THE DISTRIBUTION OF INVASIVE *CELASTRUS ORBICULATUS* IN AN ANTHROPOGENICALLY DISTURBED RIPARIAN ECOSYSTEM

A Final Report to the Tibor T. Polgar Fellowship Program

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ABSTRACT

The Hudson River Estuary has been colonized by numerous terrestrial invasive plant species, due in part to its history of anthropogenic and natural disturbance riparian dynamics. This study investigates the spatial patterns of a widespread invasion by Oriental (or Asiatic) bittersweet (*Celastrus orbiculatus* Thunb) in Schodack Island State Park, Rensselaer and Columbia Counties. The Park is home to rare species and communities, several of which are threatened by the encroachment of bittersweet. Bittersweet populations were mapped and surveyed on a fixed grid throughout the island, to determine distribution patterns. Stem densities were approximately 50% higher in sites with dredged material substrate. Local experimental tests were carried out to investigate the establishment limitations of new populations. Five site types were selected based on substrate properties (dredged material and forest floodplain) and local bittersweet densities. Ten greenhouse-grown seedlings (transplants) and 100 seeds were planted at each site, and then tracked for their survival, growth, and evidence of mycorrhizal inoculation. Transplants survived and grew at similar rates among the five experimental site types, but seed germination varied, with the highest rate in the dredged material zones (p=0.05). No ectomycorrhizae were found on roots of experimental transplants, seedlings, or wild-growing bittersweet, consistent with previous greenhouse studies by other researchers. These results indicate that controlling bittersweet populations and expansion should be focused on habitat management in dredged material-covered areas, which represent a large fraction of the island's upland area.

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INTRODUCTION

Understanding invasive species expansion is an important and difficult challenge in the Hudson River (HR) watershed. Riparian zones, which are naturally dynamic ecosystems, can be rapidly invaded by exotic plant species, particularly in sites where anthropogenic degradation has been layered over natural disturbance regimes (Stohlgren et al. 1998; Brown and Peet 2003). Disturbed ecosystems facing a series of exotic plant invasions are an ideal location to investigate the factors that may be promoting invasive species establishment and expansion.

Few studies have investigated the expansion of Oriental bittersweet after a disturbance (Ladwig 2009; Pavlovic et al. 2009; Pavlovic et al. 2010; Silveri et al. 2001). Disturbances may disrupt natural cycles within the native ecosystem, through the alteration of soil qualities and communities, and could respond to and mediate invasions (Kourtev et al. 2002; Ehrenfeld 2003; Reinhart and Callaway 2006). Anthropogenic modifications to soils may set the stage for invasion by altering the native community structure and enabling invasive plants to more easily establish sub-surface (mycorrhizal) interactions (Ferren and Schuyler 1980; Marler et al. 1999). Native communities may not be able to adjust to changes within the soil community quickly, increasing the opportunity for exotic species invasions.

A prime example is Schodack Island, once a series of natural islands and now a single landmass, created by repeated placement of dredged material over many decades (C&S Engineers 1998; USACE 2000). As a disturbed ecosystem facing a series of exotic plant invasions, Schodack Island is an ideal location to investigate the factors that may be promoting invasive species establishment and expansion.

Species characterization

One very aggressive and increasingly prominent invasive species on Schodack Island is the exotic woody vine Oriental bittersweet (*Celastrus orbiculatus* Thunb.). Documented as early as 1895, Oriental bittersweet was initially introduced in North Carolina from Eastern Asia (McNab and Meeker1987). In recent years, Oriental bittersweet densities have been steadily increasing in the northeastern region of North America (McNab and Meeker1987; Hutchinson 1992; Virginia Native Plant Society 1995; Shepard 1996; TNC 2001; Pooler et al. 2002; Swearingen 2009). Its dispersal is emphasized through various human and bird interactions. Since its introduction, Oriental bittersweet has been cultivated for its bright colored fruits that are used in decorative crafts (Dreyer 1994). Its distribution among riparian habitats is most likely the result of various native and migratory bird species. Its strong dispersal potential is characterized by high seed viability as well as being one of the few food sources for birds in the winter (Browder 2011; Dreyer et al. 1987).

In forests and on forest edges, bittersweet is a superior competitor due to its fast and opportunistic growth characteristics. Above ground, Oriental bittersweet can become established in both the canopy and the understory due to its two growth forms: cane-forming (understory layer) and liana-forming (canopy layer). Growing up to 3m per year, bittersweet has a substantial height advantage, which inhibits the growth of understory species (McNab and Loftis 2002; Patterson 1974; Silveri et al. 2001). Despite various light conditions, bittersweet has the ability to crowd, overtop and eventually kill established trees causing alterations in light gap dynamics within the understory (Albright et al. 2009). In addition, in its liana form, bittersweet can adjust growth to reduce intraspecific competition (Leicht-Young et al. 2011).

As with other invasives, bittersweet benefits from anthropogenic disturbances (Silveri et al. 2001; Ladwig 2009; Pavlovic et al. 2009; Pavlovic et al. 2010). Bittersweet persists in a wide range of habitats including various types of forests, highly to slightly disturbed areas and gaps as well as low-light environments (Leicht-Young et al. 2009; Leicht-Young et al. 2011; Browder 2011). Due to its high dispersive potential and morphological plasticity, it succeeds in a variety of open field, canopy, and sub-canopy environments to the detriment of the surrounding native plant communities (Browder 2011).

It is apparent to many people that Oriental bittersweet is becoming more prevalent throughout the northeast. On Schodack Island, bittersweet grows at high densities, often dominating canopies and some open areas. The invasion is of special concern for native and migratory bird species in the canopy layer throughout the island. Habitats are first altered by crowding, then by light gaps created when large trees are brought down by the weight of bittersweet. The impacted habitats include threatened and rare species, as well as natural communities of special interest on the island (NYS OPRHP 1998). This invasion has progressively intensified over the years, causing a serious problem for threatened and rare species inhabiting Schodack Island (Barbour and Kiviat 2001).

Mycorrhizal Associations

Below-ground competition from older bittersweet plants could also affect native vegetation (Leicht-Young et al. 2011). Like many woody invasive species, Oriental bittersweet tends to rely on generalist mycorrhizal associations that seem to be easily formed (Lett et al. 2011). The invasion of an exotic species can be magnified through the facilitation of various local mycorrhizal species, which may enhance competitive effects in exotic species causing detrimental impacts on the native community structure (Marler et al. 1999; Pringle et al. 2009; Richardson et al. 2000; Rejmanek 2000). These associations may depend on the localized environmental conditions, such as soil properties, which may determine the magnitude of ecosystem-level impacts (Ehrenfeld 2003). Such soil properties are specific to the land use history of an area, which has the potential to exacerbate microbial competition.

General properties of freshwater dredged material varies considerably, but it has the potential to exacerbate invasive species expansion (Zedler 2001; Ohimain 2004). Freshwater dredged material deposition may alter the natural soil community dynamics causing site specific vulnerabilities that encourage the establishment and overall success of Oriental bittersweet. Little is known about the recovery of native ecosystems from freshwater dredged material deposition; however, these disturbances have negatively impacted native species diversity and caused significant range reductions within the native species communities (Ferren and Schuyler 1980).

Several studies have shown that many invasive species have a demonstrated ability to alter ecological processes to their advantage (Ehrenfeld 2003; Wolfe and Kilronomos 2005). Various factors contribute to the success of Oriental bittersweet invasion including a wide range of light and habitat tolerance (Dreyer et al. 1987; Leicht and Silander 2006; Leicht et al. 2007). Few studies have documented Oriental bittersweet soil ecosystem preferences (Leicht-Young et al. 2009; Lett et al. 2011); however, none have investigated the soil and microbial communities associated with its expansion and distribution in disturbed habitats.

The Objectives of this study were to determine the driving forces influencing the distribution of Oriental bittersweet in a disturbed riparian habitat, with three specific aims:

- To determine the approximate arrival time of Oriental bittersweet on Schodack Island and its current distribution pattern, using field surveys.
- To test for site-specific conditions that may favor or limit the establishment and growth of Oriental bittersweet individuals.
- To aid in the development of management strategies to restore key habitats and limit further spread of the invasive bittersweet.

Null hypotheses were that (1) distribution patterns are random, with no focal zones of establishment; (2) sites with lower bittersweet densities are no less prone to invasion than sites with higher densities; (3) sites with native floodplain soils are no less prone to invasion than sites with soils derived from dredged material. Vulnerability to invasion was determined by a combination of mapping, field measurements, and experimental tests.

METHODS

General Site Information

Schodack Island State Park is a peninsula in the northern HR Estuary, bordered by the main channel on the west and by Schodack Creek/Muitzes Kill to the east. Schodack Island, once a series of natural islands and now a single landmass, created by repeated placement of dredged material over many decades (C&S Engineers 1998; USACE 2000). Although surrounded by tidal wetlands, Schodack is dominated by dredged material and floodplain forests. Ecological communities include successional old field, successional shrubland, dredge "spoil" forest, locally rare freshwater intertidal mudflat, freshwater tidal marsh, freshwater tidal swamp, and floodplain forest (NY NHP 2005). The park is a designated Bird Conservation Area (NYS DEC 2012), Department of State Significant Coastal Fish and Wildlife Habitat, and Significant Scenic Area (NYS DOS 2012). Since at least 1965, the site has supported a breeding population of Cerulean Warbler (*Setophaga cerulea*; NYS Species of Special Concern), with 13 singing males counted in 1997 (Barbour and Kiviat 2001), and their presence reconfirmed in 2012 by NY Audubon volunteers. Bald Eagle (*Haliaeetus leucocephalus*) maintain two active nests, Osprey (*Pandion haliaetus*) are commonly observed roosting and foraging, and a resident Great Blue Heron (*Ardea herodias*) colony contains about 50 nests.

Schodack Island began as a set of alluvial islands, once used for agriculture by Native Americans. Beginning in the 1920's, dredged material was deposited up to 2 m above river level, creating a single land mass that is a mosaic of natural and artificial topography and soils (Miller et al. 2006). Schodack Island State Park, which includes all but the southern tip of the island (still an active USACE dredged material placement area), was established in 2002, and several rounds of planning identified the significance of its avian habitats as well as the threats they faced (NYS OPRHP 1998; C&S Engineers 1998; Barbour and Kiviat 2001). The most prominent invasive species is Oriental bittersweet.

Experimental Design

Survey

In summer-fall 2012, operating with a research permit from NY State Parks, thirty transects were mapped out along the E-W axis of the island. Each transect was separated by 230 m on the N-S axis (which is totaled at 9.5 km) creating a grid within the park boundaries. Bittersweet populations were surveyed at 146 grid points (Figure 1).

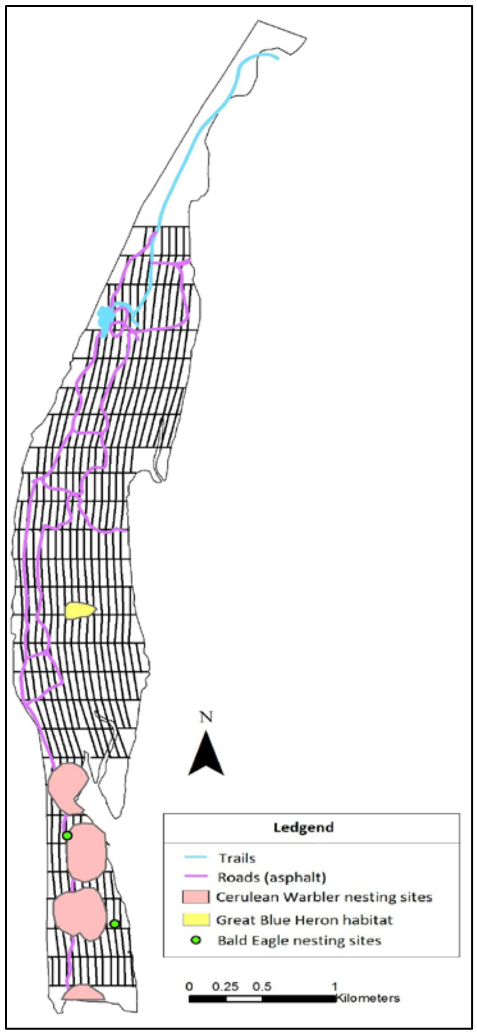


Figure 1. Map of bird habitats, roads/trails and experimental survey grid on Schodack Island. Survey points are noted as the intersection between N-S and E-W transects.

Within a 2 m radius of each point, UTM coordinates, stem densities of cane-forming and climbing bittersweet, thickest stem diameters, and reproductive status were recorded. All climbing bittersweet were cut at 0.5 m above ground level, to investigate future regrowth patterns. Rapid assessments were made along roads and trails throughout the park to locate larger bittersweet lianas (> 2 cm dia.), which were mapped, measured, cut and aged.

Phytometer Experiment

In November 2012, approximately 4,000 bittersweet fruits (with 3-5 seeds each) were collected from random locations across Schodack Island, and approximately 5,000 seeds were cleaned, batched, and stored under refrigeration (Young and Young 1992). Preliminary tests indicate germination rates of about 70% in the greenhouse (Figure 2). In March 2013, more than 1,000 seeds began germination in the greenhouse, planted in pots of sterile medium, watered and fertilized, in preparation for field transplantation, which occurred May 29-June 23, 2013. Transplants were grown in pots with 10 other seeds in the greenhouse. During installation, transplants were separated in to groups with 2-4 individuals, thinning out weaker seedlings to keep densities low.

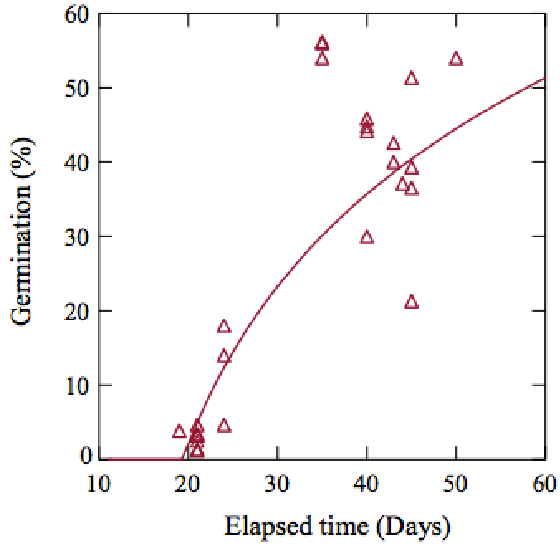


Figure 2. Scatter plot showing Oriental bittersweet time to germination in a greenhouse. Graph shows a logarithmic regression with a cluster of individuals germinating within 20 days and a second cluster of individuals germinating between 40-50 days.

Phytometer Bittersweet Densities

Twenty-five experimental sites were selected on the basis of five site categories (Figure 3), with five replicates of each. High, low and absent densities of Oriental bittersweet were quantified into categories based on the field survey (Figure 5). High densities consisted of survey points that had more than 16 stems per $2m^2$. Low densities consisted of survey points that had between 1-10 stems per $2m^2$. Absent densities consisted of survey points that had 0 stems per $2m^2$. Soil classifications were roughly based on habitat community maps provided by The New York Natural Heritage Program (Figure 3b).

Table 1. Matrix of experimental site categories, designated on the basis of previous surveys and observations. Bittersweet has not been observed at high densities in wetter, low-lying areas on Schodack Island.

Site-specific bittersweet densities	Dredged Material	Flood-plain
High	X	
Low	X	X
Absent	X	X

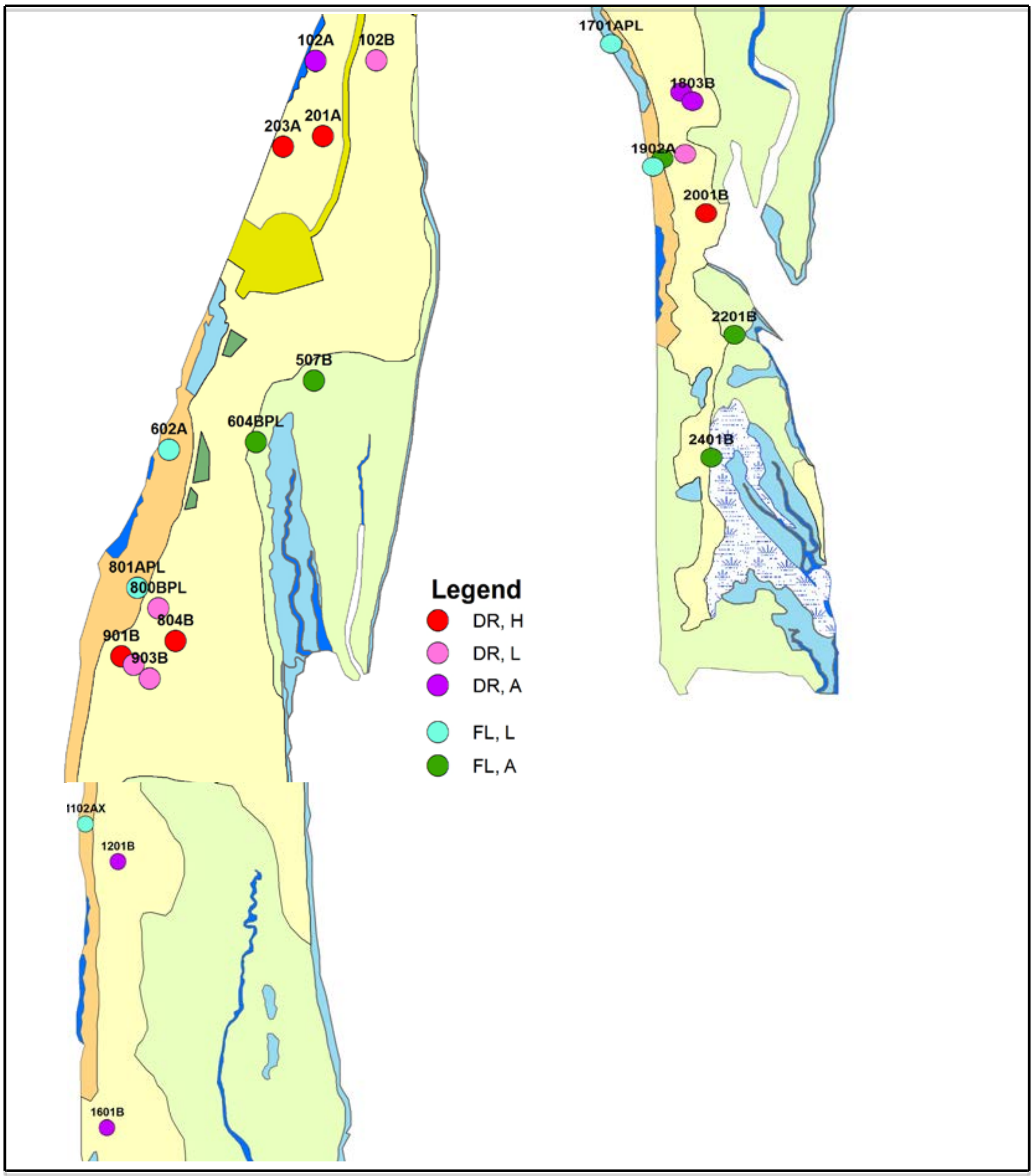


Figure 3. Map showing habitat communities and phytometer experimental sites. The number correlated with each point identifies the waypoint for each site. Warm colored points (red, pink, purple) represent sites on the dredged material habitat. Cool colored points (blue, green) represent the sites on the native floodplain forest. H (high), L (low), A (absent) is a quantification of the adult bittersweet communities at each site.

Native vs. Non-native Soil Type

At each site, 10 transplant seedlings and 100 seeds were planted in mapped and marked locations. Transplants were grouped in clusters of 2-4 stems and planted within a one meter diameter of the data collection point. Seeds were spread evenly within a two meter diameter from the data collection point at about a half meter in width. Stem length was recorded during installation and monitoring which occurred three times throughout the summer and fall (50, 40 and 30 days apart). During monitoring, percent germination was also recorded. The monitoring period ended after 120 days in which evidence of herbivory was noted for each individual plant. In addition, soil samples were collected from each of the 25 sites and sent to Cornell University's Nutrient Analysis Laboratory for soil fertility (Morgan extractable P and NO_3; K, Ca, Mg, Fe, Mn, Zn, and Al; pH; buffer pH; % H_20 and % organic matter).

Seedling Growth

Surviving seedlings were dried and weighed (separating roots and stems). Roots of collected seedlings were separated from stems (excised immediately above the uppermost root) and examined visually for evidence of ectomycorrhizae. Stems were dried in paper bags for 24 hours at 60°C. Weights of paper bags before and after drying were also taken into consideration for data collection.

Statistical Analyses

Liana and cane densities and diameters were compared between dredged materials and floodplain sites were made with two-tailed paired *t*-tests, using data from all survey points (N = 85). The same test was applied to pH values for the subset of points with soil samples (N = 26). The means and standard deviations for the phytometer experimental tests based on soil type (forest floodplain vs. dredged material) and adult densities (absent, low and high) were calculated. Experimental transplants were pooled into their original clusters (3-4 per site), using means of the 2-4 plants per cluster. This rule was applied because the transplants were moved and planted as groups (just as seeds are carried 2-4 per fruit by dispersers), and because they tended to share microenvironmental factors, such as substrate condition and herbivory. Survival (%) and growth increments (above-ground) were compared among the five treatment levels using one-way Analysis of Variance (ANOVA), following tests for normality and variance homogeneity. Mean seedling germination rate (%) was counted as the maximum value per site over three survey periods, and growth as the mean above-ground stem dry weight per site, again using one-way ANOVAs. A power analysis indicates that with five replicates at five levels, achieving a power of 0.8 (at alpha = .05) required a standard deviation < 1/2 the mean difference among treatments). Thus, a 20% difference in means would have an 80% probability of achieving a significant effect with a standard deviation < 10%.

One low-density dredged material site was found to contain well over 100 new seedlings during the final survey, well beyond the observed range of germination periods for both greenhouse and field trials. Evidence from the surrounding area indicated a high level of natural germination, confounding the results, so this site was ruled out in statistical comparisons of germination rates and seedling biomass. All analyses were performed using SYSTAT 13 (Systat Software, Inc. Chicago, IL).

RESULTS

Surveys

Oriental bittersweet showed a variety of age ranges, with the oldest stem observed being approximately 20 years old at 7 cm (Figure 4). The distribution of the largest stems seemed more proximate to the roads and trail edges. Larger stems in higher densities are generally seen in the dredged material habitat (Figure 5). Most of the fruit-bearing stems are lianas > 2.4 cm (7-10 yrs.), therefore younger populations may only be spreading through clonal expansion. Stem diameter was positively, but weakly correlated with density (R^2 = .289).

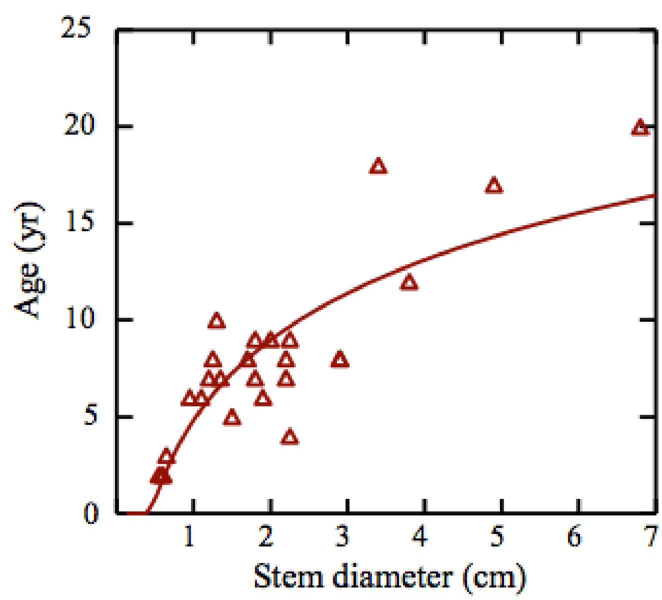
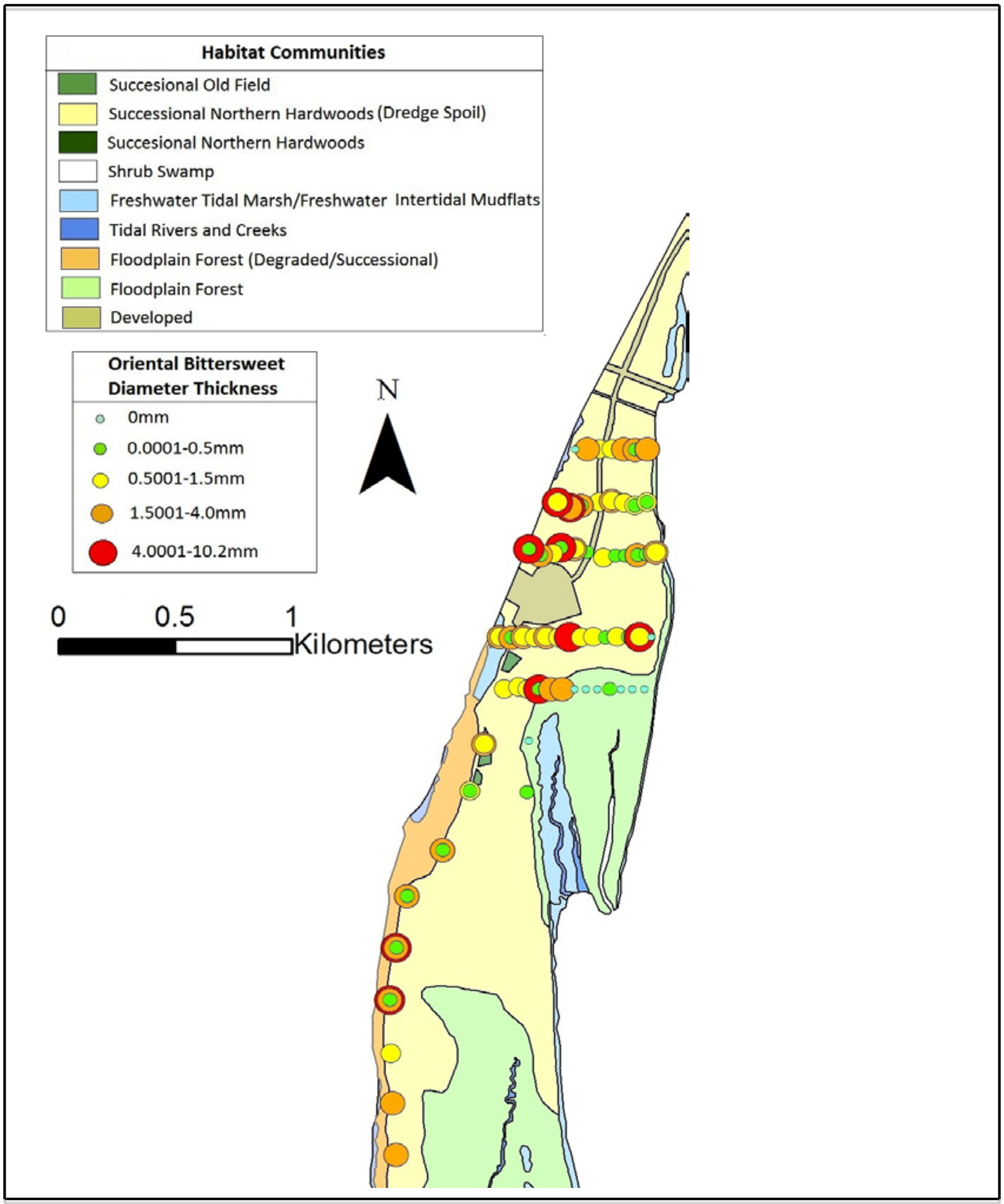


Figure 4. Scatter plot showing the relationship between Oriental bittersweet stem diameter and age. Graph shows a logarithmic regression with the oldest bittersweet stem at approximately 20 years old.



Habitat Communities
Succesional Old Field
Successional Northern Hardwoods (Dredge Spoil)
Succesional Northern Hardwoods
Shrub Swamp
Freshwater Tidal Marsh/Freshwater Intertidal Mudflats
Tidal Rivers and Creeks
Floodplain Forest (Degraded/Successional)
Floodplain Forest
Developed
Oriental Bittersweet Diameter Thickness
0mm
0.0001-0.5mm
0.5001-1.5mm
1.5001-4.0mm
4.0001-10.2mm
N
0
0.5
1
Kilometers

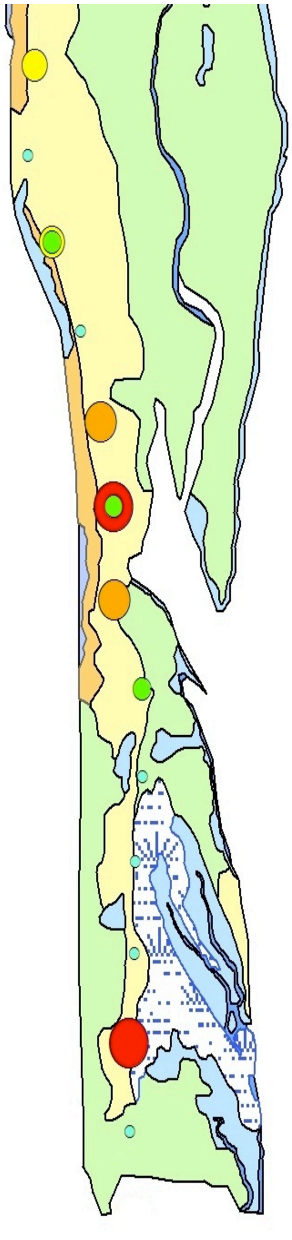


Figure 5. Map showing the habitat communities and survey points on Schodack Island. The figure on the left represents the northern part of the island, while the figure on the right represents the southern half. Survey points that are directly overlaid indicate higher densities than the single survey points.

The stem density of established Oriental bittersweet throughout the Schodack Island was significantly correlated with soil type (Figure 6). On average, stem density per 2 m^2 on the dredged material was greater than the native soil stem density (p=0.002).

Oriental bittersweet stem diameter for the largest individual per survey site averages at about 1.75 cm (or approx. 5-7 yrs.) on Schodack Island and is not strongly correlated with stem densities (R^2 = .088, N = 138 local populations). Sample sites were clustered near roads and trails, which may explain similarities in pH (Figure 7), however additional soil analyses from phytometer sites also found no significant differences (Table 2). In contrast to density differences, stem diameters for both cane and liana forming bittersweet stems were similar among site types (Figure 8a, b).

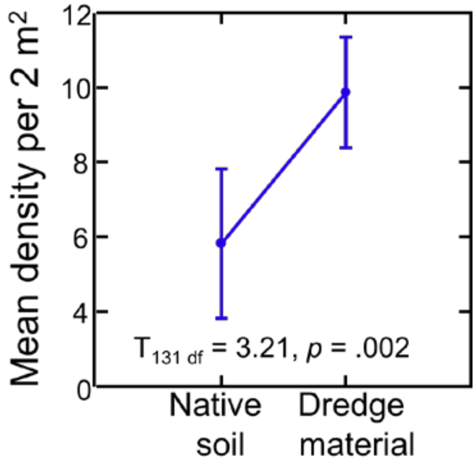


Figure 6. Line graph showing relationship between soil type and mean stem density at each survey point.

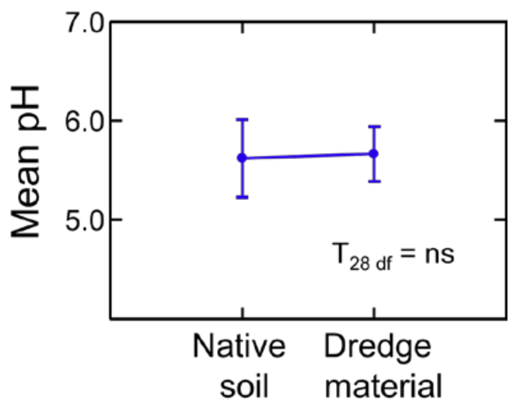


Figure 7. Line graph showing relationship between soil type and pH.

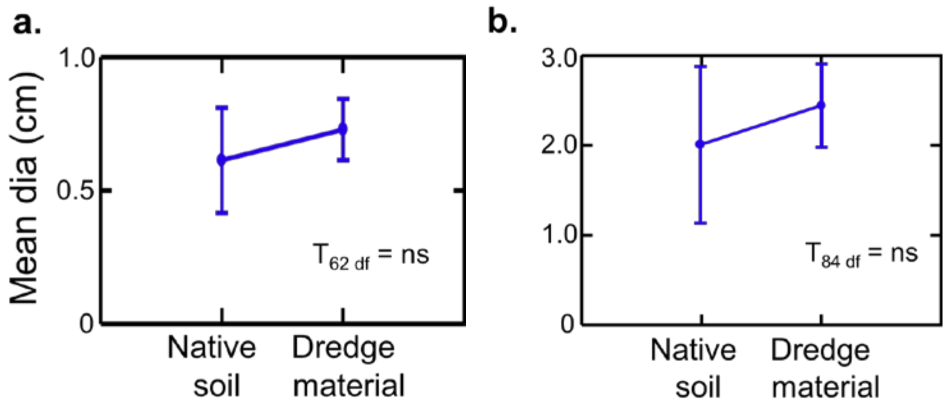


Figure 8. Line graphs showing (**a)** relationship between soil type and mean diameter of cane-forming bittersweet vines that mainly occupy the understory layer, and (**b)** relationship between soil type and mean diameter for liana-forming bittersweet vines that mainly occupy the canopy.

Phytometer Site Soil Nutrients

The native floodplain soils were much richer in organic matter, and in several major nutrients (Table 2). These differences may reflect differences in nutruent cycles as well as physical properties of the two substrates. Higher levels of Ca, Mg, and Mn may be attributable to greater clay content in native floodplains, in addition to a higher fraction of organic matter. Likewise, highly soluble nitrate may be bound less tightly in the sandy soils of dredged material origin.

Table 2. Results of tests of soil samples taken from dredged material sites (D) and floodplain sites (F). LOI = loss on ignition; OM = organic matter. Adjusted *p* values represent Bonferroni corrections for multiple *t*-tests (ns = $p > .05$).

Test Variable	Site Type	N	Mean	SD	Adjusted *p*-Value
H2O (%)	D	15	0.395	0.294	<0.0001
	F	10	1.306	0.296	
pH	D	15	5.901	0.408	ns
	F	10	6.217	0.379	
LOI (%)	D	15	2.227	1.644	<0.0001
	F	10	6.134	1.84	
OM (%)	D	15	1.327	1.15	0.001
	F	10	4.063	1.289	
P (mg/Kg)	D	15	2.026	1.559	ns
	F	10	4.693	2.597	
Al (mg/Kg)	D	15	6.315	3.006	ns
	F	10	5.607	3.536	
Ca (mg/Kg)	D	15	750.943	533.024	<0.0001
	F	10	2,448.75	411.737	
Fe (mg/Kg)	D	15	3.753	1.597	ns
	F	10	5.846	5.977	
K (mg/Kg)	D	15	52.136	23.051	ns
	F	10	77.284	25.011	
Mg(mg/Kg)	D	15	80.41	70.149	<0.0001
	F	10	234.494	63.661	
Mn (mg/Kg)	D	15	5.336	4.197	<0.0001
	F	10	14.617	2.725	
Zn (mg/Kg)	D	15	3.094	2.007	ns
	F	10	5.975	2.455	
NO_3 (mg/Kg)	D	15	4.171	3.099	0.027
	F	10	10.802	4.919	

Phytometer Bittersweet Germination, Survuval, and Growth

Of the 2,500 seeds that were planted throughout the island, only 211 seeds germinated. Final seedling counts ranged from zero (in 12 sites) to 27, for a mean of 4.7

per site, or <5% of the total introduced seeds. These values stand in contrast to the high greenhouse germination rates (above), but are not atypical of woody plants in natural systems (Harper 1977). Germination rates varied among treatments (Figure 9; Table 3). Once germinated, 64.2% of the new seedlings survived the duration of the experiment,

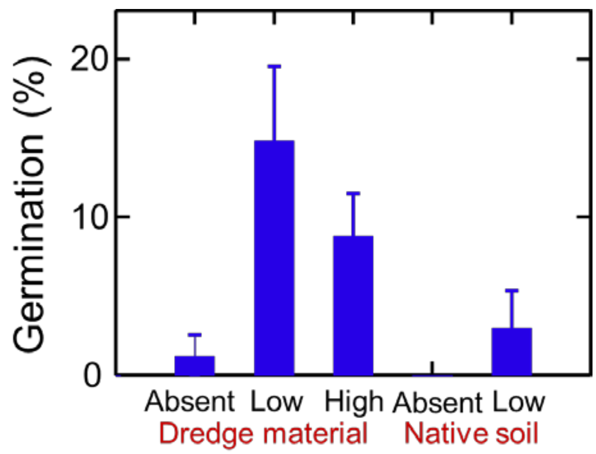


Figure 9. Bar graph representing the differences in soil type and adult bittersweet densities with mean percent germination of planted seeds (ANOVA results in Table 3).

Table 3. ANOVA results from tests of seedling germination per site type**.**

Source	Type III SS	df	Mean Sq	F-Ratio	*p*
Site type	358.358	4	89.590	2.872	0.05
Error	592.600	19	31.189		

Eighty-five percent of the total transplanted seedlings survived for the first 120 days. For the period studied, high levels of variance ruled out significant treatment differences (mean 3.53 seedlings lost; sd 5.08; ANOVA $F_{4,74} = 1.66$, $p = .167$). Sizes of plants from field-germinated seeds were equivalent among treatments (ANOVA $F_{4,74}$ = 2.17, p = .915).

Mean transplant growth was all fairly low over the 120 day period. In the most extreme cases, averaging under 5 cm across all treatments, which had similar values (mean 1.71 cm; sd 3.66; ANOVA $F_{4,74}$ = 1.66, p = .167). Under optimal conditions, established plants of Oriental bittersweet can grow up to 100 cm in 120 days (Patterson 1974; Leicht and Silander 2006). Ten of 250 transplants were clipped with an angular cut, indicating possible herbivory by meadow voles (*Microtus pennsylvanicus*; Manson et al. 2001). An additional 42 (16.8%) were not found, and categorized as unexplained losses.

Phytometer Ectomycorrhizal Inoculation

Among the 214 seedlings collected (including the potential natural seedlings from one site), all roots examined had unmodified root caps and visible root hairs, with none of the swelling or bifurcation associated with ectomycorrrhizae. This finding is consistent with results from Lett et al. (2011), whose experiments demonstrated that *C. orbiculatus* could not be inoculated with generalist ectomycorrhizal fungi in a laboratory setting.

DISCUSSION

Survey Results

Ring counts of the largest bittersweet lianas indicate a maximum age of approximately 20 yr. This is consistent with its relatively recent spread in the region, and during the course of this project, similar-aged specimens were found on nearby Papscanee Island, to the north. Given that bittersweet seeds are bird-dispersed and have high germination potential, the invader probably began arriving on Schodack Island less than 25 years ago. In contrast to null predictions, distributions of bittersweet were non-random – stem densities were greater in the dredged material-derived soils compared to the native soils. In addition, high-density bittersweet populations were not encountered in any native soil locations.

Native substrate was uniformly classified as floodplain soil because it was found in low-lying areas and on shorelines. Therefore, waterlogging could be a factor in limiting bittersweet in these areas. Confirmation would require a longer study in conjunction with manipulation experiments. Soil nutrients are an unlikely explanation for site-specific differences, because the native soils were richer in several key nutrients, and bittersweet is not known as a poor-soil specialist (Leicht and Silander 2006; Leicht et al. 2007). A further explanation for greater stem densities in dredged material soils may lie in differential patterns of bird dispersal, coupled with clonal propagation. Large stems were found in several locations across the island, but its expansion could potentially be traced back to a few major colonization points that have expanded. The positive (although weak) correlation between stem diameters and stem densities supports this latter possibility. Other research has found evidence for positive density dependence in bittersweet populations (Leicht-Young et al. 2011).

Phytometer Results

Germination rates of planted seeds differed among treatments, with lower rates in native soils and dredged material sites with bittersweet absent. Transplant survival and growth as well as growth of seedlings from planted seeds were equivocal among treatments. However, the duration studies was limited to a single season, and final results of planned concluding work may show clearer differences. In addition, the experimental design was sensitive to the levels of variance encountered, as indicated in the power analysis (see Methods). Differential herbivory may have played a role, but it was variable among sites and not directly investigated.

CONCLUSIONS

The two main results provide support for a difference between substrate type in the establishment and success of bittersweet. What remains to be demonstrated are clearer mechanisms for the apparent role of substrate. For example, although ectomycorrhizae seem unimportant, VAM inoculations can be quantified in bittersweet plants removed from the two different substrates. Mycorrhizae are sensitive to nutrient levels (Allen 1991), and invasive plants may owe a large part of their success to an ability to form mycorrhizal mutualisms in new settings (Pringle et al. 2009). Therefore, it is conceivable that properties of the native soils may limit bittersweet's potential to establish and grow via indirect interactions mediated by soil fungi.

If further work confirms that the dredged material-derived soils are preferred growth zone, more targeted management strategies can be developed for the control of bittersweet in Schodack Island State Park. Sensitive habitats and other areas of conservation interest have been demarcated for the park (NYS OPRHP 1998), and the next step is to assess bittersweet populations in their vicinity. Targeted removal of the largest stems has already begun, but supplies of new recruits are plentiful on and off the island. Using the new information from the study in this report, it seems reasonable to focus broader control efforts on source populations growing on dredged material-derived soils. An additional strategy seems apparent. Much of the Hudson River (western) shoreline of the park is rimmed with bulwarks and other hardened features, a legacy of previous use that continues to disrupt tidal floodplain connections. Restoring those connections may provide a measure of resistance to further spread of bittersweet on Schodack Island.

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REFERENCES

Albright, T.P., D.P. Anderson, N.S. Keuler, S.M. Pearson and M.G. Turner. 2009. The spatial legacy of introduction: *Celastrus orbiculatus* in the southern Appalachians, USA. Journal of Applied Ecology. 46: 1229-1238.

Allen, M.F. 1991. The Ecology of Mycorrhizae. Cambridge University Press, Cambridge, UK.

Barbour, S. and E. Kiviat. 2001. Cerulean Warbler survey of the southern portion of southern Schodack Island and Houghtaling Island, Hudson River. Final Report to U.S. Army Corps of Engineers, New York District, New York, NY.

Browder, J.R. 2011. The effect of *Celastrus orbiculatu*s, Oriental bittersweet, on the herbaceous layer along a western North Carolina creek. Master's Thesis. Western Carolina University, Cullowhee, NC.

Brown, R.L. and R.K. Peet. 2003. Diversity and invasibility of southern Appalachian plant communities. Ecology 84: 32-39.

C&S Engineers, Inc. and Terrestrial Environmental Specialists, Inc. 1998. Environmental Assessment Report (Phase I & II) for Schodack Island State Park: NYSOPRHP. Final Report to New York State Office of Parks and Recreation Heritage Program, New York, NY.

Dreyer, G.D. 1994. Element Stewardship Abstract for *Celastrus orbiculata*. The Nature Conservancy, Davis, CA.

Dreyer, G.D., L.M. Baird, C. Fickler. 1987. *Celastrus scandens* and *Celastrus orbiculatus* – comparisons of reproductive potential between a native and an introduced woody vine. Bulletin of the Torrey Botanical Club. 114: 260-264.

Ehrenfeld, J.G. 2003. Effects of exotic plant invasions on soil nutrient cycling processes. Ecosystems 6: 503-523.

Ferren, W.R. and A.E. Schuyler. 1980. Intertidal vascular plants of river systems near Philadelphia. Proceedings of the Academy of Natural Sciences of Philadelphia 32: 86-120.

Harper, J.L. 1977. Population Biology of Plants. Academic Press, London, England.

Hutchinson, M. 1992. Vegetation management guideline: round-leaved bittersweet (*Celastrus orbiculatus*). Natural Areas Journal 12:161.

Kourtev, P.S., J.G. Ehrenfeld, and M. Haggblom. 2002. Exotic plant species alter the microbial community and function in the soil. Ecology 83: 3152-3166.

Ladwig, L.M. 2009. Ecology and impacts of lianas in regenerating forests. Master's Thesis. Eastern Illinois University, Charleston, IL.

Leicht S.A., and J.A. Silander. 2006. Differential responses of invasive *Celastrus orbiculatus* (Celastraceae) and native *C. scandens* to changes in light quality. American Journal of Botany 93: 972–977.

Leicht, S.A., J.A. Silander, Jr. and A.M. Latimer. 2007. Comparative performance of invasive and native *Celastrus* species across environmental gradients. Oecologia 154: 273-282.

Leicht-Young, S.A., H. O'Donnell, A.M. Latimer and J.A. Silander. 2009. Effects of invasive plant species, *Celastrus orbiculatu*s, on the soil composition and processes. American Midland Naturalist 161: 219-231.

Leicht-Young, S.A, A.M Latimer and J.A. Silander. 2011. Lianas escape self-thinning: Experimental evidence of positive density dependence in temperate lianas *Celastrus orbiculatu*s and *C. scandens.* Perspectives in Plant Ecology, Evolution and Systematics 13: 163-172.

Lett, C.N., L.E. DeWald and J. Horton. 2011. Mycorrhizae and soil phosphorus affect growth of *Celastrus orbiculatus*. Biological Invasions 13: 2339-2350.

Manson, R.H., R.S. Ostfeld, and C.D. Canham. 2001. Long-term effects of rodent herbivores on tree invasion dynamics along forest–field edges. Ecology 82: 3320–3329.

Marler, M.J., C.A. Zabinski and R.M. Callaway. 1999. Mycorrhizae indirectly enhance competitive effects of an invasive forb on a native bunchgrass. Ecology 80: 1180-1186.

McNab, W.H. and M. Meeker. 1987. Oriental bittersweet: a growing threat to hard-wood silviculture in the Appalachians. Northern Journal of Applied Forestry 4:174-177.

McNab, W.H. and D.L. Loftis. 2002. Probability of occurrence and habitat for oriental bittersweet in an oak forest in the southern Appalachian Mountains, USA. Forest Ecology and Management 155: 45-54.

Miller, D., J. Ladd, and W.C. Nieder. 2006. Channel morphology in the Hudson River Estuary: Historical changes and opportunities for restoration. In: J. Waldman, K. Limburg, and D. Strayer, (eds.) Hudson River Fishes And Their Environment. American Fisheries Society Symposium 51:29-38.

New York Natural Heritage Program-NY NHP. 2005. Biodiversity in New York's State Park System: Summary of Findings. Report for the New York State Office of Parks, Recreation and Historic Preservation. Albany, NY.

New York State Department of Environmental Conservation-NYS DEC. 2012. "Bird Conservation Areas Program" http://www.dec.ny.gov/animals/30935.html

New York State Department of State-NYS DOS. 2012. "Designated Significant Coastal Fish and Wildlife Habitat" https://www.dot.ny.gov/divisions/engineering/environmental-analysis/manuals-and-guidance/epm/repository/4-2-a-6.pdf

New York State Office of Parks, Recreation, and Historic Preservation-NYS OPRHP. 1998. Final Master Plan/Final Environmental Impact Statement for Schodack Island State Park. Saratoga –Capital District State Park Region, Saratoga, NY.

Ohimain, E. 2004. Environmental impacts of dredging in the Niger Delta: Options for sediment relocation that will mitigate acidification and enhance natural mangrove restoration. Terra et Aqua 97: 9-19.

Patterson, D.T. 1974. The ecology of the Oriental bittersweet, *Celastrus orbiculatus*, a weedy introduced ornamental vine. Doctoral dissertation. Duke University, Durham, NC.

Pavlovic, N.B., S.A. Leicht-Young, K. Frohnapple and D. Morford. 2009. To burn or not to burn Oriental bittersweet: A fire manager's conundrum. First Progress Report by USGS, Porter, IN.

Pavlovic, N.B., S.A. Leicht-Young, K. Frohnapple, D. Morford and N. Mulconrey. 2010. To burn or not to burn Oriental bittersweet: A fire manager's conundrum. Second Progress Report by USGS, Porter, Indiana.

Pooler, M., R.L. Dix and J. Feely. 2002. Interspecific hybridizations between the native bittersweet, *Celastrus scandens*, and the introduced invasive species, *C. orbiculatus*. Southeastern Naturalist 1: 69-76.

Pringle, A. J.D. Bever, M. Gardes, J.L. Parrent, M.C. Rilling and J.N. Klironomos. 2009. Mycorrhizal symbioses and plant invasions. Annual Review of Ecology, Evolution, and Systematics 40: 699-715.

Reinhart, K.O. and R.M. Callaway. 2006. Soil biota and invasive plants. New Phytologist 170: 445-457

Rejmanek, M. 2000. Invasive plants: approaches and predictions. Australian Journal of Ecology 25: 497-506.

Richardson, D.M., N. Allsopp, C.M. D'Antonio, S.J. Milton and M. Rejmanek. 2000. Plant invasions—the role of mutualisms. Biological Reviews 75: 65-93.

Shepard, C. 1996. Invasive Plant Information Sheet: Asiatic Bittersweet (*Celastrus orbiculatus Thunb*.). The Nature Conservancy, Connecticut Chapter, Hartford, CT.

Silveri, A., P.W. Dunwiddie and H.J. Michaels. 2001. Logging and edaphic factors in the invasion of an Asian woody vine in a mesic North American forest. Biological Invasions 3:379-389.

Stohlgren, T.J., K.A. Bull, Y. Otsuki, C.A. Villa and M. Lee. 1998. Riparian zones as havens for exotic plant species in the central grasslands. Plant Ecology 138: 113-125.

Swearingen, J. 2009. "US Database of Plants Invading Natural Areas in the United States: Oriental Bittersweet (*Celastrus orbiculatus*)". ttp://www.invasive.org/weedus/subject.html?sub=3012

The Nature Conservancy-TNC. 2001. "Oriental Bittersweet: Element Stewardship" Abstract. In: Wildland Weeds Management & Research Program, Weeds on the Web. http://www.imapinvasives.org/GIST/ESA/

U.S. Army Corps of Engineers (USACE). 2000. Cultural resources investigation Hudson River habitat restoration study. Final Report to U.S. Army Corps of Engineers, New York District Planning Division, New York, NY.

Virginia Native Plant Society. 1995. "Invasive Alien Plant Species of Virginia: Oriental Bittersweet (*Celastrus orbiculatus Thunb.)"*. Virginia Department of Conservation and Recreation. http://www.state.va.us/~dcr/dnh/invcela.htm

Wolfe, B.E., and J.N. Klironomos. 2005. Breaking new ground: soil communities and exotic plant invasion. Bioscience 55: 477-487.

Young, J.A. and C.G. Young. 1992. Seeds of Woody Plants of North America. Discorides Press, Portland, OR.

Zedler, J. B. 2001. Handbook for Restoring Tidal Wetlands. CRC Press LLC, Boca Raton, FL.