringe applicator (60 CC/Ml Terumo syringe without needle [Terumo Medical Corporation, Somerset, NJ], attached to a 6 inch length of Primary IV line with a spin-lock connector [B. Braun Medical Inc., Bethlehem, PA) (Figures 7 and 8). The syringe applicator was needed to provide precise application rates required for the study. However, cut stump herbicide applications may also be made with backpack sprayers, pump bottles or small spray bottles. It is expected that efficacy results as reported herein would not change with application equipment.

Herbicide concentrations were:

- undiluted Accord (53.8% glyphosate active ingredient [a.i.]) (100% unmixed solution); and

- diluted Accord (26.9% glyphosate active ingredient [a.i.]) (50% solution mixed with water).

Treatments were applied in late June, mid-August and mid-October 2011 (only the October treatment date was used for Study 2).

Weather was within labeled strictures for use: the late June treatment day was partly cloudy with temperature ~81^{o}F and the ground wet from recent rain; mid-August treatment weather was

~68^{o}F and humid from a morning rain; late October treatments occurred with the temperature between 39-45^{o}F, with snow occurring on some sites just after treatment.

Population Characteristics of Untreated and Treated Vines

All bittersweet vines ≥0.5 inch in diameter within each study plot were measured for lower stem (within 12 inches of ground level) diameter with digital calipers and recorded. Understory oriental bittersweet (seedlings up to vines 0.5 inches diameter) were measured in paired understory quadrats in each plot (one pair in Study 1 plots, and three pairs in Study 2 plots). Quadrats in a plot were located 10 (edge of field) and 20 feet (interior in forest) from field edge into the forest along plot center (equidistant from plot edges for Study 2).

A ~0.5 inch thick stem disc section was taken from each treated vine to determine vine size and age. Each disc was air dried, labeled with indelible marker and catalogued. Discs were surfaced using an electric belt sander fitted with 150 grit paper and then polished using 400 grit sandpaper. Discs were examined using a 10x dissecting microscope (Wolfe model no. 864158, Carolina Biological Supply Company, Burlington, NC). Annual rings were counted in four directions at 90 degrees to each other in order to obtain an average number of rings. The process was repeated three times, and the average used to estimate vine age.

Measurement of Treatment Effects

Each of the 10 treated vines in each plot was examined 1-year (June 2012) and 2-years (October 2013) after treatment. Mortality of treated vines was determined by a complete absence of sprouts and lack of green coloration below the bark layer (determined by scraping the bark slightly on the stump using a pocket knife). On surviving vines, the number of sprouts and sprout length were recorded for each treated stem in 2012. It was possible that the stumps of the vines were killed with treatment, but not the roots. Root suckering was evaluated by searching for suckers around each treated vine, but none were observed indicating that if the vine stump was killed, so were the roots. Only mortality was measured at the end of the second year post treatment. Of the 360 vines that were treated in 2011, a subset of 326 were found in 2013 because vine ID tags were lost (likely destroyed by animals). A minimum of seven vines were found in each plot, allowing for meaningful calculations of second year mortality levels.

Data Analyses

A paired t-test was used to compare oriental bittersweet density between field edge and interior forest quadrats. Correlation analysis was used to test the relationship between average, plot-level average vine size and age. Analysis of variance using general linear models was used to test the hypothesis that efficacy as determined by percent mortality (and sprout length and number in Year 1) would vary as a function of herbicide concentration (including the untreated control – cut only with no herbicide) and treatment timing for Study 1, and herbicide concentration for Study 2. While it was possible to combine each year's data and run a single analysis of variance using a repeated measures design to test for time (Year 1 versus 2) and treatment effects, separate analysis of variance were run for each year in each study, with the effect of time deemed obvious based on study results – Year 1 results were clearly different than Year 2. Also, since practitioners would most likely judge treatment efficacy after treatment effects were fully expressed, and not using the average efficacy response (which is what the main effects in a single repeated measures would produce). An arcsine transformation of percent mortality, which is typical for analyzing survival data to better meet basic assumptions of analysis of variance (see Ahrens et al. 1990 and associated literature review), was applied to the data, but evaluation of treatment effects based on the transformed data did not change compared to the untransformed data. Therefore, all reported data analyses are untransformed. Statistical effects were judged as meaningful, and treatment means were separated using Duncan's method, when p-values were ≤0.10, though p-values up to 0.15 were considered as possibly significant. Interaction effects were judged as statistically significant using an alpha-level of 0.15 (Stehman and Meredith 1995). All statistical analyses and calculations were performed with SAS version 9.3. (SAS Institute Inc., Cary North Carolina, USA copyright 2002-2011) and data management with Microsoft Excel (Microsoft Home and Student 2010 version 14.0.6123.5001).

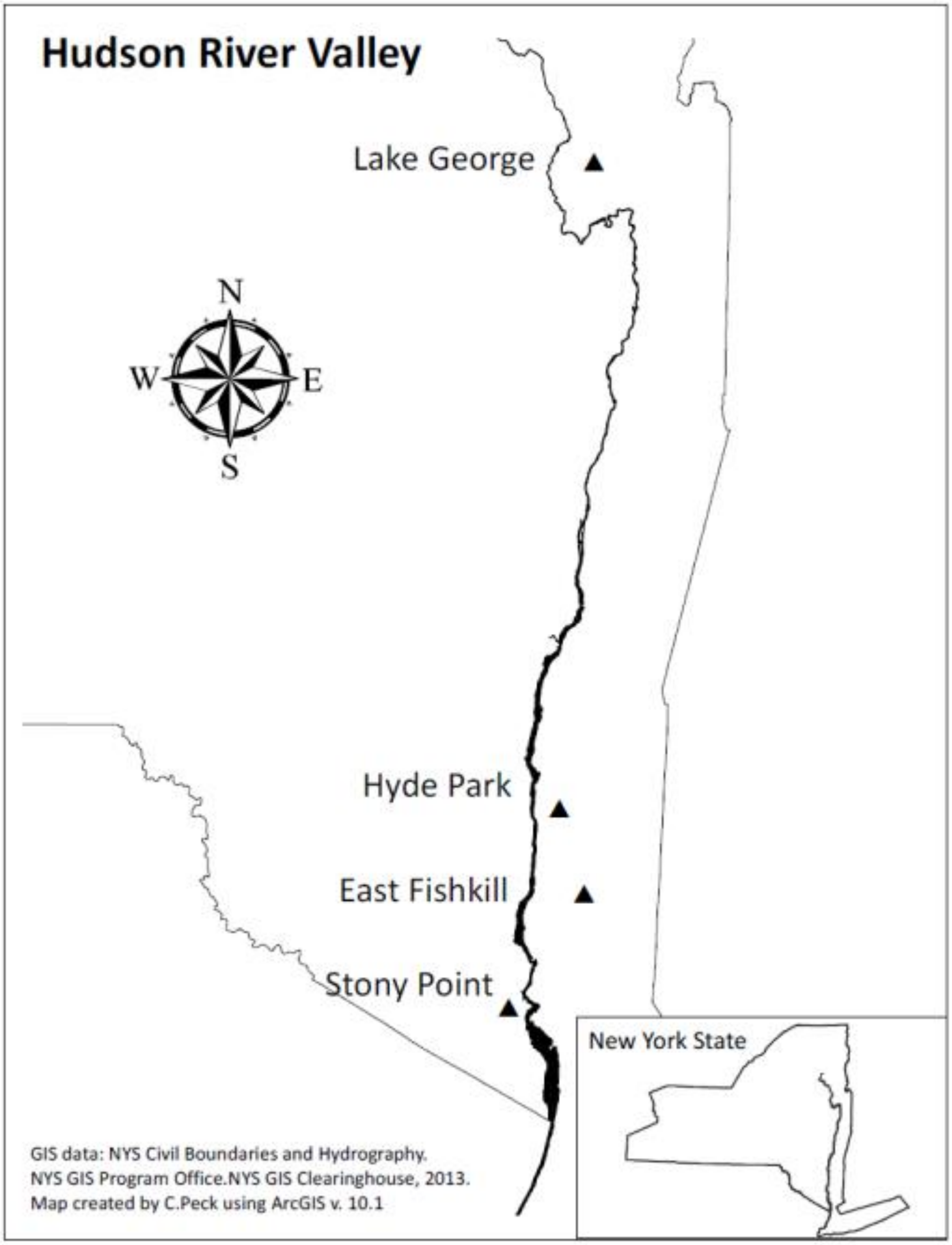

Figure 5. Map showing the location of the study sites across the Hudson Valley in eastern New York State. Study 1 was conducted on the Hyde Park site. Study 2 occurred in all four sites: the lower block combined East Fishkill and Stony Point; the middle block was in the Hyde Park Site (adjacent to Study 1 plots); and the upper block was in the Lake George site.

Figure 6. Photo of a recently cut oriental bittersweet vine. Notation on pink flag defined as follows: B3 = Block 3; P4 = Plot 4; and V17 = Vine 17. Tagged, treated vines allowed for vine-specific measurements on size, sprouting and mortality over time.

Figure 7. Photo of the syringe used to apply herbicide to cut surfaces of oriental bittersweet.

Figure 8. Photo of oriental bittersweet vine treatment effort using cut stump methods and Accord herbicide.

4 RESULTS

Oriental Bittersweet Populations

Average number of small oriental bittersweet vines (<0.5 inches in diameter) across Study 1 plots was 65,073 per acre, ranging from 0 to 291,676 per acre; for Study 2 the average was 48,581 vines per acre, ranging from 0 to 105,064 per acre. Field edge quadrats averaged nearly two times higher small vine density as compared to forest interior quadrats, 79,427 versus 44,242 vines per acre, respectively ($p < 0.001$; paired t-test, $n = 54$ pairs).

Average number of large vines (≥0.5 inches in diameter) across Study 1 plots was 5,491 per acre, ranging from 2,441 to 11,725 per acre, for Study 2 the average was 5,758 per acre, ranging from 2,338 to 10,559 per acre. These vines were observed to be located across the plot, with only slight affinity for the edge half (C. Nowak, personal observation).

Average diameter of vines ≥0.5 inches across Study 1 plots was 1.1 inches, ranging from 0.6 to 2.4 inches; for Study 2 the average was 1.0 inch, ranging from 0.7 to 1.6 inches. Age of the oriental bittersweet for Study 1 averaged 18 years, ranging from 9 to 38 years, and for Study 2 the average age was 22 years, ranging from 10 to 36 years. The largest and oldest vine observed in the study had a stem diameter of 6.0 inches and was 48 years old (Figure 9). Vine age and stem diameter were strongly, linearly correlated across the study sites (Studies 1 and 2 combined) ($r = 0.77$; $p = <0.0001$; $n = 36$) (Figure 10).

Oriental Bittersweet Vine Responses to Cutting and Herbicide Treatments

First Year After Treatment – Study 1

Percent mortality, number of sprouts and length of sprouts on surviving vines were affected by treatments. Early season treatments were more efficacious than later treatments; lower herbicide concentration was as efficacious as high concentration. There was no interaction of treatment effects (Table 1).

Percent mortality ranged from 10% to 100%, and averaged 73% across all treatments. June treatments (87%) were more efficacious than August or October (average: 66%). Herbicide in high (91%) or low (82%) concentration was better than cutting only (44%) in killing large oriental bittersweet, but there was not a significant difference between low and high concentrations in effect (Table 1).

The average number of sprouts across all treatments was 2.0 per vine. Cutting only resulted in more sprouts (3.1 per vine) than herbicide treatment (average of 1.4 per vine). Early treatment resulted in lower numbers of sprouts (0.4 per vine) than mid or late season treatments, which had 2.5 and 3.0 sprouts per vine, respectively (Table 1).

Length of sprouts in the cut only treatment (average: 21.7 inches) was greater than in herbicide treatments (combined average 10.2 inches). Sprouts as long as 50 inches were recorded in the cut only treatment, and averaged 15.0 inches in length across all treatments. There was no significant difference in average sprout length based on time of treatment (Tables 1).

First Year After Treatment – Study 2

Percent mortality was marginally affected by treatments; number of sprouts and length of sprouts on surviving vines was not (Table 2). Low and high concentration herbicide treatments produced the same percent kill (67%) that was statistically, significantly greater than that observed with cutting alone (13%). Percent kill with herbicides was similar to that observed in Study 1 (October only = 62%), but percent mortality with cut only was lower – 13% for Study 2 compared to an overall 44% for Study 1.

The average number of sprouts and length of sprouts across all treatments was 2.0 per vine and 21.7 inches per sprout (Table 2). Unlike Study 1, there was no change in characteristics of sprouting with treatment.

Second Year After Treatment – Study 1

Percent mortality was still affected by treatments in the second year, with cut only treatment at 92% and the herbicide treatments averaging nearly 100% (Table 1). Mortality was the same across the different treatment times, June through October. There was no interaction of treatment effects (Table 1).

Second Year After Treatment – Study 2

Percent mortality was not affected by treatments (Table 2). Average percent mortality across treatments was 89%, ranging from 70 to 100%.

Figure 9. Photo of the largest oriental bittersweet vines treated at the Vanderbilt Mansion site – it was 6.0 inches diameter and from a stem that was 48 years old. While the average size of stems in a plot was much smaller, many large vines were encountered on each plot.

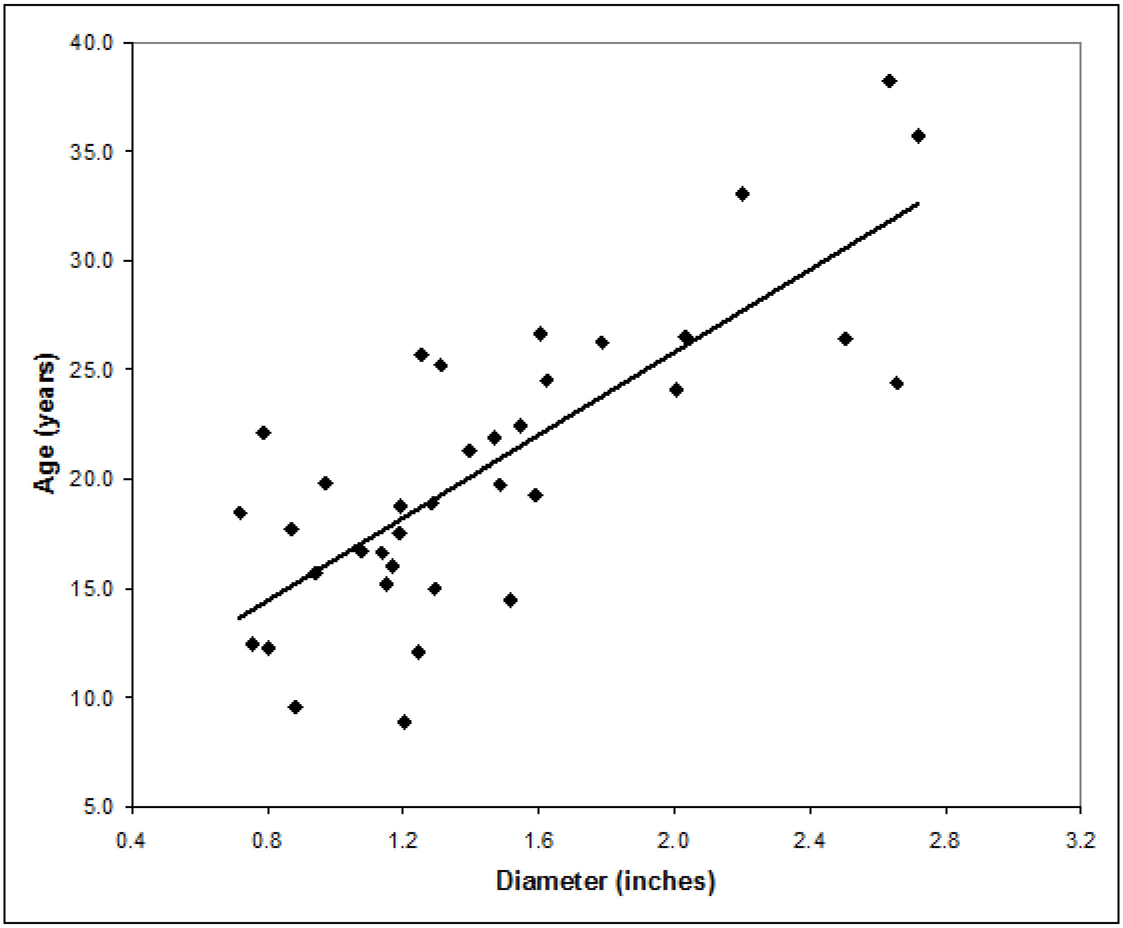

Figure 10. Relationship between average oriental bittersweet vine age and stem diameter (Studies 1 and 2 combined) ($r = 0.77$; $p < 0.0001$). Each observation is the average of 10 vines for each of the 36 treatment plots.

Table 1. First and second year average oriental bittersweet vine responses to cut stump treatments and associated analyses of variance results from Study 1.

Treatment Factors	1st Year After Treatment*: Percent Mortality	1st Year After Treatment*: Number of sprouts per vine	1st Year After Treatment*: Length of sprouts (cm)	2nd Year After Treatment*: Percent Mortality
Cut Stump Treatment Type				
Cut only	44 b (11)**	3.1 a (0.9)	21.7 a (1.6)	92 b (4)
Herbicide: low concentration	82 a (9)	2.1 ab (0.8)	9.8 b (3.9)	99 a (1)
Herbicide: high concentration	91 a (4)	0.8 b (0.4)	11.0 b (3.9)	100 a (0)
Time of Treatment				
June	87 a (9)	0.4 b (0.2)	18.5 a (5.1)	99 a (1)
August	69 b (11)	2.5 a (0.9)	15.7 a (3.9)	95 a (4)
October	62 b (12)	3.0 a (1.0)	12.2 a (3.5)	98 a (2)

Analysis of Variance Sources of Variation and Associated p-values

	Degrees of Freedom	p-values			
Block	2	0.06	0.95	0.04	0.08
Stump Treatment (ST)	2	<0.01	0.11	0.02	0.08
Treatment Time (TT)	2	0.07	0.04	0.13	0.44
ST*TT	4	0.27	0.25	0.43	0.19
Error	16				

* Means followed by the same letter within "Cut Stump Treatment Type" or "Time of Treatment" are not statistically different from each other (Duncan's, alpha=0.10); ** Standard errors are in parentheses.
NOTE: sample size for treatment means was 9 for all variables except sprout length, which was 7, 6 and 4 for the cut, low and high treatments, and 4, 6 and 7 for the June, August and October treatments, respectively.

Table 2. First and second year average oriental bittersweet vine responses to cut stump treatments and associated analyses of variance results from Study 2.

	1st Year After Treatment*			2nd Year After Treatment*
Cut Stump Treatment Type	Percent Mortality	Number of sprouts per vine	Length of sprouts (cm)	Percent Mortality
Cut only	13 b (3)**	2.8 a (0.5)	24.4 a (8.7)	70 a (25)
Herbicide: low concentration	67 a (28)	0.7 a (0.3)	3.9 a (3.1)	97 a (3)
Herbicide: high concentration	67 a (19)	8.1 a (6.8)	14.2 a (6.3)	100 a (0)

Analysis of Variance Sources of Variation and Associated p-values

	Degrees of Freedom	p-values			
Block	2	0.21	0.44	0.10	0.33
Stump Treatment	2	0.13	0.47	0.22	0.33
Error	4				

* Means followed by the same letter within "Cut Stump Treatment Type" are not statistically different from each other (Duncan's, alpha=0.10).

** Standard errors are in parentheses.

NOTE: sample size for treatment means was three for all variables.

5 DISCUSSION

Abundances of both small and large oriental bittersweet vines were high across the study sites. Sites were chosen to have a high number of vines for consistent high opportunities for treatment, focusing on those vines with diameters that were 1 inch in size at a minimum. While we treated 10 vines per plot, which equates to over 2,000 vines per acre in Study 1 and just over 500 per acre in Study 2, there were still thousands of other, untreated vines along the field and roadside right-of-way edges. Additionally, there were thousands of vines per acre less than 0.5 inches diameter. While these small vines were not part of the efficacy study (only those vines with a 0.5 inch diameter or greater), they indicate the magnitude of the oriental bittersweet problem and provide context for management. Even if we control all the large vines per site, there are thousands more small vines to recolonize the released trees. Yet, once a vine is controlled on a tree, it should take many years before a new vine – seedling or sprout – develops fully into a renewed problem on that tree. Since all of the trees that had treated vines were still alive, and the range of average ages for the studied vines was between 9 and 38 years, we can expect it will take decades after initial vine control before new vines produce the same problem for the same trees. Putz (1991) made a similar observation in his long standing studies of liana vines around the world. He stated that while most cut liana stumps sprout, the sprouts generally grow slowly and fail to grow back up into the mature forest canopy.

In the first year after treatment, herbicide treatments did reduce sprouting and result in higher mortality of treated oriental bittersweet vines compared to vines that were cut only. In both Study 1 and 2, the lower concentration herbicide treatment (26.9% a.i. glyphosate) produced levels of mortality that were effectively the same as the high concentration herbicide treatment. Average mortality for low and high concentration herbicide treatments in Study 1 was 82 and 91%, respectively, and for Study 2 it was 67 and 67%, respectively. The lower percent mortality in Study 2 may be due to their only being an October treatment. In Study 1, the October treatment had a lower percent mortality than June, yet the same for August – the overall average mortality of Study 1 includes the high percent mortality for June.

It is not clear why the June treatment produced a higher mortality rate than August or October in Study 1 – this is opposite to what was expected in the study based on previous work with cut stump treatment of trees (Ballard and Nowak 2006; NOTE: the Ballard and Nowak study did not include cutting alone). It may be that cut vines in June have a lowered stored carbon in roots that reduces sprouting numbers, size and vigor, similar to sprouting patterns observed with trees (Kays and Canham 1991). A similar timing of cut stump treatment with and without herbicides response was observed by Petrice and Haack (2011) for white ash trees. This timing of cutting result in the current study loses some importance as it disappears by the second year after treatment.

First year results from the current study are supported by two recent "unpublished" studies that tested cut stump herbicide treatments with glyphosate applied to oriental bittersweet (both studies were found as Master of Science theses). Lynch (2009) conducted a 1-year study in West Virginia of individual, large (0.4-2.0 inches diameter) oriental bittersweet control that included a cut stump herbicide treatment with 50% Accord (26.9% a.i. glyphosate) applied in July. Vines were climbing trees in a fully-stocked, 55-yr-old forest. Sixteen weeks after treatment, the cut stump herbicide treatment had only 10% of the vines survive, compared to 60% survival for the cut only treatment. Across all treatments, many vine sprouts were observed to die over that first growing season. Lynch (2009) also described that cut stump with herbicide treatment and a cut only treatment had average sprout numbers of 8 and 20 per treated vine, and average sprout length of 4.7 and 16.9 inches, respectively, which are similar to the current study. Wooten (2013) studied population-level control in Pennsylvania by treating all vines – small and large – on plots with isolated, tree-climbing oriental bittersweet. Cut stump with glyphosate (GlyphoMate 41; 41% a.i. glyphosate) was applied to treated vines in July. Total number of vines alive at the end of the first growing season with herbicide treatment was found not to be different than cutting alone. Unfortunately, both studies were concluded after the first year – there is no second year of treatment response. As in the current study, a second year of study may have changed conclusions.

In the current study's second year after treatment, herbicide effects were nearly gone – vine cutting alone produced nearly or the same effects as cut stump treatment with herbicide. Study 1 still had a significant herbicide treatment effect into the second year, but the increase in percent mortality with herbicides was much less in Year 2 compared to Year 1. In Year 1, herbicide treatments nearly doubled the percent kill (44 versus 86%), but in Year 2 the increase in percent kill was only 8% (92 versus ~100%).

In Study 2, percent mortality did not differ among the treatments after the second year, averaging 89% across the treatments. While the average percent mortality in the cut only plots was 70%, this was not statistically different than the herbicide treatments which averaged 98%. The low percent kill for the cut only treatment in the second year of Study 2 is due to very low percent kill in only one plot – 20% kill in the youngest, northern most treatment plot (Lake George site). The other two cut-only plots in Study 2 had 90 and 100% mortality. It is not clear why the one plot had such low mortality. It may be that the smaller, younger vines in the northern plot – averaging 1.1 inches diameter and 15 years old – were not as readily killed with cutting alone, as compared to the older and large vines treated in the southern plots, where the vines averaged 2.0 and 2.7 inches diameter, and 26 and 36 years old. In addition to vine size considerations to explain high sprout survival in the one plot, it could be that the cut-only plot in the northern site had a more open canopy, allowing for greater survival of stump sprouts due to higher plot-level light levels (see discussion, below). Unfortunately, light quantity was not measured in the current study.

It was fortuitous that a second year of study was added to observe treatment effects, as the conclusions based on the second year are very different than would have been based on the first year alone. Three other studies of cut stump treatments conducted for 2 years affirm the importance of a second year of study. Ballard and Nowak (2006) observed that trees treated with cut stump herbicides often were alive after the first year, but dead the second year. Petrice and

Haack (2011) reported higher mortality for ash tree species treated with cutting only and cut stump with herbicide in the second year compared to the first. Zedaker et al. (1987) observed the opposite – trees that were thought to be dead after 1-year were alive the second year, which still affirms the importance of 2 years of study. In the current study, at the end of the first year after treatment, many treated vines were not dead (yet), and had many large basal sprouts. Nearly all of these sprouts were dead by the end of the second year. Of the 326 vines measured in Year 2 post treatment, only 17 were still alive, and eight of these were in one cut-only plot.

It is not clear why nearly all sprouts from the first year died by the end of the second year. One factor could have been herbivory as oriental bittersweet is browsed by deer and other mammals (Ashton and Lerdau 2008; Lynch 2009). Impact of deer and other herbivores on current study sprouts was observed to be low, as many sprouts in the second year were observed to be standing dead without evidence of browse, and all sites had large, live sprouts at the end of the second year (albeit a greatly reduced number compared to the first year). Additionally, high second-year mortality was generally consistent across the three broadly separated study sites across the Hudson Valley, with likely differences in browsing pressure that did not cause high site-level variation in mortality (see non-significant block effect for Study 2).

A more likely reason for the near complete mortality of stump sprouts through 2 years is that sprouts may have exhausted carbohydrate reserves in the roots after the first year. Carbohydrate storage and release are long recognized as key to the vegetative regrowth of woody plants (Kayes and Canham 1991; Kozlowski 1991; Kozlowski et al. 1991), including vines (Mooney and Gartner 1991). Woody vines have a wide variety of carbohydrate storage patterns, with some species having storage in stems, and others in roots (Mooney and Gartner 1991). Existing information of vines and their carbohydrate compounds and carbon storage capacity comes from agronomic literature. *Vitis* species (grapes), because of their economic values, have had detailed plant physiology study. The bittersweet family (Celastraceae) has similar anatomical vine structure as the grape family (Vitaceae) (Carlquist 1991), so research on grapes could apply to bittersweet. Winkler and Williams (1945) (cited in Mooney and Gartner 1991) found that bark in older grapevine roots had greater than 50% total non-structural carbohydrates (this is the source of carbon available to developing sprouts, in addition to defenses) that was nearly depleted by the end of the growing season – stored carbon in roots was enough to only support only 1-year's worth of grape development, which classed them as having a "deep depletion cycle" of total non-structural carbohydrates. It may be that oriental bittersweet has similar carbon dynamics, and can support sprouts for only 1-year, after which each sprout must produce enough photosynthates to carry out its life needs. Apparently, this may not have been the case in the current study where all of the sprouts were growing in full shade of a forest canopy.

While oriental bittersweet is considered to be shade tolerant as a seedling with a capacity to shift ecophysiology to be more like a shade-intolerant in full sun (Greenburg et al. 2001; Ellsworth et al. 2004), it may be less shade tolerant throughout its life that reported. In the current study, higher density of small oriental bittersweet along the forest edge versus interior of the study plots supports the notion that oriental bittersweet is less than shade tolerant, and may possibly be shade intermediate. It is known that oriental bittersweet reproduces better as seedlings, sprouts and root suckers in forest gaps, old fields and clearcuts, and open/forest edges (Fike and Niering 1999; Silveri et al. 2001; Londré and Schnitzer 2006), indicating that when vine-invaded systems and vines themselves are disturbed, regeneration is successful in areas with increased sunlight. A key aspect of the current study may be that the vines were treated without disturbing the forest. It is expected that if both vines and the subject trees and forests were disturbed, long-term treatment effects may have been different; in specific, herbicide use may have been shown to produce added kill and control of oriental bittersweet populations because more of the sprouts would have stayed alive in the cut-only treatment.

6 CONCLUSIONS

Based on 2 years of field study, we conclude that it may not be necessary to apply herbicide via cut stump methods to kill large oriental bittersweet vines (where large means vines that > 1 inch in diameter) in areas were the invaded trees and forest systems are not significantly disturbed. Cutting alone of vines whose stumps remained in full shade resulted in >95 percent kill across the study plots, excluding the one northern plot in Study 2 with only 20 percent kill and vines averaging 1.1 inches diameter. Herbicide treatments resulted in nearly 100 percent kill, but this result was not statistically different from the percent kill with cutting alone.

Our recommendation to not use herbicides to kill large, cut stump treated vines is in contrast with published recommendations. Hutchinson (1992) is often cited source for using cut stump herbicides to kill oriental bittersweet vines (e.g., see citation in Williams and Timmins 2003; Webster et al. 2006), with a recommendation to use a 100% Roundup mix (glyphosate herbicide similar in rate to the high concentration herbicide treatment in the current study) on cut vine surfaces late in the growing season (just after late frost). But, this and other like recommendations in the literature apparently are not based on field research. This discovery – of published literature full of recommendations to cut stump treat oriental bittersweet vines with herbicides that is not founded in research and the scientific method – highlight the importance of conducting long-term herbicide research in support of vegetation management.

7 STATEMENT ON IMPLEMENTATION

Results from the current study can be implemented immediately and across New York State. The recommendation to not use herbicides in conjunction with cut stump methods to kill oriental bittersweet applies only to large vines whose cut stumps are in shade after treatment. Large vines are defined as having a minimum, near-ground stem diameter of 1 inch. These vines are usually twining around large trees, growing up into the canopy, and causing problems to tree health. While many management guidelines include cut stump treatment with herbicide to kill tree climbing oriental bittersweet vines, it appears that these guidelines are anecdotal and not based on rigorous research as used in the current study.

Current study results likely do not apply to smaller oriental bittersweet, particularly those small, trailing, shrub-like vines that are commonly abundant in old fields and mowed roadside rights-of-way. These small vines often look like small tree or shrub seedlings, and with populations observed with over 200,000 stems per acre (C. Nowak, personal observation). It may be that persistent mowing or foliar herbicides may be needed to control these younger oriental bittersweet populations.

If persistent mowing or foliar applications were used on small vines, the New York State Department of Transportation currently recommends that vegetation managers replant areas where the vines were removed with native vegetation (J. Rowen, NYSDOT, personal communication). Revegetating ***might*** limit the likelihood of the vine reappearing after treatment.

The researcher applied to – and received from – the New York State Department of Environmental Conservation (DEC), the state agency that regulates pesticides in New York, a 2ee “unlabeled pest” letter authorizing the application of Accord herbicide to oriental bittersweet. DEC interprets pesticide laws and regulations to require that a plant be on a label if the plant is a target of an herbicide. The 2ee letter process has been used to authorize herbicide use on plants that have recently become a problem as noxious or invasive.

After the herbicide treatments were completed, Dow Agro, the company that makes Accord, discontinued production of Accord. However, Dow Agro’s staff received a 2ee letter to allow the use of two of its other products, Accord XRT II and Rodeo, to control oriental bittersweet with cut stump or foliar applications.

Roundup Pro Concentrate and Roundup Custom are labeled to allow foliar applications to control oriental bittersweet.

Various other woody vines native to North America can cause problems for vegetation managers similar to oriental bittersweet. Wild grapevines (*Vitis* spp.) can be nuisance vegetation on the roadside and the research on them may help roadside vegetation managers control oriental bittersweet and other unwanted vines.

Research on control of wild grapevines in context of forestry was conducted in the eastern United States over the past five decades. Trimble and Tyron (1979) synthesized earlier research and produced management guidelines for cut stump treatments for grape similar to the current study with oriental bittersweet. In general, Trimble and Tyron reported that cut grapevines under forest canopies produced sprouts that died in 3 years, but if the overstory was removed the grape sprouts thrived. They recommended that severing grape vines growing in well-stocked stands is an effective and inexpensive way to eliminate them, and that this method works because grapevines are shade intolerant. While wild grapes are shade intolerant throughout their lives, and oriental bittersweet is considered shade tolerant (though argued in the current study as possibly being shade intermediate) as a seedling and shade intolerant as a climbing vine, control recommendations for grape and large bittersweet vines are intriguingly similar. Smith (1984) well captured the recommendation for grapes that has bearing for oriental bittersweet, paraphrased as follows. Vines can be controlled in shaded areas of mature stands by severing or cutting the large vines that grow in trees. Vines can be severed near groundline using blades, hatchets or chainsaws depending on vine size. The cut vine will likely resprout, but those sprouts will die within a few years barring any drastic increase in sunlight with overstory removal or natural disaster, and not become a problem in the future.

Research on use of herbicides to control oriental bittersweet should continue to confirm (or not) and extend the results of the current study. At the least, the current study could be duplicated to determine if the high 2-year mortality by cutting vines alone can be reproduced. Future cut stump studies with glyphosate could follow the same designs in the current study, but should add the following independent variables: size of vines that are smaller (<0.5 inches) and younger than in the current study; cut stumps of treated vines exposed to varying amounts of sunlight after treatment; and measured levels of herbivory (fence off some of the treated stumps to control herbivore access). Clearly, the mechanisms to explain why there was such high mortality in the cut only plots after 2 years needs to be investigated with both observational and manipulative experiments. Results of these new studies, along with the current study, do not address do not address the problems of oriental bittersweet growing in open fields with shrub-like form. The high density and small stem diameter does not match well with cut stump methods, but other herbicide application techniques could be tested, including cut stubble and foliar. Like cut stump treatments of oriental bittersweet, there is a paucity of published research on foliar application of herbicides to control oriental bittersweet.

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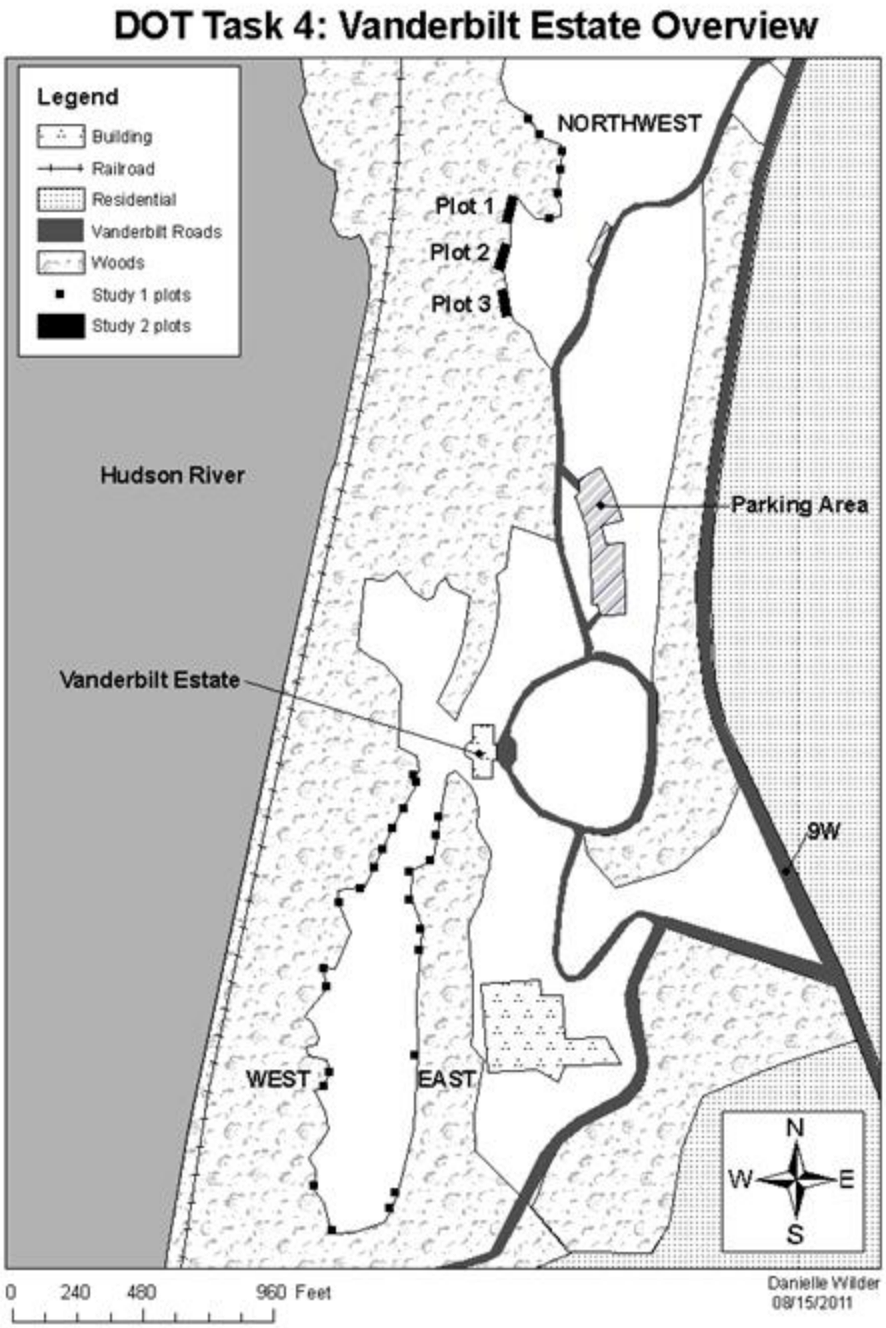
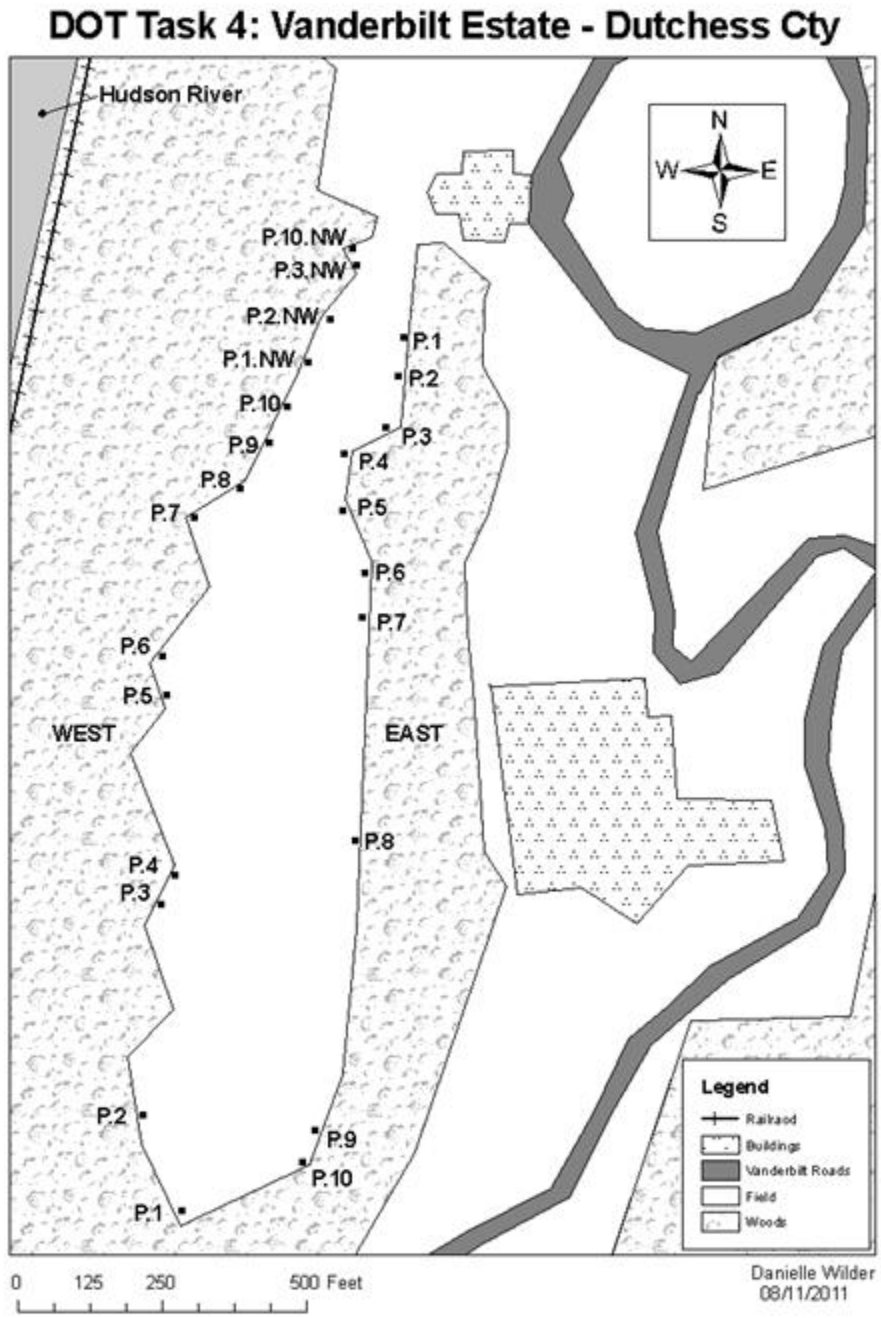
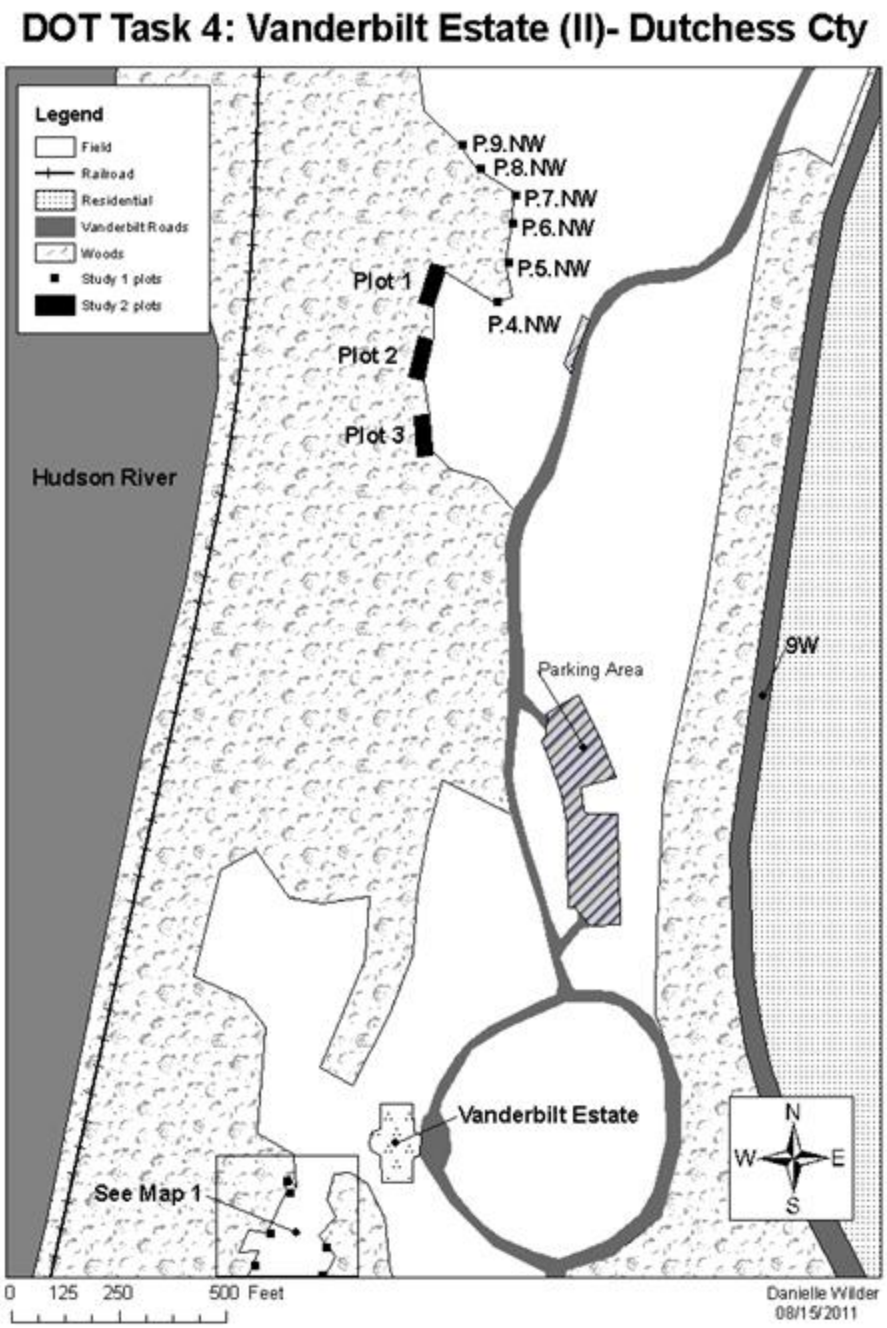
A APPENDIX: MAPS OF THE TASK 4 STUDY SITES



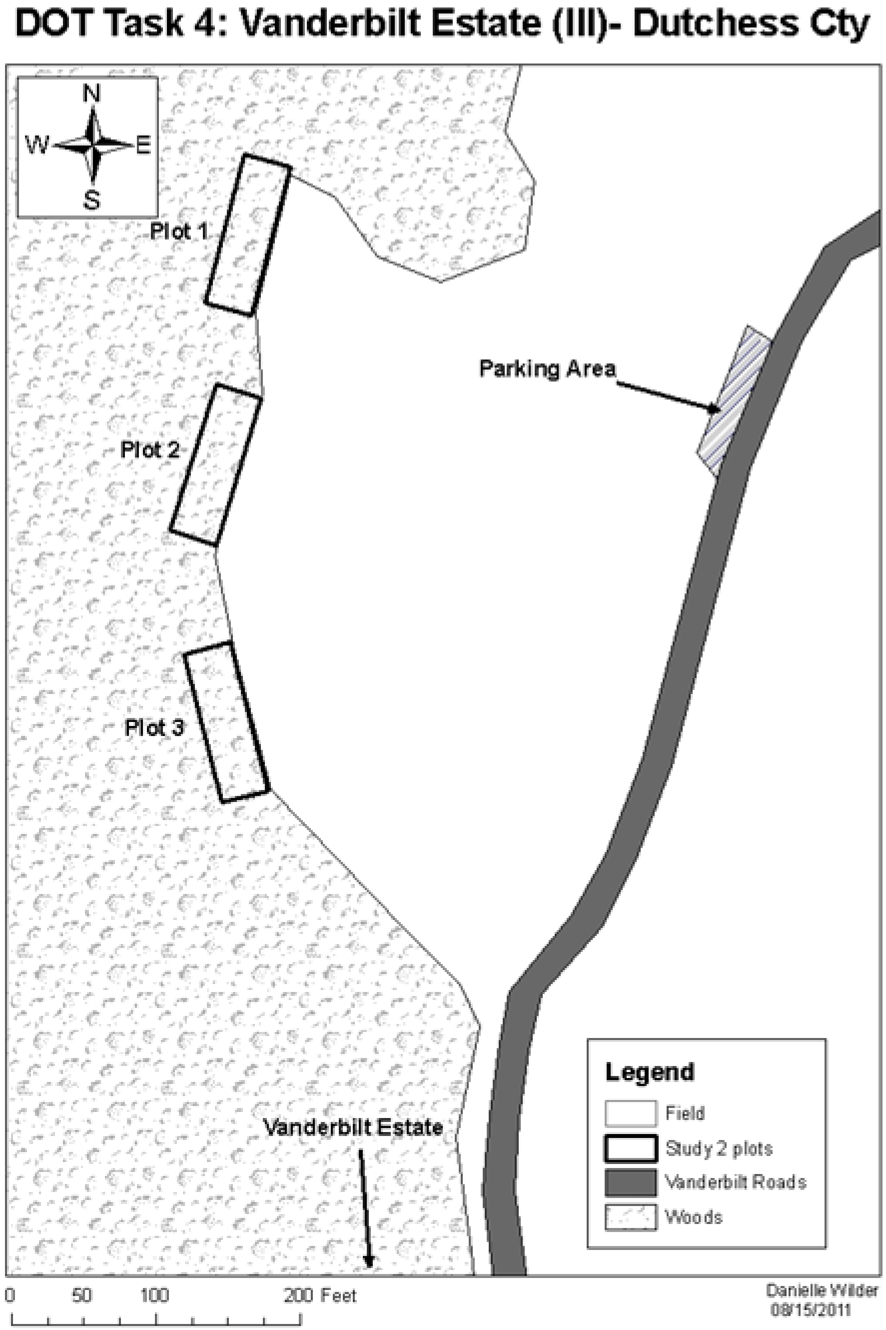
Map (1 of 4) of Task 4 plots for both Studies 1 and 2 on the National Park Service's Vanderbilt National Historic Site near the Village of Hyde Park. (UTM coordinates: X (easting) 587891.2321192305, Y (northing) 4627893.748051945)



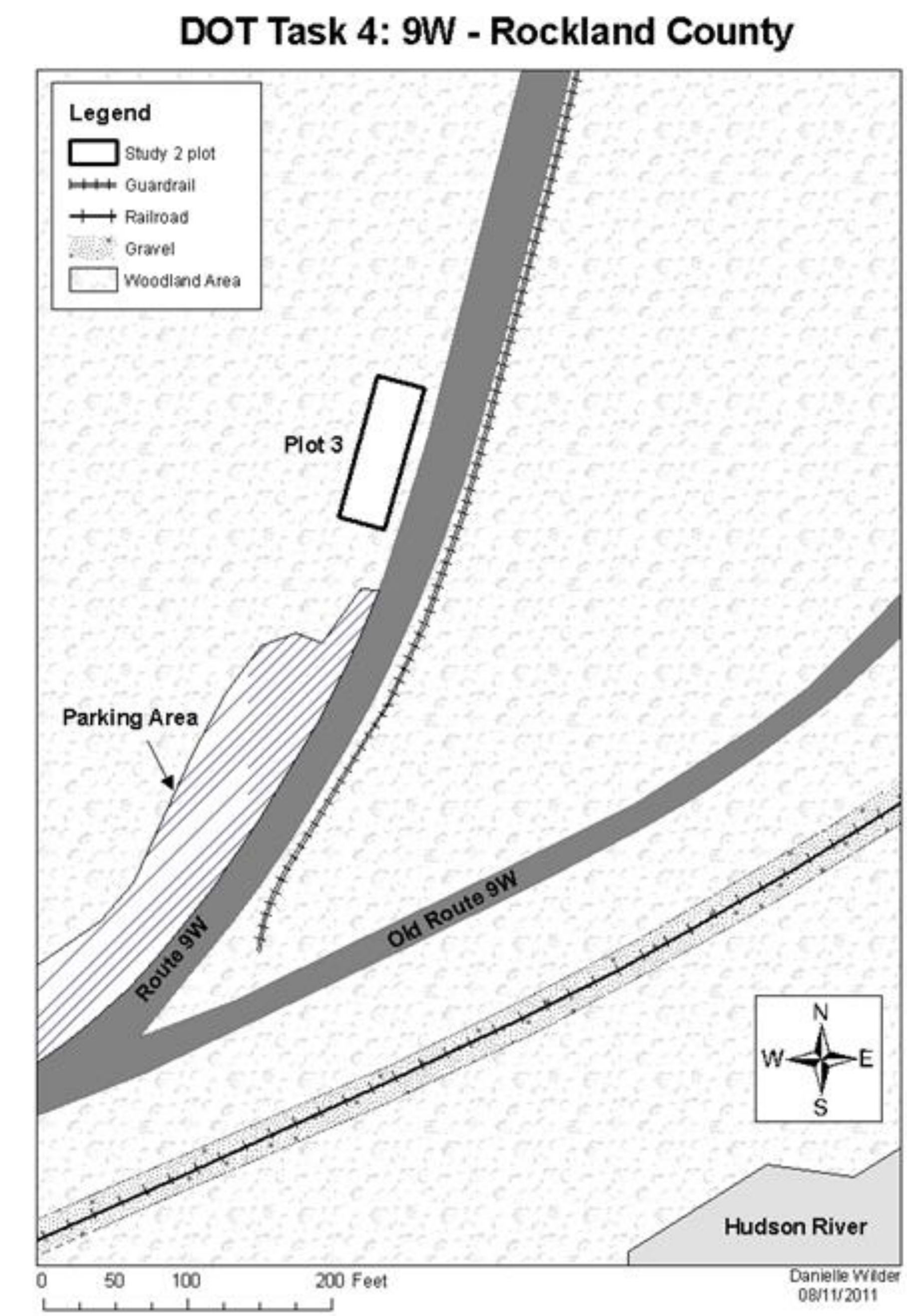
Map (2 of 4) of Task 4 plots (black squares, Study 1) on the National Park Service's Vanderbilt National Historic Site. Plots are organized into three blocks: east, west and northwest (NW).



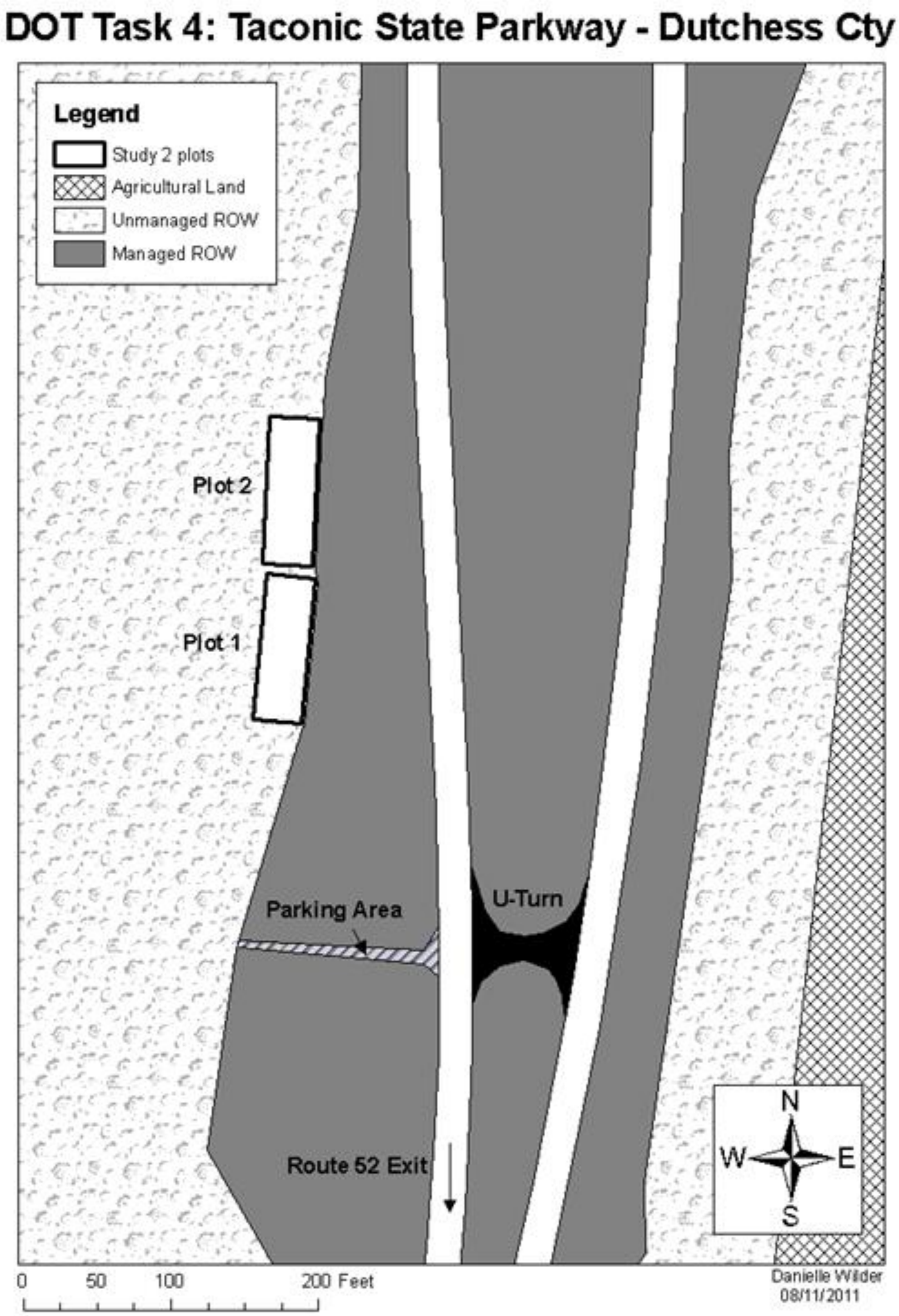
Map (3 of 4) of Task 4 plots (black squares, Study 1; black rectangles, Study 2) on the National Park Service's Vanderbilt National Historic Site.



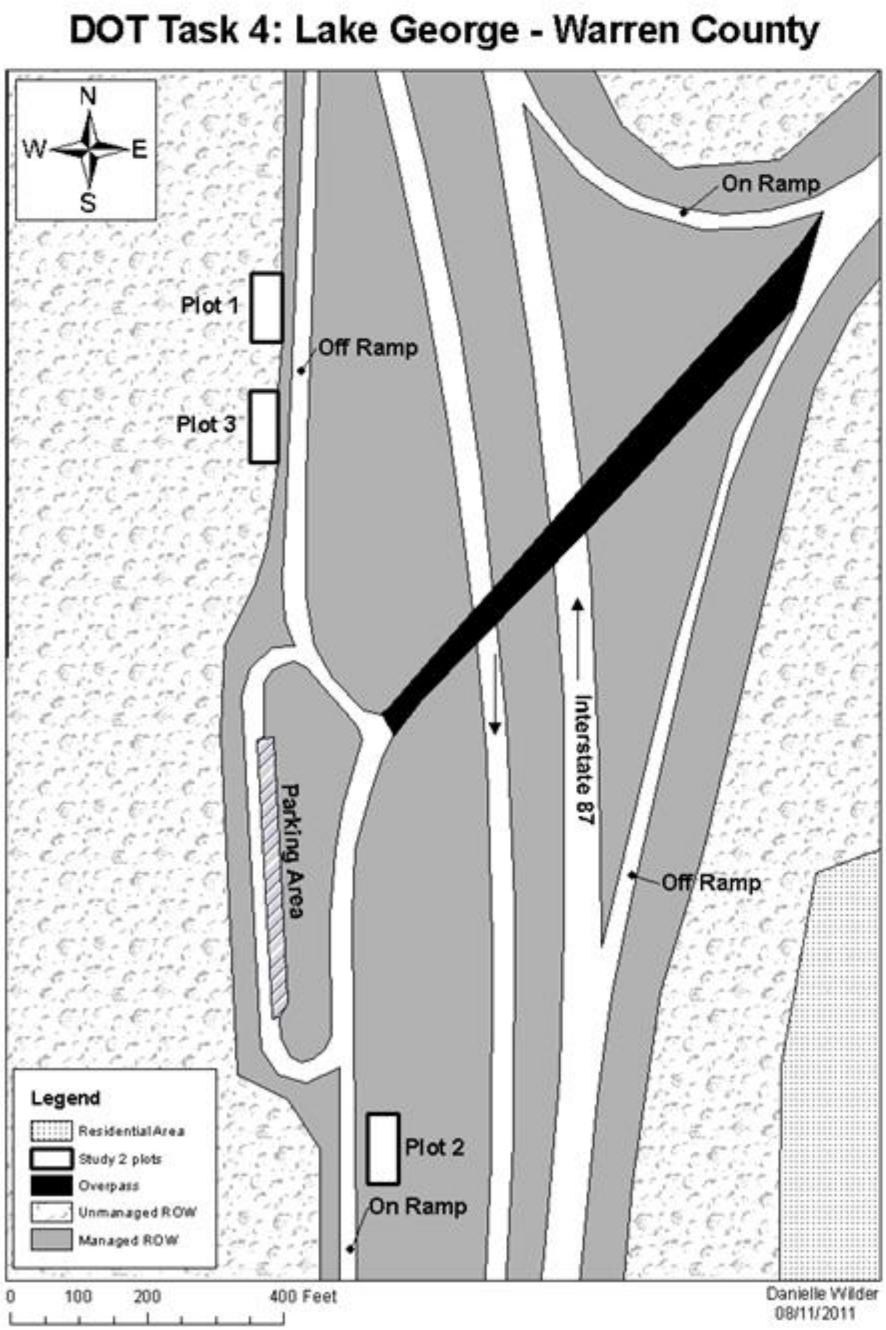
Map (4 of 4) of Task 4 plots associated with Study 2 on the National Park Service's Vanderbilt National Historic Site.



Map of a Task 4, Study 2, treatment plot established in NYSDOT Region 8 near the Town of Stony Point, NY. (UTM coordinates: X (easting) 586969.6738075833, Y (northing) 4570562.466042469)



Map of Task 4, Study 2, treatment plots established in NYSDOT Region 8 near the Town of East Fishkill, NY. (UTM coordinates: X (easting) 601710.7736446878, Y (northing) 4603097.393727536)



Map of Task 4, Study 2, treatment plots established in NYSDOT Region 1 near the Village of Lake George, NY. (UTM coordinates: X (easting) 603536.8591695434, Y (northing) 4809276.255588576)