ABSTRACT

WILLHITE, LAUREN, TAYLOR. Long-term Survivorship and Species Invasion on a Restored Urban Stream. Under the direction of Dr. Steph Jeffries).

Rocky Branch is a restored urban stream completed in three phases on North Carolina State's campus, providing a unique opportunity to examine plant communities 21 (Phase I), 17 (Phase II), and 13 (Phase III) years post-restoration. Stream restoration projects often are not monitored long-term, so survivorship of planted species and level of invasion in plant communities beyond seven years are not assessed, which was the focus of this study. At every third 10-meter plot along the stream, we did stem counts, species classification (planted, native volunteer, non-native volunteer, or invasive), and cover class by invasive species and by strata. Planted species were inventoried in every plot. For planted species, we assessed survivorship and well-performing species and for invasive species, we identified the highest-impact species. The most common planted species by number of stems was *Morella cerifera* (wax myrtle), *Calycanthus floridus* (Carolina allspice), *Ulmus americana* (American elm) *Sambucus canadensis* (American elderberry), and *Liriodendron tulipifera* (tulip-poplar). Importance values additionally showed *Celtis laevigata* (hackberry), *Platanus occidentalis* (sycamore), and *Betula nigra* (river birch) to be common planted species. Shared traits amongst these species include having facultative status, medium to high abundance of fruit and seed, and spreading vegetatively. These high-performing native plants as well as other species that are share similar functions and traits should be considered for future planting lists. Cover class data suggests that the highest impact invasive species are *Hedera helix* (English ivy), *Ligustrum lucidum* (glossy privet), *Microstegium vimineum* (Japanese stiltgrass), *Pyrus calleryana* (Callery pear), and *Ligustrum sinense* (Chinese privet). Indicator species analysis and ordinations of invasive species across phases/successional stages were also conducted. Based on the successional stage

additional species to target will vary assuming resource availability. Overall, future planting lists in the southeastern U.S. should consider facultative species with medium to high abundance of fruit/seed and vegetative growth capabilities. Furthermore, considering the study area has nearly 60% invasive cover, long-term management of vegetation should be incorporated into all restoration efforts, including assessment of planted species and continued, targeted management of high-impact invasives to ensure long-term success of the restored native plant communities.

Long-term Survivorship and Species Invasion on a Restored Urban Stream

by
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BIOGRAPHY

The author is a final-year graduate student at NC State University and was born in Chapel Hill, North Carolina. She is passionate and interested in invasive species in urban areas as well as the environment as a whole.

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1.1 Introduction

1.1.1 Stream Restoration

Riparian ecosystems are at particular risk and will be impacted the most dramatically as urbanization and human population increases (Malmqvist & Rundle, 2002). Consequently, stream restoration is of significant importance within urban environments given their frequent degradation and surrounding development (Ehrenfeld, 2008). These impacts cause streams to be unstable and erode, contributing large volumes of sediment resulting in overall stream degradation (Doll et al. 2004). To combat this degradation, an increasing number of stream restoration projects have been used as management strategies in urban areas (Bernhardt & Palmer, 2007; Violin et al. 2011). The goals of restoration typically focus on enhancing water quality, managing and optimizing floodplain and riparian function, improving in-stream habitat, increasing habitat heterogeneity, and securing bank stabilization (Bernhardt et al. 2005; Doll et al. 2004). Shifts in priorities additionally focus on flood control (Buchholz et al. 2016). While the hydrologic and habitat components are fundamental, it is also essential to consider meaningful incorporation of revegetation and subsequent plant communities within these projects. Hydrology-focused stream restoration projects are beneficial but may miss other important ecosystem services that could otherwise be implemented with the addition of riparian vegetation (Riis et al. 2020). Therefore, revegetation is a crucial part of stream restoration and can help maximize the benefits of projects by providing services such as increasing water-use efficiency (Zheng et al. 2019), increasing the diversity of the soil microbiome (Gellie et al. 2017), managing high nutrient loads (Hejna & Cutright, 2021; Mayer et al., 2022), and preventing erosion by anchoring stream banks (Monteiro et al. 2016).

Revegetation, however, isn't the end-all for the restoration project. Continued management of the area and long-term post-restoration analysis are crucial to ensure the success of the project. The emphasis on monitoring is a more recent phenomenon with many states now requiring restoration projects to have annual monitoring reports for a duration after the project construction is complete. Unfortunately, such requirements weren't always in place and monitoring has not always kept pace with the increasing number of projects. In fact, only about 10% of restoration projects were being monitored post-restoration as of 2005 (Bernhardt et al. 2005). Studies analyzing stream restoration projects in the U.S. are outdated, so the current state of stream restoration monitoring has not been summarized (Castillo et al. 2016). Of these older projects that were actually monitored, most were not monitored for more than a few years (Bernhardt et al. 2005). Even when monitoring was conducted, it isn't always clear what data should be recorded or how to determine the success of a project. Success can be measured in several ways; taxonomic diversity, richness, or abundance of invertebrates have been used as measures of biological success, while water chemistry and aquatic habitat have been used as measures of hydrological success (Violin et al. 2011). However, more is needed to standardize metrics of success and incorporate plant communities into them (Zan et al. 2017). Moreover, most urban stream restoration projects are monitored at a few locations that do not capture the full variability seen across the entire study site, resulting in data that are unlikely to represent the entire project or to detect ecosystem changes (Kaushal et al. 2023; Zan et al. 2017). Despite these issues, monitoring is crucial to evaluate the success, make necessary management changes to the stream, and inform future restoration projects.

1.1.2 North Carolina Stream Restoration Process and Requirements

North Carolina is the exception to the trends of inadequate monitoring across the United States. For instance, the North Carolina Department of Mitigation Services (DMS), is an in-lieufee mitigation company that has adopted some of the most thorough monitoring guidelines and practices of any state early on (Ecosystem Enhancement Program, 2007). DMS permittees give funds to an in-lieu-fee sponsor instead of having the permittee complete the mitigation themselves or purchase credits from a mitigation bank (Chowning et al. 2000). DMS Furthermore, North Carolina has the highest number of projects compared to other southeastern states in addition to a very high monitoring rate (Sudduth et al. 2007). This indicates that it was and remains ahead of most other states with regards to proper monitoring and management of stream restoration projects.

In North Carolina, the Wilmington District of the U.S. Army Corps of Engineers has planted vegetation performance standards all stream restoration projects conducted for Clean Water Act 404 mitigation purposes. These include standards on density of species within the mitigation list and tree height requirements. Alternative standards can also be proposed in the Mitigation Plan for sites that are to be revegetated with slow growing species, woody shrubs, or understory species in later stages. Seven years of vegetation plot monitoring is required with these standards in mind. Monitoring events must occur in years 1, 2, 5, and 7. This requirement was previously five years but was extended in 2016 (Tugwell, 2016). If a project is not doing well or is not meeting the standards, monitoring may be extended. After the monitoring is complete and a project is determined to have met the performance criteria, it closes out and enters a stage known as long-term management in perpetuity. Sites are transferred to a third party which is responsible for periodic inspection. This inspection is only to ensure that restrictions required in the conservation easement are upheld (North Carolina Department of Environmental

Quality, 2017). Crucially, this stage doesn't have any requirement for continued vegetation monitoring. This process may overlook long-term implications on vegetation communities and results that can't be observed or documented during the seven-year timeframe. To determine the success of meeting restoration plant community objectives, long-term management should include vegetation monitoring out to 25 years or longer to allow for the accumulation of species over time (Hasselquist et al. 2015). However, institutional constraints that require these projects to be declared as finished in shorter time spans don't align with the extended timelines required for the development of plant communities to occur. However, agencies could still evaluate older projects to ensure their projects remain successful.

1.1.3 Species Planting Selection

To maximize investments and maximize project success, deliberate selection of the species that are most likely to survive within the project site – considering the various zones within a restoration site including the streambank, the floodplain, and adjacent upland areas – is recommended. Species must be carefully selected to survive and thrive in differing conditions in each of these zones. Generally, fast-growing woody species are (ex. willows, maples, etc.) often recommended, planted, and successful because they assist in the successful re-establishment of native plant communities (Hammer and Gunn, 2021; Drayer et al. 2017). Furthermore, having species that promote canopy closure is critical because canopy closure is likely to reduce the number of invasive species in streams, although it is unlikely to achieve complete eradication of exotic plant species (Parendes and Jones 2001).

Another impact aside from the species is the type of plant materials installed. Several types – live stakes (planted on streambanks), bare-root seedlings, and plug/container – are used, and type can affect the resulting plant success (Doll et al. 2003). Furthermore, habitat or landscape zones can sometimes be identified and delineated to assist in directing the arrangement

of planted species to improve planting survival and increase ecological function following rehabilitation (Bair et al. 2021). Volunteer species, species that either persist in the seedbank and come up on their own or disperse into the system (U.S. Department of Agriculture, 2013), should also be considered when thinking about survivorship because these species can outcompete the planted species and overall target plant community. Many native volunteer species often exist within seedbanks, which brings into question how much to revegetate and which species to choose based on the robustness and species present in the seedbank. Some volunteer plants found in North Carolina include pines, maples, sweet gum, elms, and other light-seeded species (Sea Grant North Carolina, 2010a; WK Dickson and Co., Inc., 2007; ARCADIS G&M of North Carolina, Inc., 2015). Considering the slow development of some chosen planted species, restoration projects often rely on faster-growing volunteer native tree species to suppress invasive species while stand development progresses (Nickelson et al. 2015). Some volunteer species have been observed as being overall more suitable to the sites compared to the planted ones (Bradburn et al., 2010).

Overall, species selection is contingent on many factors and is often informed by curated lists that compile species that have already been proven to perform well in restored areas as well as local guides within the area (Appendix A). Furthermore, species should be selected using a combination of vegetation surveys, historical records, and field trials (Webb & Erskine, 2003). Now that we have more restoration projects with plant communities in later successional stages, we can collect data on these communities to see which species are successful. These vegetation surveys and records will supplement local guides and recommendations to further assist in appropriate species selection.

1.1.4 A Gap in our Knowledge

While the importance of long-term assessment has been justified, little research has resampled older streams to understand the success or failure of the planted species after seven years. The restoration ecology scientific community, particularly, the National Association of Wetland Managers, has emphasized the need for more research and evaluation of stream restoration projects that are at least 8–10 years old (U.S. Army Corps of Engineers & NC Department of Environmental Quality, n.d.). Assessment of older projects will help to better understand the success of frequently planted native species, informing future investment decisions and planting lists for restoration projects. The purpose of the current study is to help fill that gap.

1.1.5 Study Site: Rocky Branch

Rocky Branch is a first-order stream that runs just over a mile through North Carolina State University's campus in Raleigh, North Carolina. At the downstream end of campus, the creek has a 1.5 km^2 urban watershed with 99.2% of the watershed developed and 34.8% covered by impervious surfaces (Violin et al. 2011). This urban creek was restored in three phases; Phase I runs from Gorman Street to Dan Allen Drive and completed in 2002, Phase II runs from Morrill Drive to Pullen Road and finished in 2006, and Phase III is the connecting segment between Dan Allen Drive and Morrill Drive completed in 2010 (Sea Grant North Carolina, 2010b) (Figure 1.3). Because the project was completed in three phases, it presented a unique opportunity to examine plant communities 21, 17, and 13 years post-restoration, which is a longer timeframe than typical post-restoration monitoring and inventory is done. Historically, the stream was timbered and channelized (i.e. deepened, widened and straightened), likely for agriculture. When NC State's campus continued to expand the floodplain, soils were covered with construction fill

(Figure 1.1). Left undisturbed and in optimum condition, it takes between 200–400 years to form 1 cm of new soil (Semedo & Junod, 2020), so due to the construction fill, the soil layers have been highly disturbed and the upper portions are undeveloped. The Department of Agriculture's soil survey determined the soil of the stream to previously be Cecil fine sandy loam (Figure 1.2). Rocky Branch pre-restoration was found to have macroinvertebrate communities and high sediment discharges characteristic of degraded water quality (Duda et al. 1978). Post-restoration, the stream's creek stabilized, its water quality improved, and its aquatic wildlife habitat was enhanced. These improvements are due in large part to the revegetation done by the project, which provided habitat, cover, and food for wildlife (Doll et al. 2004; Sea Grant North Carolina, 2010b). This restoration used natural channel design techniques, allowing the stream to meander through a new floodplain (Jennings, 2003, Doll et al. 2004).

Figure 1.1 Photograph of the study site before the stream was channelized. The stream is behind the barns in the back of the photo (Brinkley et al. 1914).

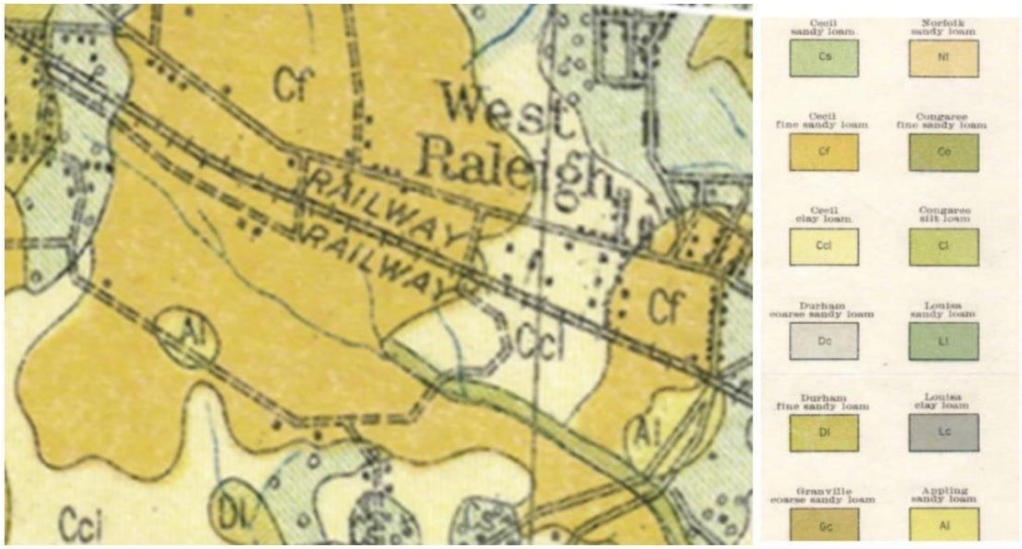


Figure 1.2 1914 soil survey of the study site (U.S. Department of Agriculture, Bureau of Soils, 1914).

For revegetation each phase had its own planting lists. These lists designated tree, shrub, and herbaceous species to be installed in separate landscape zones. Phase I plant communities included narrow floodplain (tree), gentle slope forest (tree), upland-oak hickory forest (tree), seed mix A, seed mix B, live stakes, temp seed and several communities associated with adjacent stormwater control measures (SCM) (shrub, deep emergent, shallow emergent, shrub, and bioretention area). However, the SCM plant communities were outside of our sampling area and consequently are not included in the analysis. Phase II consisted of narrow floodplain (tree), gentle slope forest (tree), floodplain pools (herbaceous), riparian seed mix, live stake, and temp seed. Phase III consisted of floodplain (tree and live stake), gentle slope forest (tree), streambanks (tree), park lawn seed mix, grassed floodplain, *Juncus* streambanks, permanent seed mix, and temp seed mix (Appendix B). A temporary seed mix was utilized to reduce soil erosion because it quickly establishes an herbaceous cover. On the other hand, the permanent vegetation included other native grasses, shrubs and trees across the different landscape zones (Harman &

Starr, 2011). Planting lists were developed in accordance with natural resource reports, the geographic region, and by consulting with data and staff from the NC Natural Heritage Program, Triangle Land Conservancy, U.S. Fish and Wildlife Service, and NC Wildlife Resources Commission. Hardy species were chosen for planting, considering the possibility of inconsistent maintenance on the site. Fast-growing woody plants were selected to stabilize the stream assuming other plant species would naturally establish once the area was stabilized (Hall K., Personal Communication, 2023).

A five-year vegetation survey on Phase I of Rocky Branch was conducted in 2007 to determine the survivorship of planted species as well as considering volunteer and invasive species. The monitoring methods used were based on U.S. Army Corps of Engineering and NC Division of Water Quality Guides. This survey indicated that volunteer vegetation was prolific and greatly outnumbered the planted species. While they weren't as numerous, the planted trees shrubs, specifically *Quercus* spp. (oak species), were noted as having low mortality at the time of the survey. Furthermore, *Liriodendron tulipifera* (tulip-poplar) and *Salix nigra* stakes (black willow) were cited as being particularly healthy. Among the planted species, willows were a concern since they were so prolific that they formed dense monocultures along the streambank. *Swida amomum* (silky dogwood), *Sassafras albidum* (sassafras), and *Calycanthus floridus* (Carolina allspice) were also noted as performing well. For volunteer species, *Pinus taeda* (loblolly pine) was the dominant tree species across the phase with *Baccharis halimifolia* (sea myrtle) occupying much of the shrub layer. *Rubus* spp. (blackberry and dewberry) comprised much of the herbaceous layer (Sea Grant North Carolina, 2010a).

1.2 Methods

The data for the current study were collected within 10-meter-long plots that extended perpendicular across the stream to the edge of the planted boundary on both sides of the riparian corridor. The width of plots varied due to include only the restored part of the stream corridor. We began the plots below a manicured garden area of the study site to minimize confounding data. We collected data for every third plot. We collected stem counts by species at breast height, invasive cover by species, and cover percentage by stratum (tree, shrub, and herb). The assessment protocols developed for the Carolina Vegetation Survey were applied using values of trace = 1; 0–1% = 2; 1–2% = 3; 2–5% = 4; 5–10% = 5; 10–25% = 6; 25–50% = 7; 50–75% = 8; 75–95% = 9; 95–100% = * (Peet et al. 2018). For each plot we plotted the four corners with the application ArcGIS Collector to map their geospatial locations (Figure 1.3). Photos of each plot were also taken at each corner. To get a comprehensive survivorship of planted species, we also surveyed the entire restored stream corridor, marking the presence and absence of planted species. Phase I was sampled first, followed by Phase III, and then Phase II. Phase I contained 30 plots, Phase III contained 14 plots, and Phase II contained 15 plots.

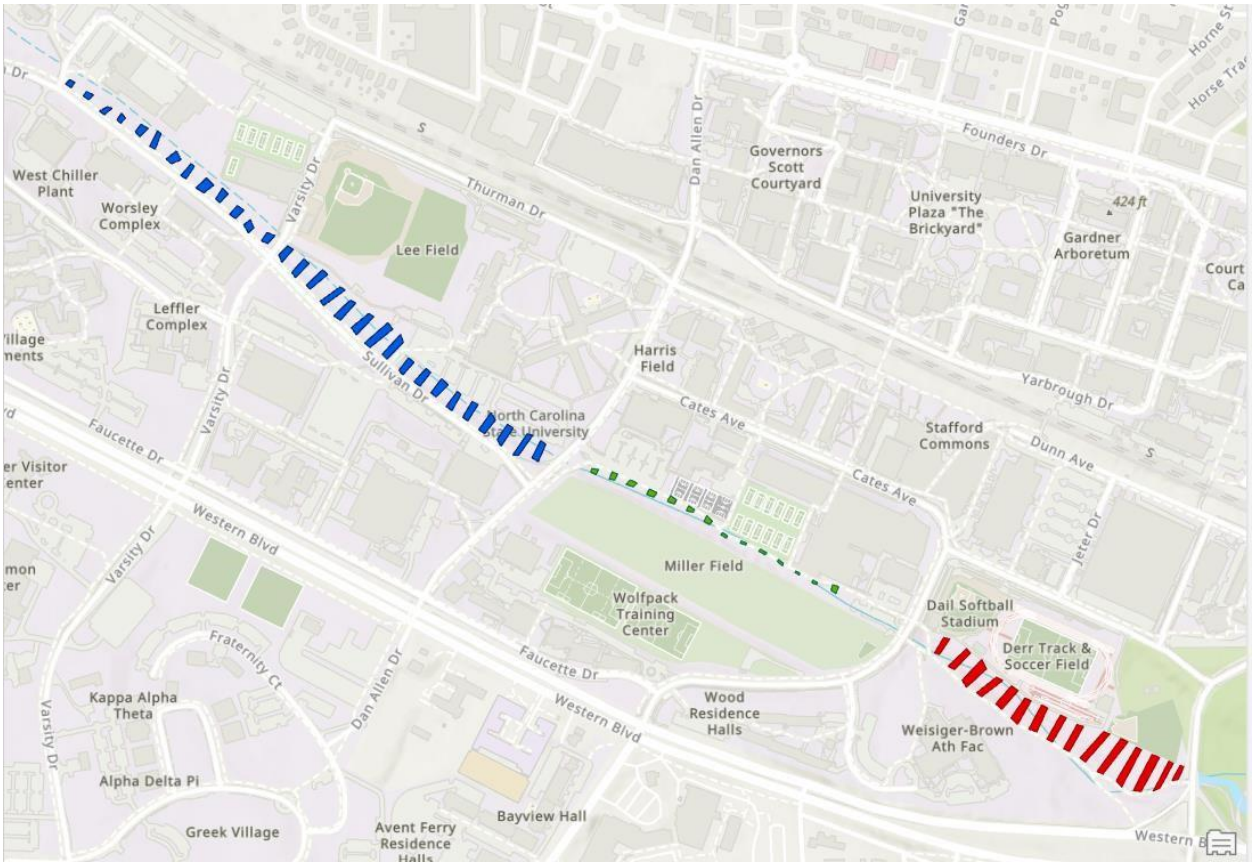


Figure 1.3 Rocky Branch Phase I (blue), Phase II (red), and Phase III (green) plots boundaries based on ArcCollector data. The section of stream in Phase III near Morrill Drive was not sampled because the stream is culverted to pass under the road.

Once data were collected, each species was labeled as planted, invasive, volunteer, or volunteer non-native. If they were included in Rocky Branch's planting list from that phase the species would be considered planted. They were labeled as invasive species if they were listed on the North Carolina Invasive Plant Council Invasive List at any level (NC Invasive Plant Council, 2023). If the species was determined to be native to North Carolina then it was designated as a volunteer species. If a species was determined to be non-native to North Carolina then it was considered volunteer non-native. The nativeness of each species was determined using Vascular Plants of North America and the Biota of North America Program (Vascular Plants of North

America, n.d.; Biota of North America Program, n.d.). Each phase had different species planted, so some species can be considered either planted or volunteer if they were planted in one phase but not another. For instance, *Parthenocissus quinquefolia* (Virginia creeper) was planted in Phase III but not in Phase I or II, so it is considered a planted species in Phase III and volunteer in Phase I or II (Appendix B).

Survivorship was calculated based on the proportion of species present in the studied area from the planting list. This calculation excludes planting categories not intended to survive or planting categories not within the study area. The chi-squared test of homogeneity was run to compare the distributions of the number of species and growth forms across planted, invasive, volunteer, and volunteer non-native species. The chi-squared test of homogeneity was also run on the stem count distribution across planted, invasive, volunteer, and volunteer non-native species. This determined if the distributions were statistically the same. Modified importance values were calculated using the equation: Relative Density + Relative Frequency (Curtis & McIntosh, 1950; Rasingam & Parthasarathy, 2009). The possible range for this modified importance value index (IVI) is 0–200. The frequency was determined based on the number of plots each species appeared in, which differed across species designations. Density was determined based on stem counts. Trait tables used within this study were created based on the U.S. Department of Agriculture trait characteristics database (USDA Plants Database, n.d.).

Some species and traits weren't included within the database and these gaps were filled with other resources (The University of Texas at Austin, 2022; North Carolina Extension Gardener Plant Toolbox, n.d.-a; Practical Plants, n.d.; Team, 2021; Minnesota Seasons, 2024; U.S. Forest Service, n.d.-a; U.S. Forest Service, n.d.-b; Rutgers Landscape & Nursery, 2013; FloraVeg, n.d.; MySeedsCo, 2021; Gilman et al. 2023; Heiser, 2015; Mid Atlantic Native Plant Farm Inc., 2024;

Lichvar, 2013; Sullivan, 1993-a; Sullivan, 1993-b; Sullivan, 1994; Oklahoma State University, 2023; Lázaro-Lobo et al. 2021).

For the multivariate analysis, PCORD7 software was used. An indicator species analysis was done using the stems main matrix and cover secondary matrix. This analysis was conducted by phase (I, II, and III) and by invasion level. Invasion level was determined by the amount of cover within the plot; if the invasive was less than 25% the plot was considered less invaded, if the invasive was between 25% and 50% the plot was considered moderately invaded, and if it had over 75% invasive cover the plot was considered highly invaded. To determine which plots to include within this analysis, I conducted a Sorrenson outlier analysis with a 2.0 cutoff number of standard deviations (Appendix E). Furthermore, several ordinations were performed. Ordinations are a technique in which plots, species, etc. can be represented as points in a twodimensional space; points that plot closer together are more similar to one another. This display can help determine how similar or different particular plots, phases, or species are, enabling interpretation of the driving factors for those communities. An NMS (non-metric multidimensional scaling) ordination was done using the stems main matrix and the secondary matrix for cover at the R^2 level 0.2, this value tells us the amount of variation in y-values described by x-values. I excluded plots 8, 10, 12, and 13 from Phase III, as determined by the Sorrenson outlier analysis (Appendix E). These areas were particularly narrow and had very few stems compared to the rest of Phase III. A Bray-Curtis ordination was used for the trait analysis with the variance-regression endpoint selection method and three axes using the trait main matrix and trait secondary matrix. This analysis was chosen because the NMS was not suitable and could not graph the data. Trait data was retrieved from the TRY Plant Trait database (TRY, n.d.). All traits with had non-zero values for at least one of the species were included within the analysis. Another Sorrenson outlier analysis was performed on the trait matrices and species

were removed accordingly. These species included *Acer floridanum* (Southern sugar maple), *Quercus rubra* (red oak), *Fagus grandifolia* (American beech), *Pinus taeda* (loblolly pine), *Acer rubrum* (red maple) (Appendix G).

1.3 Results

1.3.1 General Results

The study area within each phase ended up being approximately a third of its total area due to the sampling method of collecting data within every third plot across the phase (Table 1.1). Across the study area, 283 different plant species were identified. Of these species, the majority were volunteers followed by invasive, planted, and volunteer non-native. Within the planted category for growth form, tree species were the highest for all categories. Phase I contained the highest number of species for planted tree, shrub, and herb species. Phase II had the highest number of planted vine species because it was the only phase that planted a vine (Appendix B). Across phases the distributions were similar in that volunteer species account for the highest species category and herb species account for the highest growth form category within each phase (Figure 1.4; Table 1.2). While the overall results are similar across phases, the distributions were statistically different at the alpha 0.05 level. This is demonstrated by the results of the chi-squared test of homogeneity (Chi-squared statistic = 10.65) (Appendix H).

Table 1.1 Overall studied area, total area, and the number of plots for each phase.

	Study Area m^2	Total Area m^2	Total Number of Plots
Phase I	6154	26965	30
Phase II	5363	15125	15
Phase III	853	2455	14

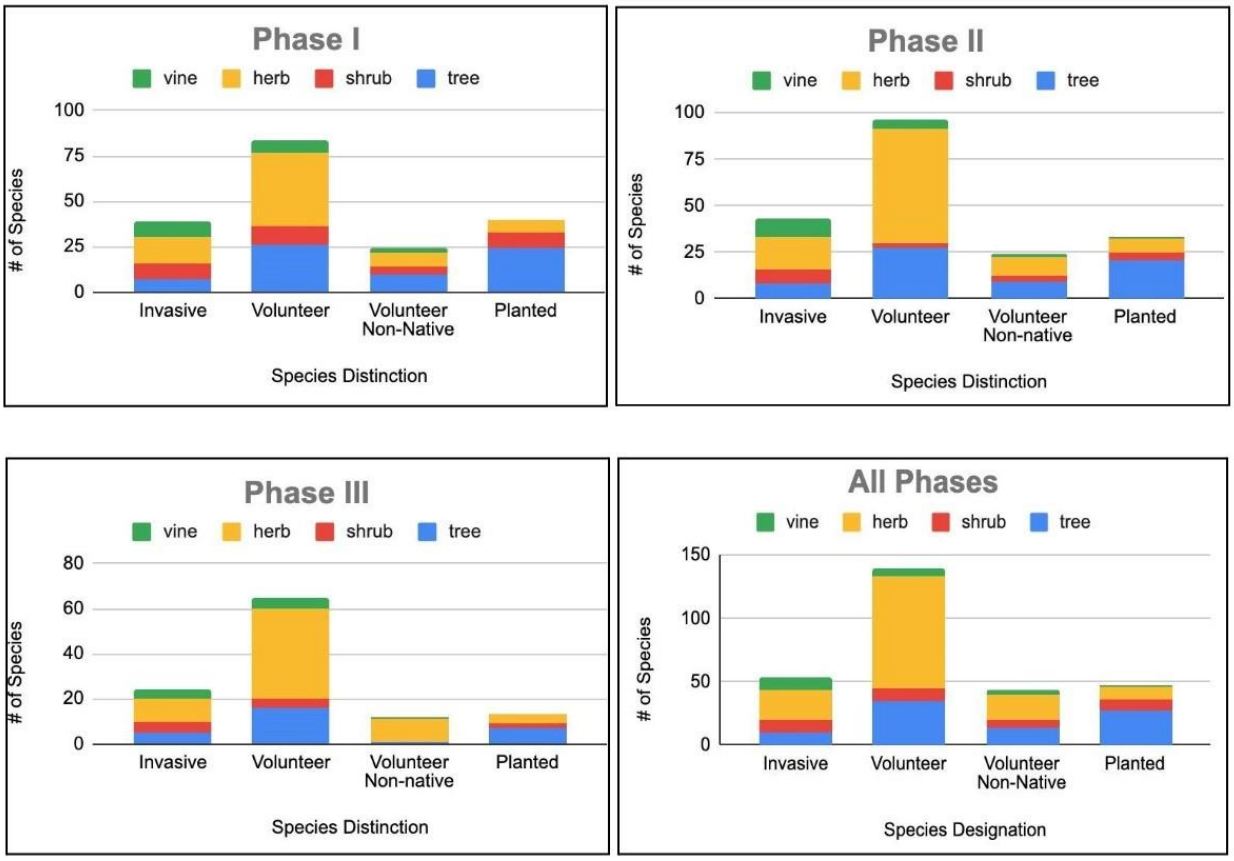


Figure 1.4 Distribution of the number of species by designation and by growth form in Phase I (top left), Phase II (top right), Phase III (bottom left), and across all phases (bottom right).

Table 1.2 Number of species within each species type and growth form across phases.

		Tree	Shrub	Herb	Vine	Totals
All Phases	Invasive	10	10	23	11	54
	Volunteer	35	10	88	7	140
	Volunteer Non-Native	14	6	20	3	43
	Planted	27	9	10	0	46
		86	35	141	21	283
		Tree	**Shrub**	**Herb**	**Vine**	**Totals**
Phase I	Invasive	7	9	14	9	39
	Volunteer	26	10	41	7	84
	Volunteer Non-Native	10	4	8	2	24
	Planted	24	9	7	0	40
		67	32	70	18	187
		Tree	**Shrub**	**Herb**	**Vine**	**Totals**
Phase II	Invasive	8	8	17	10	43
	Volunteer	27	3	61	5	96
	Volunteer Non-native	9	3	10	2	24
	Planted	21	4	7	1	33
		65	18	95	18	196
		Tree	Shrub	Herb	Vine	**Totals**
Phase III	Invasive	5	5	10	4	24
	Volunteer	16	4	40	5	65
	Volunteer Non-native	1	0	10	1	12
	Planted	7	2	4	0	13
		29	9	64	10	112

As for stems, 9844 stems occurred at breast height within the measured plots: 5494 stems were in Phase I, 3629 stems were in Phase II, and 721 stems were in Phase III. Across all phases, invasive species accounted for the largest proportion of the stem distribution followed by volunteer, planted, and volunteer non-native. Volunteer and planted species proportions differed slightly across phases, with planted species being the second largest group in Phase I while Phase II and III have volunteer species as their second largest group. While the overall results are similar across phases, the distributions are statistically different at the alpha 0.05 level, shown by the results of the chi-squared test of homogeneity (Chi-squared statistic = 286.59) (Appendix I).

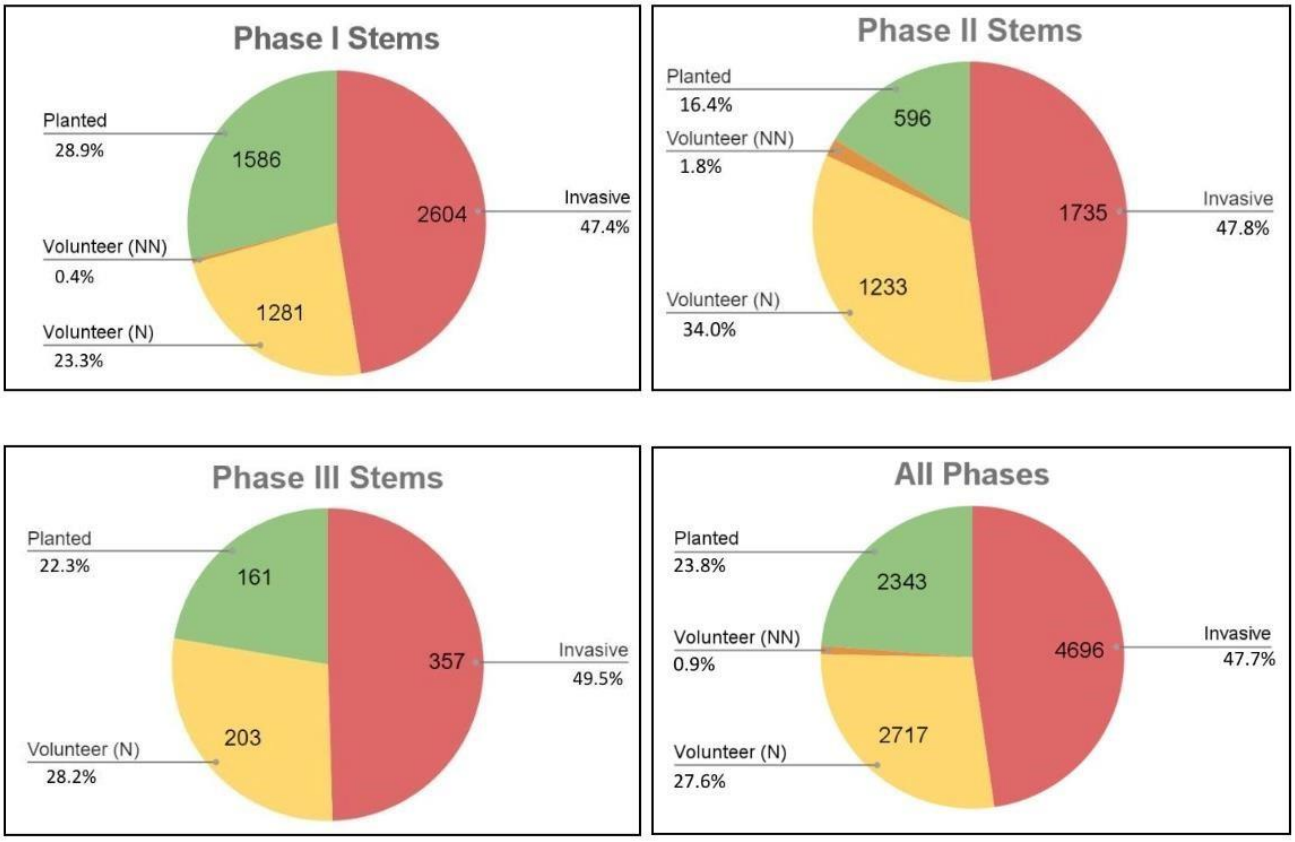


Figure 1.5 Stem counts for each plant designation in Phase I (top left), Phase II (top right), Phase III (bottom left), and across all phases (bottom right).

1.3.2 Phase Analysis

The significant indicator woody species for each phase are provided below in Table 1.3. Based on the species distributions and strata cover, Phase I is considered a mid-successional closed canopy plant community, Phase II is considered a mid-successional open canopy plant community, and Phase III is considered an early-successional community.

Table 1.3 Significant woody indicator species for each phase. Full analysis with associated pvalues in Appendix J.

Phase I		Phase II		Phase III	
Common Name	Species Name	Common Name	Species Name	Common Name	Species Name
Pawpaw	*Asimina triloba*	Box elder	*Acer negundo*	Tulip-poplar	*Liriodendron tulipifera*
Flowering dogwood	*Benthamidia florida*	Smooth alder	*Alnus serrulata*	American elm	*Ulmus americana*
Carolina allspice	*Calycanthus floridus*	River birch	*Betula nigra*		
Spicebush	*Lindera benzoin*	Ironwood	*Carpinus caroliniana*		
Black cherry	*Prunus serotina*	Hawthorn	*Crataegus* spp.		
Laurel oak	*Quercus laurifolia*	Sweetgum	*Liquidambar styraciflua*		
Water oak	*Quercus nigra*	Sycamore	*Platanus occidentalis*		
Loblolly pine	*Pinus taeda*	Laurel cherry	*Prunus caroliniana*		
		Black locust	*Robinia pseudoacacia*		

Ordination plots show that the three phases group separately from each other in a way that aligns with their successional stage designations (Figure 1.6). Phase III plotted on the left side of the ordination with early successional species while Phase II and Phase I plotted within the middle and along the right side of the ordination with the comparatively later successional species. Points that are further towards the top right of the ordination were plots with higher cover in all categories (invasive, tree, shrub, and herb). This consists of plots from both Phase I and Phase II. Based on the ordination, we've determined axis two, the vertical axis, is likely based on wetter vs. drier preferences for the indicator species, with Phases II and III having species with higher water requirements than Phase I (Table 1.1). Axis one, the horizontal axis, can be described by cover since cover across all stages points towards the right side of the ordination, particularly the upper right-hand corner. Furthermore, the associated R^2 values for all the cover types in the secondary matrix were higher in axis one than in axis two (Table 1.4).

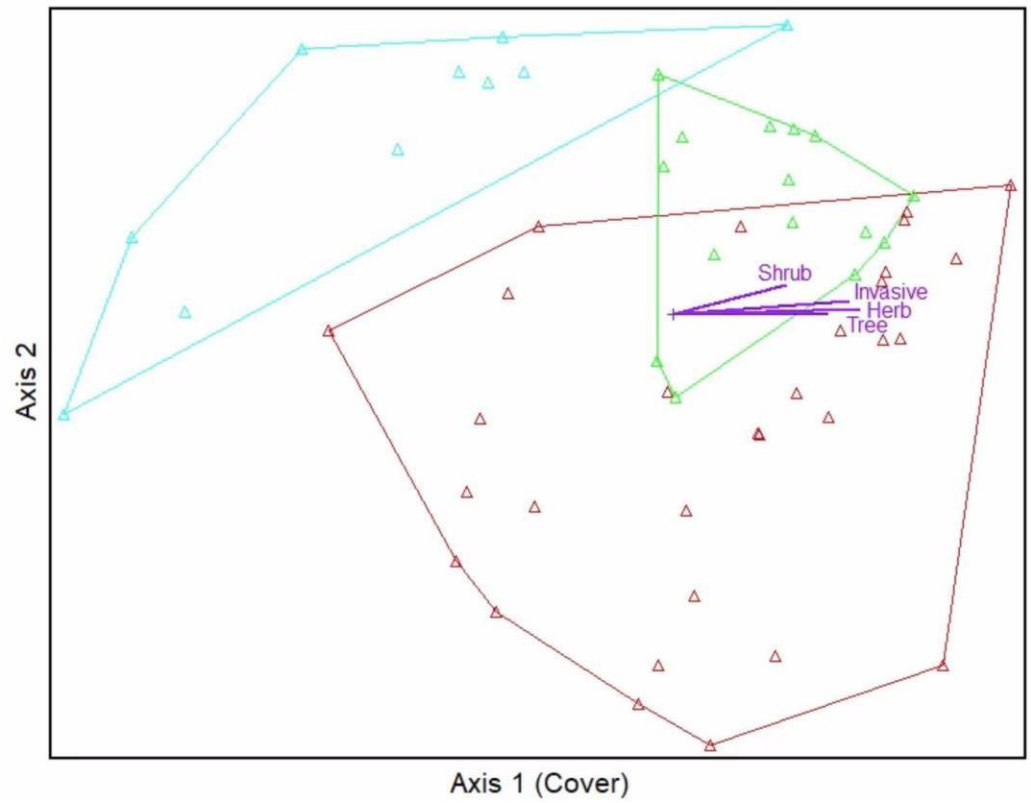


Figure 1.6 Ordination with stems as the main matrix variable and invasive, tree, shrub, and herb cover as the secondary matrix variables at $R^2 = 0.2$.

Table 1.4 Statistics table from PCORD7 with the R^2 values for the secondary matrix variables axis in regards to each axis.

Axis	**1**			**2**		
	r	r-sq	tau	r	r-sq	tau
Invasive Cover	0.608	0.37	0.569	0.17	0.029	0.041
Herb Cover	0.57	0.325	0.437	0.046	0.002	-0.059
Shrub Cover	0.49	0.24	0.514	0.246	0.061	0.147
Tree Cover	0.627	0.394	0.49	0.104	0.011	0.059

1.3.3 Planted Species Survivorship

Survivorship of planted species was determined by the presence or absence of each species across each phase. In Phase I, 20 species included on the plant list were not found, in Phase II, 23 were absent, and in Phase III, 23 were absent. The woody species that weren't found

anywhere within the study site included *Magnolia tripetala* (umbrella magnolia), *Quercus falcata* (Southern red oak), and *Vaccinium arboreum* (sparkleberry) (Table 1.5). Separate planting zones (or community zones) were identified for each design, and lists of tree, shrub, live stake and seed mix communities were specified for installation in zone(s) (Appendix C).

Table 1.5 Planted species that were absent in Phase I, II, and III in 2023.

	Phase I		Phase II		Phase III	
	Common Name	Scientific Name	Common Name	Scientific Name	Common Name	Scientific Name
Tree	Umbrella magnolia	*Magnolia tripetala*	Flowering dogwood	*Bentamidia florida*	Boxelder	*Acer negundo*
	Black gum	*Nyssa sylvatica*	Witch-hazel	*Hamamelis virginiana*	Flowering dogwood	*Benthamidia florida*
	Sourwood	*Oxydendrum arboreum*	Umbrella magnolia	*Magnolia tripetala*	Pignut hickory	*Carya glabra*
	Southern red oak	*Quercus falcata*	Swamp chestnut	*Quercus michauxii*	Fringe tree	*Chionanthus virginicus*
					Black gum	*Nyssa sylvatica*
					White oak	*Quercus alba*
					Southern red oak	*Quercus falcata*
					Overcup oak	*Quercus lyrata*
					Swamp chestnut	*Quercus michauxii*
Shrub	Sparkleberry	*Vaccinium arboreum*	Pinxter-flower	*Rhododendron periclymenoides*	American strawberry bush	*Euonymus americana*
					Pinxter flower	*Rhododendron periclymenoides*
					Blackhaw	*Viburnum nudum*
Herb	Little bluestem	*Andropogon scoparius*	Fringe sedge	*Carex crinita*	Redtop	*Agrostis gigantea*
	Blunt spikerush	*Eleocharis obtusa*	Hop sedge	*Carex lupulina*	Creeping bentgrass	*Agrostis stolonifera*
	Cardinal flower	*Lobelia cardinalis*	Blunt spikerush	*Eleocharis obtusa*	Coreopsis	*Coreopsis lanceolata)*
	Annual rye	*Lolium multiflorum*	Joe pye weed	*Eupatorium fistulosum*	Weeping lovegrass	*Eragrostis curvula)*
	Switchgrass	*Panicum virgatum*	Bottle-brush weed	*Hystrix patula*	Purpletop lovegrass	*Eragrostis spectabilis*
	Three-square bulrush	*Scrius americanus*	Virginia willow	*Itea virginica*	Creeping red fescue	*Festuca rubra*
	Woolgrass	*Scirpus cyperinus*	Leathery rush	*Juncus coriaceus*	Leathery rush	*Juncus coriaceus*
	Yellowroot	*Xanthorhiza simplicissima*	Rice cut grass	*Leersia oryzoides*	Switchgrass	*Panicum virgatum*
			Cardinal flower	*Lobelia cardinalis*	Kentucky bluegrass	*Poa pratensis*
			Green arrow-arum	*Peltandra virginica*	Pennsylvania smartweed	*Polygonum pensylvanicum*
			Pickerelweed	*Pontederia latifolia*	Little bluestem	*Schizachyrium scoparium*
			Broadleaf arrowhead	*Sagittaria latifolia*	Indian grass	*Sorghastrum nutans*
			Three-square bulrush	*Scirpus americanus*	Gamma	*Tripsacum dactyloides*
			Woolgrass	*Scirpus cyperinus*		

Overall the survivorship for Phase I, II, and III was 75.8%, 68.3%, and 43.1% respectively. Phase I had the highest percentage of species survival followed by Phase II and Phase III. In Phase I, live stakes, narrow floodplain, gentle slope forest, and upland oak-hickory had above 75% survivorship within the category. For Phase II, live stake, narrow floodplain, and gentle slope forest had above 75% survivorship. For Phase III, streambanks had survivorship above 75% (Table 1.6).

Table 1.6 Survivorship by proportion of species within each planting category for Phase I (top left), Phase II (top right), and Phase III (bottom). Excludes planting categories not intended to survive or planting categories not within the study area.

Phase I		Phase II		Phase III	
Planting Zone	Proportion of Species Present	Planting Zone	Proportion of Species Present	Planting Zone	Proportion of Species Present
Live Stakes	3/3	Live Stake	3/3	Streambanks	4/5
Narrow Floodplain	12/13	Narrow Floodplain	15/17	Gentle Slope Forest	7/12
Gentle Slope Forest	15/18	Gentle Slope Forest	17/20	Juncus Streambanks	1/2
Upland Oak-Hickory	8/10	Riparian Seed Mix	5/13	Permanent Seed Mix	5/12
Seed Mix A	8/14	Floodplain Pool	3/10	Floodplain	4/14
Seed Mix B	1/4			Park Lawn Seed Mix	1/4
				Grassed Floodplain	0/2
TOTAL:	47/62	**TOTAL:**	43/63	**TOTAL:**	22/51
PERCENTAGE:	75.80	**PERCENTAGE:**	68.25	**PERCENTAGE:**	43.14

over 75%
25-50%
under 25%

1.3.4 Most Common Planted and Volunteer Species

The five planted species with the most stems are *Morella cerifera* (common wax myrtle), *Calycanthus floridus* (Carolina allspice), *Sambucus canadensis* (American elderberry), *Liriodendron tulipifera* (tulip-poplar), and *Ulmus americana* (American elm), (Table 1.7). The overlapping species that also had the highest volunteer importance values include *Morella cerifera* and *Liriodendron tulipifera*. However, *Celtis laevigata* (hackberry), *Platanus occidentalis* (sycamore), and *Betula nigra* (river birch) are seen for highest importance values but not stem counts (Table 1.8). These species have a lower number of stems but more frequency across the study site.

When species were plotted in ordination space based on traits, most of the species plot closely together in comparison to the rest of the species alignment in the ordination space (Figure 1.7). Traits that are similar across the species include active growth period, drought tolerance, facultative status, growth rate, fruit/seed abundance, moisture use, nitrogen fixation, propagation by seed, and vegetative growth (Table 1.9).

Table 1.7 Five planted species with the highest stem count.

Common Name	Scientific Name	Stem Count
Common wax myrtle	*Morella cerifera*	364
Carolina allspice	*Calycanthus floridus*	326
American elderberry	*Sambucus canadensis*	141
Tulip-poplar	*Liriodendron tulipifera*	139
American elm	*Ulmus americana*	133

Table 1.8 Five planted species with the highest importance values. Full importance value list in Appendix L.

Common Name	Scientific Name	Stem Count	Modified IVI
Hackberry	*Celtis laevigata*	124	79.87
Sycamore	*Platanus occidentalis*	123	79.83
Common wax myrtle	*Morella cerifera*	364	64.69
Tulip-poplar	*Liriodendron tulipifera*	139	58.47
River birch	*Betula nigra*	109	55.50

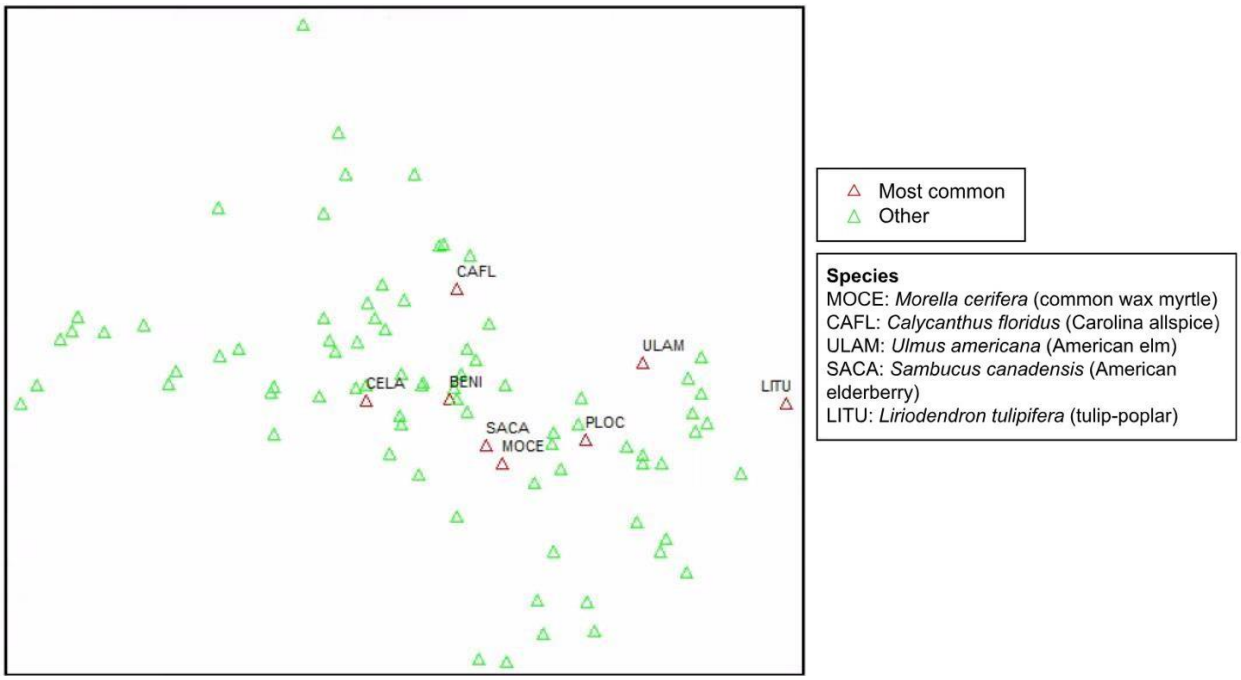


Figure 1.7 Ordination highlighting the most common species. Species plotted in the ordination space based on traits.

Table 1.9 Traits table based on USDA, Forest Service, NC State Extension, and others.

	Morella cerifera	*Calycanthus floridus*	*Ulmus americana*	*Sambucus canadensis*	*Liriodendron tulipifera*
Active Growth Period	Spring & Summer	Spring & Summer	Spring & Summer	Spring & Summer	Spring & Summer
Dispersal method	Animal	Not obvious	Water, wind	Animal	Wind
Drought Tolerance	Medium	Medium	Medium	Medium	Low
Fertility Requirement	Low	Medium	Medium	Medium	High
Fruit/Seed Abundance	High	Medium	High	High	High
Growth form	Shrub	Shrub	Tree	Shrub	Tree
Growth Rate	Moderate	Moderate	Rapid	Rapid	Rapid
Height, Mature	10 ft	9 ft	50 ft	7 ft	120 ft
Lifespan	50 years	20 years	200 years	5 years	300 years
Moisture Use	High	Medium	High	Medium	Medium
Nitrogen Fixation	None	None	None	None	None
Propogated by Seed	Yes	Yes	Yes	Yes	Yes
Resprout Ability	No	Yes	Yes	Yes	Yes
Seedling Vigor	Medium	-	Medium	High	Medium
Shade Tolerance	Intolerant	Tolerant	Intermediate	Intolerant	Intolerant
Successional Stage	Early	-	Mid	Mid	Early
Vegetative Growth	Yes	Yes	Yes	Yes	Yes
Wetland status	FAC	FACU	FACW	FACW	FACU

	Celtis laevigata	*Platanus occidentalis*	*Betula nigra*
Active Growth Period	Spring & Summer	Spring & Summer	Spring & Summer
Dispersal method	Animal, water	Water, wind	Water, wind
Drought Tolerance	Low	Low	Low
Fertility Requirement	Medium	Medium	Medium
Fruit/Seed Abundance	High	Medium	High
Growth form	Tree	Tree	Tree
Growth Rate	Moderate	Rapid	Rapid
Height, Mature	80 ft	100 ft	70 ft
Lifespan	150 years	200 years	75 years
Moisture Use	High	High	High
Nitrogen Fixation	None	None	None
Propogated by Seed	Yes	Yes	Yes
Resprout Ability	Yes	Yes	Yes
Seedling Vigor	Medium	Medium	High
Shade Tolerance	Tolerant	Intermediate	Intolerant
Successional Stage	Mid to Late	Early to Mid	Early
Vegetative Growth	Yes	Yes	Yes
Wetland status	FACW	FACW	FACW

We also determined the most common volunteer species. These include *Prunus caroliniana* (laurel cherry), *Pinus taeda*, *Robinia pseudoacacia* (black locust), *Liquidambar styraciflua* (sweetgum), and *Acer floridanum* and *Prunus serotina* (black cherry) (Table 1.10). The top six species are reported rather than the top five due to the uncertain provenance with laurel cherry. While it does not appear in any state or national invasive species list (Invasive Plant Atlas of the United States, n.d.), this species is questionably native in North Carolina outside of the coastal plain (Virginia Tech Dendrology, 2021). Moreover, it is considered aggressive and weedy in disturbed areas (North Carolina Extension Gardener Plant Toolbox, n.d.-b). When looking at the species with the highest importance values some additional species stand out. The overlap between species with the highest volunteer importance values and stem counts include *Prunus caroliniana*, *Pinus taeda*, *Robinia pseudoacacia*, and *Prunus serotina*

(black cherry). However, *Quercus phellos* (willow oak) shows up on the importance values but not on the stem counts (Table 1.11). These species have a lower number of stems but more frequency across the study site.

Table 1.10 Six volunteer species with the highest stem counts (**debate on nativeness).

Common Name	Scientific Name	Stem Count
**Laurel cherry	*Prunus caroliniana*	897
Loblolly pine	*Pinus taeda*	356
Black locust	*Robinia pseudoacacia*	206
Sweetgum	*Liquidambar styraciflua*	176
Southern sugar maple	*Acer floridanum*	145
Black cherry	*Prunus serotina*	176

Table 1.11 Six volunteer species with the highest importance values. Full importance value list in Appendix M (**debate on nativeness).

Common Name	Scientific Name	Density	Importance Value
**Laurel cherry	*Prunus caroliniana*	897	114.37
Black locust	*Robinia pseudoacacia*	206	83.85
Willow oak	*Quercus phellos*	63	73.51
Loblolly pine	*Pinus taeda*	356	72.42
Black cherry	*Prunus serotina*	135	69.38
Sweetgum	*Liquidambar styraciflua*	176	55.63

1.3.5 Species in Less and Highly Invaded Plots

The species with the highest relative abundance in the less invaded category, less than 25% cover by invasive species, include *Betula nigra* (river birch), *Catalpa speciosa* (northern catalpa), *Crataegus* spp. (hawthorn), *Quercus shumardii* (Shumard oak), *Salix nigra*, *Ulmus americana* (American elm), *Viburnum nudum* (withe-rod), and *Viburnum prunifolium* (blackhaw) (Table 1.12). While none of these species were not significant indicators at the a = 0.05 level for the less invaded plots, they did appear within the indicator species for the less invaded category (Appendix N). The species grouped out when plotted in the trait-based

ordination, indicating similarities in traits amongst the species. We can see that the green points, the less invaded plot group, cluster the closest together with a smaller polygon compared to the other two (Figure 1.8).

Table 1.12 Native species whose highest relative abundance was in the less invaded plots (<25% invasive cover). Full analysis in Appendix N.

Common Name	Scientific Name	Less invaded	Moderately Invaded	Highly Invaded
River birch	*Betula nigra*	39	36	24
Northern catalpa	*Catalpa speciosa*	63	37	0
Hawthorn	*Crataegus* spp.	46	16	38
Shumard oak	*Quercus shumardii*	45	22	34
Black willow	*Salix nigra*	37	36	27
American elm	*Ulmus americana*	49	31	20
Withe-rod	*Viburnum nudum*	51	49	0
Blackhaw	*Viburnum prunifolium*	100	0	0

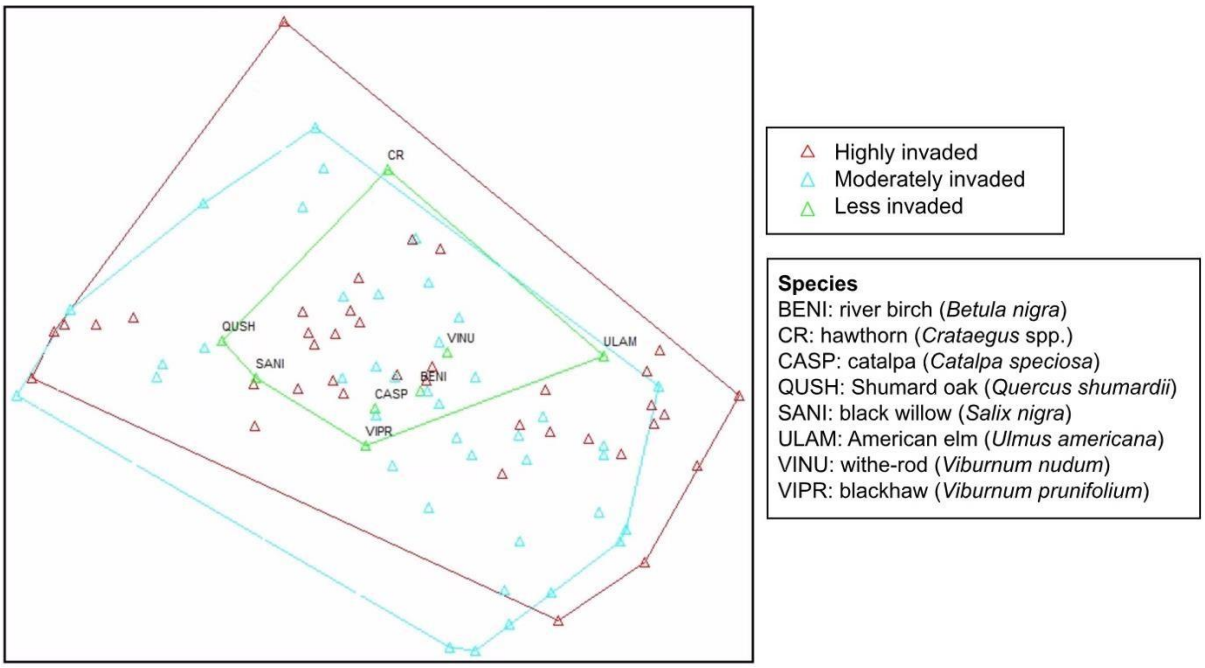


Figure 1.8 Trait ordination grouped by invasion level. Species plotted in the ordination space based on traits.

Many species had their highest relative abundance in the highly invaded plots (>75% invasive cover) (Table 1.13). Several of these species were statistically significant indicators of

the highly invaded plots. These species included *Celtis laevigata*, *Ilex opaca* (American holly), and *Prunus caroliniana* (Table 1.14). The species in this highly invaded category have fewer clear similarities in traits, being more scattered throughout the ordination (Figure 1.8). This is likely due to the fact that these species can have many different ways in which they outcompete or survive against the invasives within these plots. Those ways are not quite captured by this array of traits within the database.

Table 1.13 Native species whose highest relative abundance was in the highly invaded plots (**debate on nativeness). Full analysis in Appendix N.

Common Name	Scientific Name	Less Invaded	Moderately Invaded	Highly Invaded
Southern sugar maple	*Acer floridanum*	34	23	43
Box elder	*Acer negundo*	39	17	44
Silver maple	*Acer saccharinum*	0	0	100
Sea myrtle	*Baccharis halimifolia*	0	35	65
Ironwood	*Carpinus caroliniana*	23	13	64
Mockernut hickory	*Carya tomentosa*	17	5	78
Hackberry	*Celtis laevigata*	30	15	55
American strawberry bush	*Euonymus americanus*	24	22	54
American beech	*Fagus grandifolia*	18	0	82
Green ash	*Fraxinus pennsylvanica*	32	19	49
Honey locust	*Gleditsia triacanthos*	49	0	51
Deciduous holly	*Ilex decidua*	19	18	63
American holly	*Ilex opaca*	15	14	71
Sweetgum	*Liquidambar styraciflua*	31	4	64
Tulip-poplar	*Liriodendron tulipifera*	19	37	44
Red mulberry	*Morus rubra*	0	0	100
Sourwood	*Oxydendrum arboreum*	0	0	100
Laurel cherry	***Prunus caroliniana*	22	21	57
Black cherry	*Prunus serotina*	28	23	49
White oak	*Quercus alba*	20	6	75
Swamp white oak	*Quercus bicolor*	37	25	38
Water oak	*Quercus nigra*	40	3	56
Pin oak	*Quercus palustris*	0	0	100
Pinxter-flower	*Rhododendron periclymenoides*	30	28	42
Black locust	*Robinia pseudoacacia*	26	33	42
Sassafras	*Sassafras albidum*	10	0	90
Bald cypress	*Taxodium distichum*	19	26	55
Mapleleaf viburnum	*Viburnum acerifolium*	0	0	100

Table 1.14 Native species that were statistically significant indicators for the highly invaded plots. Full table in Appendix O (**debate on nativeness).

Common Name	Scientific Name	Indicator Group	p-value
Hackberry	*Celtis laevigata*	Highly invaded	0.0210
American holly	*Ilex opaca*	Highly invaded	0.0042
Laurel cherry	***Prunus caroliniana*	Highly invaded	0.0338

1.4 Discussion

Overall the three phases of the study site were similar in terms of stem distributions, species composition, and invasive cover; however, they differed in terms of indicator species, community type, and how well the planted species within each performed. Phase I is a midsuccessional closed canopy plant community. Phase II is a mid-successional open canopy plant community. Phase III is an early-successional plant community.

Phases I and II were the main drivers of the overall cover including invasive, tree, shrub, and herb cover, aligning with their later successional stages, as compared to Phase III (Figure 1.6). The significant indicator native species of Phase I demonstrates this phase to be a midsuccessional plant community with a more closed canopy. The species within it are also more indicative of a bottomland community. This is a flood-tolerant community with slightly drier conditions compared to the riparian floodplain species found adjacent to streams. Phase II's significant indicator species also point towards it being a mid-successional plant community with a more open canopy. The species within this phase are wetter, riparian floodplain species. The significant indicator species of Phase III point towards it being an early-successional plant community. These species are light-seeded and fast-growing species (Table 1.1).

Planted species took up 23.7% of the overall stems across the entire study site; however, it is interesting to note that the distribution of stems looks relatively similar across all phases, with about half being invasive, followed by volunteer and planted species which take approximately a quarter each. Lastly, volunteer non-natives are a small sliver of the total stem distribution (if anything). This is further seen in the distribution of species across designations,

where across all phases the distributions are similar. These distributions were too different to be considered significantly the same (Appendix I); however, this can possibly be attributed to the differences in planted survivorship across the phases (Table 1.6). Volunteer species account for the highest stem count followed by invasive and planted rather evenly, then lastly followed by volunteer non-natives (Figure 1.5). This differs from what was seen in the five-year vegetation survey for Phase I, which found volunteer species to outnumber the planted species by nearly half. In this survey, volunteer species were considered anything that was not planted. There appears to be no distinction between native and non-native volunteers (Sea Grant North Carolina, 2010a). This demonstrates that often planted species take longer to establish, which is why volunteer species are so important in the early stages of a restoration project. Furthermore, the extent of planted species' success and distribution can't be fully realized on a short-term scale.

Despite the differences one may expect to find with separate phases implemented at different times and with different planting lists, the stem and species type distributions converged across all phases (Figure 1.5; Figure 1.4; Table 1.2). This indicates that planted species persist and grow over time, gaining their standing to at least breast height, somewhere between five years and thirteen years in the case of Rocky Branch. Additionally, after a certain threshold, time no longer appears to be a key factor for determining the relative species distribution of stems for planted, invasive, volunteer, and volunteer non-native species. While the composition of species within these categories can shift and change, across successional stages species distributions will be similar. This demonstrates the importance of catching invasive species early on because once they have established within a community they remain deeply entrenched within that community, almost to the same degree as they were in its earlier successional stages.

The survivorship of planted species in terms of presence-absence is relatively high within Phase I and II, and in this regard the Rocky Branch restoration was successful. It seems most

species were appropriately selected for this site within Phases I and II, particularly within the categories for live stakes, narrow floodplain, gentle slope forest. Phase I was additionally successful within the upland oak-hickory category. However, Phase III was less successful in this regard with only 40.0% of the species planted present. Its most successful category was streambanks (Table 1.6). This could be attributed to the narrowness of the floodplain and lack of space for the plants to survive. This narrowness causes the bank to be more unstable and more susceptible to disturbances which could have negatively impacted the survival of the slowergrowing, vulnerable species. Furthermore, Rocky Branch runs through NC State's campus and Phase III, the connecting segment, is located in the central part of main campus where it is subject to more human foot traffic and associated destabilization which could contribute to species loss (Figure 1.3).

The species that didn't survive from the planting lists across all phases were primarily temporary seeds species that weren't intended to survive, such as *Panicum ramosum* (browntop millet) or *Secale cereale* (rye). When considering woody species, slow-growing species like oaks often didn't survive (Table 1.3). This suggests that these species couldn't compete with their faster-growing counterparts. Other species that didn't survive such as *Magnolia tripetala* require high nutrient soils. These species were not likely to survive due to the extensive history of soil disturbance and lack of a developed soil horizon (Figure 1.1; Figure 1.2). Furthermore, several species were planted that generally prefer drier conditions such as *Quercus falcata* and *Vaccinium arboreum* that were chosen for the more upland portions of the landscape. However, they are species not characteristic of riparian corridors, making them uncompetitive in the site.

The most common planted species plotted similarly compared to the rest of the species within Rocky Branch (Figure 1.7). All five species share some key traits that help explain their dominance. First, the most common species were all facultative species (Lichvar, 2013), which

are typically recommended for stream restoration projects because they can tolerate dry periods that obligate wetland species cannot, while still being well adapted to the moist conditions of stream ecosystems (Medford H., Personal Communication, 2024). They also have traits that assist with aggressive reproduction such as a medium to high abundance of fruit and seed. Furthermore, these species are able to spread vegetatively (Table 1.9).

The species with the highest relative abundance in less invaded plots (<25% invasive cover) plotted similarly within the trait ordination (Figure 1.8). These commonalities could suggest that these species are suppressing invasion. The shared traits may allow the species to quickly occupy a niche space that would have otherwise been filled by invasives. It is noteworthy that all the species except *Viburnum prunifolium* also had some level of abundance in the moderately invaded plots (25–75% invasive cover) and/or highly invaded plots (>75% invasive cover). Two species *Crataegus* spp. and *Quercus shumardii*, even had their second highest abundance in the highly invaded plots which could suggest that the species may not be vulnerable and, if given proper time and space to establish, they could be preventative in some capacity (Table 1.12). However, more study is needed to determine if these species had the highest abundance in the less invaded plots because they are more vulnerable to invasive species, if they are suppressing invasive species, or if the lack of association between these species and invasives was a random occurrence isolated to our study site.

The species that had the highest relative abundance in the most invaded plots (>75% invasive cover) have a wider range of traits compared to the species who had highest relative abundance in the moderately invaded or less invaded plots (Figure 1.9). While there were many species that had their highest abundance in highly invaded plots (Table 1.13), there were only three significant indicators, including *Celtis laevigata*, *Ilex opaca*, and *Prunus caroliniana* (Table 1.14). It is important to know what species can survive in highly impacted areas and can exist in

spaces with high invasive risk. These species could potentially be planted at sites with high invasion risk and low long-term invasive species management resources available. However, at this time, it may be best to avoid planting *Prunus caroliniana* given the current debate surrounding its nativeness outside of the coastal plain.

Many different volunteer species are present across all phases of Rocky Branch (Figure 1.4). The most common volunteer species were mostly expected as they are frequent volunteers in North Carolina (Table 1.10). *Acer floridanum* is a more surprising volunteer because it has a moderate growth rate compared to the other volunteer species. However, its high fruit/seed abundance, a trait shared with the most common planted species, and its shade tolerance are likely contributing to its success (USDA, n.d.). It also has been planted in other North Carolina stream restoration projects, so it does have a precedence on some planting lists in similar projects (URS Corporation, 2008). Furthermore, *Quercus phellos* had one of the highest importance values as a volunteer species (Table 1.11), which was a surprising result since oaks aren't normally common or prolific volunteers. However, *Quercus phellos* is a faster growing oak species, is well adapted to urban areas, and is the most common oak species on the university campus, which could explain its success at this site (University of Kentucky Department of Horticulture, n.d.; Gilman & Watson, n.d.; Rudder, 2011). Both species should be more often considered in future planting lists.

1.5 Conclusion

It is critical that future planting lists consider the environment and historical data of their planting site. Careful selection of species is crucial to ensure that species survive within the site. In this case, several species were chosen that were likely to not survive due to the wetter conditions as well as the nutrient content of the soil. The species that were most able to thrive within the given environment from the planting lists were *Morella cerifera*, *Calycanthus floridus*,

Ulmus americana, *Sambucus canadensis*, *Liriodendron tulipifera*, *Celtis laevigata*, *Platanus occidentalis*, and *Betula nigra*. These species had several traits that allowed them to have high importance and dominance within this post-restoration plant community: facultative species status, medium to high fruit/seed abundance, and vegetative growth capabilities. When considering species for future urban stream restoration projects, species that share these traits should be planted to ensure that native species take up meaningful space within the site. Furthermore, when planning a planting list for a restoration site, practitioners should avoid planting the species that dominate the seedbank and will likely volunteer. If they notice successful volunteer species from other projects that are not prevalent within a site, they consider planting those species. In the case of Rocky Branch, for example, some possible recommendations for other projects could be *Acer floridanum* and *Quercus phellos.*

This case study also demonstrates the need for consideration of slower-growing species. When planting these species, additional management will likely be necessary to ensure they survive. Such management may include tree shelters or selective removal of surrounding species to allow for appropriate space and resources (Sweeney et al. 2002). Another approach could be to install these plants after the initial species have taken hold. Alternative performance standards for mitigation projects are available for vegetation vigor or density that can be applied if revegetating with slow growing species, woody shrub species, or with understory species (Tugwell, 2016). This could also allow for a more developed community to occur over time and allows for management to be done in stages with different objectives. Either way, long-term monitoring of these species should be done to ensure their success in these projects and to better understand the ecological trajectory of restoration projects (Hill et al. 2013).

In terms of survivorship within this restoration project, Rocky Branch was fairly successful, especially in Phases I and II. The project has an immense number of invasive stems;

however, management and removal of these stems could better assist in the continued success and survival of both planted and volunteer species. It is important to know the success of planted species because they can support or inform changes within future planting decisions. Planting lists are an essential part of stream restoration planning as they can determine the resulting diversity and effectiveness of the plant community. While a large number of volunteer species can enter and assist a given restoration project (Figure 1.4), planted species can be equally effective if species are thoughtfully chosen. The species that were most commonly found in the less invaded plots (<25%) could either be vulnerable to invasion or suppressing invasion from occurring. This potential prevention could be attributed to the empty niche hypothesis, whereby the native species fills the invader's niche space, keeping them out. In contrast, the species that were most commonly found in the most invaded plots (>75%) may be species that are hardy and able to tolerate high levels of invasion. If there is a high invasion risk and resources are minimal, it may be beneficial to plant these species to ensure survival and presence of some native species.

Lastly, determinations of a vegetation success should be expanded to reflect the importance of long-term assessment. Neither five nor seven-year timescales required for mitigation provide adequate time for fully analyzing the success of planted species in restoration projects (Sea Grant North Carolina, 2010a). Furthermore, the long-term management that is required for mitigation is only focused on monitoring the conservation easement rather than monitoring vegetation standards. To determine the success of restoration plant community objectives, long-term management should include vegetation monitoring out to 25 years or longer to allow for the accumulation of species over time and to better understand the overall plant community (Hasselquist et al. 2015, Nilsson et al. 2015).

1.6 Further Research

Work is needed to find ways to make long-term monitoring affordable and integrated within the mitigation guidelines. By doing so, more data like this could be readily available across many stream restoration projects. However, even within these longer timeframes monitoring done on this study site, it is still not long enough to have a fully realized and recovered plant community; therefore, this site should be studied again in the future to once again determine the success of planted species and see how the community has changed. This should especially be done after appropriate invasive species removal has been conducted. Furthermore, for the species with highest relative abundance in the less invaded plots (<25% invasive cover), more should be done to determine if they are particularly vulnerable to invasive species, have some traits or characteristics that could assist in invasive species prevention, or if these results are based only on the randomness within this data. The species with highest relative abundance in more invaded plots (>75% invasive cover) should also be tested to see if they are consistently able to withstand invasion or if this case study is an outlier.

REFERENCES

ARCADIS G&M of North Carolina, Inc. (2015). *Year 2 of 5 Monitoring Report FINAL Five-Mile Branch Stream and Wetland Restoration, Iredell County* (p. 3). North Carolina Department of Environment and Natural Resources, Ecosystem Enhancement Program Raleigh, North Carolina.

Bair, J. H., Loya, S., Powell, B., & Lee, J. C. (2021). A new data-driven riparian revegetation design method. *Ecosphere*, *12*(8), 1–22. https://doi.org/10.1002/ecs2.3718

Bernhardt, E. S., & Palmer, M. A. (2007). Restoring streams in an urbanizing world. *Freshwater Biology*, *52*(4), 738–751. https://doi.org/10.1111/j.1365-2427.2006.01718.x

Bernhardt, E. S., Palmer, M. A., Allan, J. D., Alexander, G., Barnas, K., Brooks, S., Carr, J.,

Clayton, S., Dahm, C., Follstad-Shah, J., Galat, D., Gloss, S., Goodwin, P., Hart, D., Hassett, B., Jenkinson, R., Katz, S., Kondolf, G. M., Lake, P. S., … Sudduth, E. (2005). Synthesizing U.S. River Restoration Efforts. *Science*, *308*(5722), 636–637. https://doi.org/10.1126/science.1109769

Bradburn, B.N., Dolloff, C.A., Cumbia, D., & Creighton, J. (2010). Evaluation of riparian forests established by the Conservation Reserve Enhancement Program (CREP) in Virginia. *Journal of Soil and Water Conservation* 65(2): 105-112. https://doiorg.prox.lib.ncsu.edu/10.2489/jswc.65.2.105

Brinkley, L.L., Allen, R.T., & Derrick, B.B. (1914). Soil Survey of Wake County, North Carolina (pp. 517-557). In Field Operations of the Bureau of Soils, 1914. United States Department of Agriculture.

Buchholz, T. A., Madary, D. A., Bork, D., & Younos, T. (2016). Stream Restoration in Urban Environments: Concept, Design Principles, and Case Studies of Stream Daylighting. In T. Younos & T. E. Parece (Eds.), *Sustainable Water Management in Urban Environments* (pp. 121–165). Springer International Publishing. https://doi.org/10.1007/978-3-319-29337-0_5

Invasive Plant Atlas of the United States. *Carolina laurel cherry*. (n.d.). Invasive Plant Atlas of the United States. Retrieved February 28, 2024, from https://www.invasiveplantatlas.org/subject.html?sub=6919

Castillo, D., Kaplan, D., & Mossa, J. (2016). A Synthesis of Stream Restoration Efforts in Florida (USA): Florida Stream Restoration. *River Research and Applications*, *32*(7), 1555–1565. https://doi.org/10.1002/rra.3014

Chowning, J., Morales, L., Stedman, S., & Matusiak, M. (2000). *Federal Guidance on the Use of In-Lieu-Fee Arrangements for Compensatory Mitigation under Section 404 of the Clean*

Water Act and Section 10 of the Rivers and Harbors Act. https://www.epa.gov/sites/default/files/2015-08/documents/inlieu_fee_mitigation_guidance.pdf

Curtis, J. T., & McIntosh, R. P. (1950). The Interrelations of Certain Analytic and Synthetic Phytosociological Characters. *Ecology*, *31*(3), 434–455. https://doi.org/10.2307/1931497

Doll, B. A., Grabow, G. L., Hall, K. R., Halley, J., Harman, W. A., Jennings, G. D., & Wise, D. E. (2003). *Stream Restoration: A Natural Channel Design Handbook*. NC Stream Restoration Institute, NC State University.

Doll, B., Jenkins, J., Patterson, J., Coleman, J., Jennings, G., Buckner, C., & Mayes, D. (2004). Urban Stream Restoration Using a Natural Channel Design Approach. *Protection and Restoration of Urban and Rural Streams*. Symposium on the Protection & Restoration of Urban and Rural Streams: American Society of Civil Engineers. https://doiorg.prox.lib.ncsu.edu/10.1061/40695(2004)31

Drayer, A., Sena, K., Barton, C., & Andrews, D. (2017). Long-Term Response of Stream and Riparian Restoration at Wilson Creek, Kentucky USA. *Ecological Restoration* 35(3): 246-254. https://doi-org.prox.lib.ncsu.edu/10.3368/er.35.3.246Duda, A., Lenat, D., & Penrose, D. (1978). *Water Quality Degradation in Urban Streams of the Southeast: Will Non-Point Source Controls Make Any Differences?* 151–159.

Ehrenfeld, J. (2008). Exotic invasive species in urban wetlands: environmental correlates and implications for wetland management. *Journal of Applied Ecology* 45(4): 1160-1169. https://doi-org.prox.lib.ncsu.edu/10.1111/j.1365-2664.2008.01476.x

FloraVeg. (n.d.). *Calycanthus floridus* [Factsheet]. Database of European Vegetation, Habitats and Flora. Retrieved March 10, 2024, from https://floraveg.eu/en/taxon/overview/Calycanthus%20floridus

Gellie, N. J. C., Mills, J. G., Breed, M. F., & Lowe, A. J. (2017). Revegetation rewilds the soil bacterial microbiome of an old field. *Molecular Ecology*, *26*(11), 2895–2904. https://doi.org/10.1111/mec.14081

Gilman, E., Klein, R., & Hansen, G. (2023, March 7). *Calycanthus floridus Carolina Allspice, Sweetshrub*. Ask IFAS - Powered by EDIS. Retrieved February 28, 2024, from https://edis.ifas.ufl.edu/publication/FP095

Gilman, E., & Watson, D. (n.d.). *Quercus phellos: Willow Oak*. Ask IFAS. Retrieved February 28, 2024, from https://edis.ifas.ufl.edu/publication/ST556

Hammer, C. & Gunn, J. (2021). Planting native trees to restore riparian forests increases biotic resistance to nonnative plant invasions. *Invasive Plant Science and Management* 14(2): 126-133. https://doi-org.prox.lib.ncsu.edu/10.1017/inp.2021.11

Harman, W., & Starr, R. (2011). *Natural Channel Design: REVIEW CHECKLIST* (p. 20). U.S. Fish and Wildlife Service, Chesapeake Bay Field Office, Annapolis, MD and U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Wetlands Division.

Hasselquist, E. M., Nilsson, C., Hjältén, J., Jørgensen, D., Lind, L., & Polvi, L. E. (2015). Time for recovery of riparian plants in restored northern Swedish streams: a chronosequence study. *Ecological Applications*, *25*(5), 1373–1389. https://doi.org/10.1890/14-1102.1

Heiser, C. (2015). *Habitat Gardening for Wildlife*. Virginia Cooperative Extension. https://dwr.virginia.gov/wp-content/uploads/habitat-gardening.pdf

Hejna, M., & Cutright, T. J. (2021). Stream restoration reduces elevated phosphorus levels in an urban watershed. *Limnologica*, *91*, 125921. https://doi.org/10.1016/j.limno.2021.125921 Hill, T., Kulz, E., Munoz, B., & Dorney, J. R. (2013). Compensatory Stream and Wetland Mitigation in North Carolina: An Evaluation of Regulatory Success. *Environmental Management*, *51*(5), 1077–1091. https://doi.org/10.1007/s00267-013-0027-7

Jennings, G. (2003). *Stream Restoration Case Studies in North Carolina* [Proceedings]. https://repository.gatech.edu/server/api/core/bitstreams/b4b08508-0416-4078-bc94f37a67c89851/content

Kaushal, S. S., Fork, M. L., Hawley, R. J., Hopkins, K. G., Ríos-Touma, B., & Roy, A. H. (2023). Stream restoration milestones: monitoring scales determine successes and failures. *Urban Ecosystems*, *26*(4), 1131–1142. https://doi.org/10.1007/s11252-023-01370-8

Lázaro-Lobo, A., Lucardi, R. D., Ramirez-Reyes, C., & Ervin, G. N. (2021). Region-wide assessment of fine-scale associations between invasive plants and forest regeneration. *Forest Ecology and Management*, *483*, 118930. https://doi.org/10.1016/j.foreco.2021.118930

Lichvar, R.W. (2013). The National Wetland Plant List: 2013 wetland ratings. *Phytoneuron* 2013(49): 1–241. Published 17 July 2013. https://www.phytoneuron.net/2013Phytoneuron/49PhytoN-2013NWPL.pdf

Malmqvist, B., & Rundle, S. (2002). Threats to the running water ecosystems of the world. *Environmental Conservation*, *29*(2), 134–153. https://doi.org/10.1017/S0376892902000097

Mayer, P. M., Pennino, M. J., Newcomer-Johnson, T. A., & Kaushal, S. S. (2022). Long-term assessment of floodplain reconnection as a stream restoration approach for managing nitrogen in ground and surface waters. *Urban Ecosystems*, *25*(3), 879–907. https://doi.org/10.1007/s11252-021-01199-z

Mid Atlantic Native Plant Farm Inc. (2024). Calycanthus floridus, Sweetshrub Native Bare Root Shrubs. *Mid Atlantic Native Plant Farm Inc.* Retrieved March 10, 2024, from

https://midatlanticnatives.com/product/calycanthus-floridus-sweetshrub-native-bare-rootshrubs/

Minnesota Seasons. (2024, February 14). *American elderberry*. Minnesota Seasons. Retrieved March 10, 2024, from http://www.minnesotaseasons.com/Plants/American_elderberry.html#:~:text=American%20elderberry%20is%20a%20fast,rising%20from%20the%20same%20rootstock

MySeedsCo. (2021). *Calycanthus floridus*. MySeedsCo. Retrieved March 10, 2024, from https://www.myseeds.co/products/calycanthus-floridus-carolina-allspice-commonsweetshrub-eastern-sweetshrub

Monteiro, J. A. F., Kamali, B., Srinivasan, R., Abbaspour, K., & Gücker, B. (2016). Modelling the effect of riparian vegetation restoration on sediment transport in a human-impacted Brazilian catchment. *Ecohydrology*, *9*(7), 1289–1303. https://doi.org/10.1002/eco.1726

NC Invasive Plant Council. (2023). *Invasive List July 2023*. https://docs.google.com/document/d/1YY7k_an4qco-mcKQZSV1CBYbzw-6ihe_/edit?usp=sharing&ouid=106723197835414326092&rtpof=true&sd=true&usp=embed_facebook

Nilsson, C., Polvi, L. E., Gardeström, J., Hasselquist, E. M., Lind, L., & Sarneel, J. M. (2015). Riparian and in-stream restoration of boreal streams and rivers: success or failure? *Ecohydrology*, *8*(5), 753–764. https://doi.org/10.1002/eco.1480

North Carolina Department of Environmental Quality. (2017). *Division of Mitigation Services Stream and Wetland Mitigation Plan Template and Guidance*. https://www.deq.nc.gov/mitigation-services/document-management-library/guidanceand-template-documents/mitigation-plan-components/10-mitplan-june-2017/download

North Carolina Extension Gardener Plant Toolbox. (n.d.-a). *Calycanthus floridus*. Retrieved March 10, 2024, from https://plants.ces.ncsu.edu/plants/calycanthus-floridus/

North Carolina Extension Gardener Plant Toolbox. *Prunus caroliniana*. (n.d.-b). North Carolina Extension Gardener Plant Toolbox. Retrieved February 28, 2024, from https://plants.ces.ncsu.edu/plants/prunus-caroliniana/

NC State Biological and Agricultural Engineering Department. (n.d.). *Piedmont Riparian Species*. https://www.bae.ncsu.edu/wpcontent/uploads/2017/07/piedmont_riparian_species.pdf

Oklahoma State University. (2023, August 1). *Sugarberry*. OSU Extension. https://extension.okstate.edu/programs/plant-id/plant-profiles/sugarberry/index.html

Parendes, L. & Jones, J. (2001). Role of Light Availability and Dispersal in Exotic Plant Invasion along Roads and Streams in the H. J. Andrews Experimental Forest, Oregon. *Conservation Biology* 14(1): 64-75. https://doi-org.prox.lib.ncsu.edu/10.1046/j.1523-1739.2000.99089.x

Peet, R. K., Palmquist, K. A., Wentworth, T. R., Schafale, M. P., Weakley, A. S., & Lee, M. T. (2018). Carolina Vegetation Survey: an initiative to improve regional implementation of the U.S. National Vegetation Classification. *Phytocoenologia* 48(2), 171–179. https://doi.org/10.1127/phyto/2017/0168

Practical Plants. (n.d.). *Calycanthus floridus (Carolina Allspice)*. Practical Plants. Retrieved March 10, 2024, from https://practicalplants.org/wiki/calycanthus_floridus/

Rasingam, L., & Parthasarathy, N. (2009). Diversity of understory plants in undisturbed and disturbed tropical lowland forests of Little Andaman Island, India. *Biodiversity and Conservation*, *18*(4), 1045–1065. https://doi.org/10.1007/s10531-008-9496-z

Rudder, C. (2011). *NCSU Campus Forest Inventory Data Collection Method for Sustainability*

Management [Master of Natural Resources, NC State University]. https://repository.lib.ncsu.edu/server/api/core/bitstreams/59f43136-ac33-4f04-87b3f5bdbbba1279/content

Rutgers Landscape & Nursery. (2013). *Common Sweetshrub (Calycanthus floridus) at* [Plant Finder]. Rutgers Landscape & Nursery Plant Finder. http://plants.rutgersln.com/12150011/Plant/67/Common_Sweetshrub

Team, B. (2021, August 21). *Wax Myrtle Tree*. Footsteps in the Forest. https://footstepsintheforest.com/wax-myrtle-tree/

The Biota of North America Program. *North American Vascular Flora*. (n.d.). The Biota of North America Program. Retrieved February 28, 2024, from http://www.bonap.org/

The University of Texas at Austin. (2022, October 17). *Calycanthus floridus* [Plant Database]. Lady Bird Johnson Wildflower Center. Retrieved March 10, 2024, from https://www.wildflower.org/plants/result.php?id_plant=cafl22#:~:text=Eastern%20sweet shrub%20or%20Carolina%20allspice,Flower%20are%20often%20quite%20fragrant

TRY. *Plant Trait Database*. (n.d.). TRY. Retrieved February 28, 2024, from https://www.trydb.org/TryWeb/Home.php

Tugwell, T. (2016). *Notification of Issuance of Guidance for Compensatory Stream and Wetland Mitigation Conducted for Wilmington District*. U.S. Army Corps of Engineers Wilmington District.

Rubin, Z., Kondolf, G. M., & Rios-Touma, B. (2017). Evaluating Stream Restoration Projects: What Do We Learn from Monitoring? *Water*, 9(3), 174. https://doi.org/10.3390/w9030174

Sea Grant North Carolina. (2010a). *ROCKY BRANCH - PHASE 1 STREAM RESTORATION 2007 FINAL MONITORING REPORT* [Monitoring Report]. North Carolina Department of Transportation.

Sea Grant North Carolina. (2010b). *Rocky Branch Stream Restoration and Greenway Project*. https://ncseagrant.ncsu.edu/ncseagrant_docs/products/2010s/rocky_branch_projectsummary.pdf

Semedo, M.-H., & Junod, M. (2020, January 24). *Soil: the foundation of life on Earth*. John Innes Centre. https://www.jic.ac.uk/advances/soil-the-foundation-of-life-on-earth/

Silver, D., & Ruth, C. (n.d.). *Riparian Plants for Stream Stabilization*. NC State and AT&T Cooperative Extension. https://henderson.ces.ncsu.edu/wpcontent/uploads/2015/06/Riparian-Plants-for-Stream-Bank-Stabilization.pdf?fwd=no

Sudduth, E. B., Meyer, J. L., & Bernhardt, E. S. (2007). Stream Restoration Practices in the Southeastern United States. *Restoration Ecology*, *15*(3), 573–583. https://doi.org/10.1111/j.1526-100X.2007.00252.x

Sullivan, J. (1993-a). *Betula nigra*. In *Fire Effects Information System*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. Retrieved February 29, 2024, from https://www.fs.usda.gov/database/feis/plants/tree/betnig/all.html

Sullivan, J. (1993-b). *Celtis laevigata*. In *Fire Effects Information System*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. Retrieved February 29, 2024, from https://www.fs.usda.gov/database/feis/plants/tree/cellae/all.html

Sullivan, J. (1994). *Platanus occidentalis*. In *Fire Effects Information System*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. Retrieved February 29, 2024, from https://www.fs.usda.gov/database/feis/plants/tree/plaocc/all.html

Sweeney, B., Czapka, S., & Yerkes, T. (2002). Riparian Forest Regeneration: Increasing Success by Reducing Plant Competition and Herbivory. *Restoration Ecology* 10(2): 392-400. https://doi-org.prox.lib.ncsu.edu/10.1046/j.1526-100X.2002.02036.x

University of Kentucky Department of Horticulture. *Willow Oak*. (n.d.). University of Kentucky Department of Horticulture. Retrieved February 28, 2024, from https://www.uky.edu/hort/Willow-Oak

URS Corporation. (2008). *Newfound Creek Stream Restoration Project* [Restoration Plan]. North Carolina Department of Environment and Natural Resources Ecosystem Enhancement Program.

U.S. Army Corps of Engineers Wilmington District, & NC Department of Environmental Quality. (n.d.). *NORTH CAROLINA'S STREAM MITIGATION PROGRAM*. https://www.nawm.aswm.org/pdf_lib/nc_mitigation_program.pdf

U.S. Department of Agriculture. (2013, December 6). *Volunteer Plants*. NAL Agricultural Thesaurus. https://agclass.nal.usda.gov/vocabularies/nalt/concept?uri=https://lod.nal.usda.gov/nalt/198241

U.S. Department of Agriculture, Bureau of Soils. (1914). Soil survey of North Carolina. Retrieved February 28, 2024, https://dc.lib.unc.edu/cdm/ref/collection/ncmaps/id/301

USDA Plants Database. (n.d.). USDA Plants Database. Retrieved February 28, 2024, from https://plants.sc.egov.usda.gov/home/plantProfile?symbol=ACFL

U.S. Forest Service. (n.d.-a). *Liriodendron tulipifera L* [Factsheet]. Southern Research Station. Retrieved March 10, 2024, from https://www.srs.fs.usda.gov/pubs/misc/ag_654/volume_2/liriodendron/tulipifera.htm#:~:t

ext=Yellow%2Dpoplar%20(Liriodendron%20tulipifera),coves%20and%20lower%20mountain%20slopes

U.S. Forest Service. (n.d.-b). *Ulmus americana L* [Factsheet]. Southern Research Station. Retrieved March 10, 2024, from https://www.srs.fs.usda.gov/pubs/misc/ag_654/volume_2/ulmus/americana.htm#:~:text=American%20elm%20is%20a%20long,some%20older%20than%20300%20years

Vascular Plants of North America. *Vascular Plants of North Carolina*. (n.d.). Retrieved February 28, 2024, from https://auth1.dpr.ncparks.gov/flora/index.php

Virginia Tech Dendrology. (2021). *Laurel Cherry Fact Sheet*. https://dendro.cnre.vt.edu/DENDROLOGY/syllabus/factsheet.cfm?ID=349

Violin, C. R., Cada, P., Sudduth, E. B., Hassett, B. A., Penrose, D. L., & Bernhardt, E. S. (2011). Effects of urbanization and urban stream restoration on the physical and biological structure of stream ecosystems. *Ecological Applications*, *21*(6), 1932–1949. https://doi.org/10.1890/10-1551.1

Webb, A. A., & Erskine, W. D. (2003). A practical scientific approach to riparian vegetation rehabilitation in Australia. *Journal of Environmental Management*, *68*(4), 329–341. https://doi.org/10.1016/S0301-4797(03)00071-9

WK Dickson and Co., Inc. (2007). *South Fork Mitigation Project Catawba County, North Carolina Year 3 Monitoring Report* (p. 5) [Monitoring Report]. Environmental Banc and Exchange, LLC.

Zan, R., Kondolf, M., & Rios-Touma, B. (2017). Evaluating Stream Restoration Projects: What do we Learn from Monitoring? *Water* 9(3): 174. https://doi.org/10.3390/w9030174

Zheng, H., Lin, H., Zhou, W., Bao, H., Zhu, X., Jin, Z., Song, Y., Wang, Y., Liu, W., & Tang, Y. (2019). Revegetation has increased ecosystem water-use efficiency during 2000–2014 in

the Chinese Loess Plateau: Evidence from satellite data. *Ecological Indicators*, *102*, 507–518. https://doi.org/10.1016/j.ecolind.2019.02.049

CHAPTER 2: INVASION POST-RESTORATION IN ROCKY BRANCH

2.1 Introduction

2.1.1 Invasive Species in Restoration

Invasive plant species are of crucial importance and play a major role in stream restoration. They alter the plant and macroinvertebrate communities, influencing the stream's ecological processes (Woods et al. 2019). Riparian zones in urban restoration sites are particularly at risk for invasion (Isabel et al. 2014). Restoration projects cause disturbance within a site, disrupting the soils, which makes them optimal locations for invasive species introductions

(New York Department of Environmental Conservation, n.d.). Furthermore, it is difficult to keep newly restored sites in urban areas from being invaded because urban riparian areas commonly serve as dispersal corridors for invasive species. They can serve as dispersal corridors not only for species transported by water but also for wind-dispersed invasives that are frequently transported downstream and take root in riparian zones (Samuel and Kowarik, 2010). Furthermore, urban streams have flashier hydrological regimes resulting in the floodplains being more often and aggressively flooded. This results in vegetation being ripped out and soil disturbance, which further promotes invasion (Kuglerová et al., 2019). Animal dispersal, particularly by birds is another major spreader of invasive species in urban areas. Despite this, our understanding of the relationship between birds and the success of alien plants invasion is limited, resulting in ineffective management (Gosper et al. 2005). Additionally, the complexity of urban landscapes and dispersal mechanisms makes it more difficult and expensive to treat and manage invasive species, which underscores the emphasis placed on prevention of biotic invasion. While chemical control methods can be effective, the results don't last long enough to prevent reinvasion, so control methods need to be used in combination with prevention tactics to create long-lasting restoration sites (Weidlich et al., 2020).

One hypothesis that attempts to address invasive species prevention is the empty niche, which asserts that a high species richness will ensure that all niches within the community are filled and subsequently no resources are available for invaders (Shea and Chesson, 2002, Funk et al. 2008; Hammer and Gunn, 2021). This theory suggests that invasive species would struggle to establish if other species with similar characteristics were present within the community, thereby, stream restoration projects with robust communities of native species with similar functional traits to likely invaders should be more resistant to biotic invasion. Some caveats exist for this hypothesis. First, at larger scales it is no longer a concern whether the niche is empty or not.

Instead, concern is about functional differences in niches and how resources are partitioned since species can fill niches in multiple ways, consequently, species richness becomes less of a defining factor (Shea and Chesson, 2002). Second, if there are major changes in the ecological filter, such as human transport of seed or increased resource availability, this would shift the niche/trait availability within the community and again render species richness less important (Funk et al. 2008). With these caveats in mind, the overall implication for conservation that restoration planners should take advantage of, in theory, is that if the forest has a healthy community that fills all niches then it's harder for invaders to establish and thrive.

The competition paradigm is similar to the empty niche hypothesis; however, it asserts that species cannot coexist if they have overlapping resource needs. Native and invasive species must compete under various hydro-geomorphological conditions and this interspecific competition influences the makeup of a stream site post-restoration (Tickner et al. 2001). For example, Vidra et al. (2006) found that exotic species and native species were negatively correlated, meaning they were unable to coexist spatially. Specifically, they found that the two most common invasive species, *Microstegium vimineum* (Japanese stiltgrass) and *Hedera helix* (English ivy), did not co-occur with several native tree species. However, Vidra et al. (2006) found one exception, *Lonicera japonica* (Japanese honeysuckle), which did occur in areas with high native tree richness. Being able to identify these relationships and exceptions can help inform planting plans and implementation strategies for stream restoration projects if a major goal is to prevent invasive species. However, native planted species are seldom capable of preventing invasion through competitive exclusion alone, so this should not be solely relied on (Davis, 2003).

While prevention is an important aspect of invasive species management, in an urban setting it is nearly impossible to have total eradication of invasive species. Therefore, quantifying

the impact of invasive species and selecting species to target for removal is an important aspect of site management. Not all invaders have the same ecological impact; therefore, the damage that a single high-impact species causes can outweigh the damages caused by multiple low- or moderate-impact invasives (Nunez-Mir et al. 2017). The highest-impact invasives also tend to have mechanisms that enable quick and large-scale invasion via numerous reproductive events and many individuals produced during each event (Kolar and Lodge 2001). Prioritizing the species that are causing the most damage and spreading the fastest and most expansively is crucial to managing and maintaining restored areas.

2.1.2 North Carolina Stream Restoration Process and Requirements

In North Carolina all stream restoration projects must comply with performance standards from the Wilmington District of the U.S. Army Corps of Engineers for Clean Water Act 404 mitigation purposes on planted vegetation and invasive species. For instance, there are requirements for a yearly table in monitoring reports where providers must list known invaded areas within their site. If treatment of invasive populations is insufficient this results in loss of credits

2.1.3 A Gap in our Knowledge

While the importance of long-term assessment has been demonstrated, little research has been done to resample older streams and better understand the levels of invasion as well as the species that invade restoration sites past the seven-year mark. The need for this has been emphasized within the restoration ecology scientific community; particularly, the National Association of Wetland Managers has encouraged more research evaluating older stream restoration projects that are at least 8–10 years old and to resample them for comparison (US Army Corps of Engineers Wilmington District & NC Department of Environmental Quality,

n.d.). We need to better understand the ecological impacts of invasive species in restoration projects in the long-term and the consequences of inconsistent or improper management. Furthermore, we need to understand the benefits of proper invasive species management on sites where invasive species have been successfully suppressed.

2.1.4 Study Site: Rocky Branch

Rocky Branch is a first-order stream that runs just over a mile through North Carolina State University's campus in Raleigh, North Carolina. The creek has a 1.5 km^2 urban watershed with 99.2% of the watershed developed and 34.8% covered by impervious surfaces (Violin et al. 2011). This stream was restored in three phases; Phase I runs from Gorman Street to Dan Allen Drive and was completed in 2002, Phase II runs from Morrill Drive to Pullen Road and was finished in 2006, and lastly, Phase III is the connecting segment between Dan Allen Drive and Morrill Drive and was completed in 2010 (Sea Grant North Carolina, 2010b) (Figure 2.3). The three phases presented a unique opportunity to examine plant communities 21, 17, and 13 years post-restoration. This is a longer timeframe than typical post-restoration monitoring and inventory. Pre-restoration, Rocky Branch was considered one of North Carolina's most polluted urban streams (Duda et al., 1978). Historically, the stream was timbered and channelized, meaning it was deepened, widened and straightened, likely for agriculture, which was the prior land use. When NC State's campus expanded, the floodplain soils were covered with construction fill (Figure 2.1). Left undisturbed and in optimum condition, it takes between 200–400 years to form 1 cm of new soil (Semedo & Junod, 2020); however, due to the construction fill, the soil layers have been highly disturbed and the upper portions are undeveloped. The NC Department of Agriculture's soil survey determined the soil of the stream to be Cecil fine sandy loam (Figure 2.2). Post-restoration, the stream's creek stabilized, its water quality improved, and its aquatic wildlife habitat was enhanced. These improvements are due in large part to the

revegetation done by the project, which provided habitat, cover, and food for wildlife (Doll et al. 2004; Sea Grant North Carolina, 2010b). The project employed natural channel design techniques, meandering the stream through a new floodplain (Jennings, 2003; Doll et al. 2004).

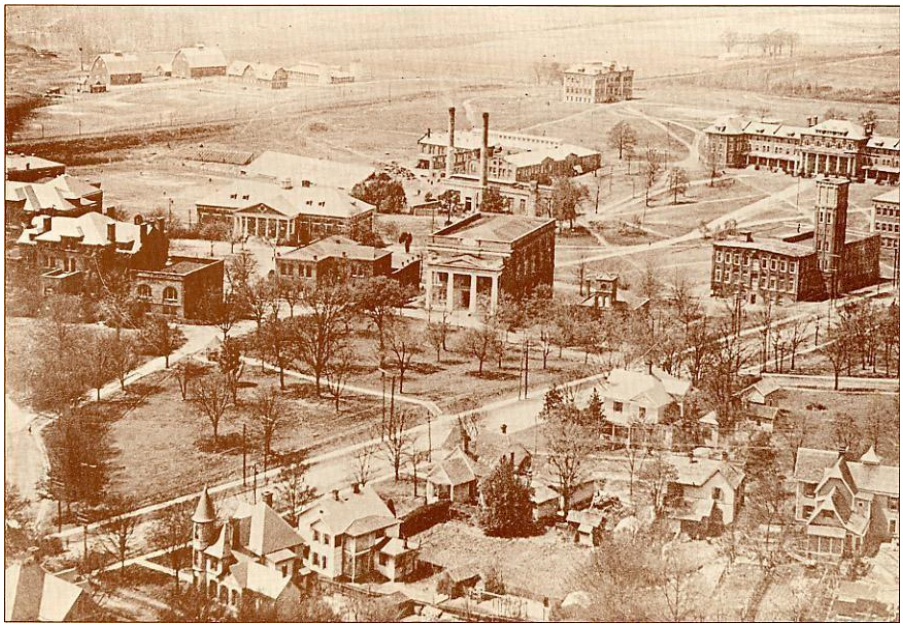


Figure 2.1 Photograph of the study site before the stream was channelized. The stream is behind the barns in the back of the photo (Brinkley et al. 1914).

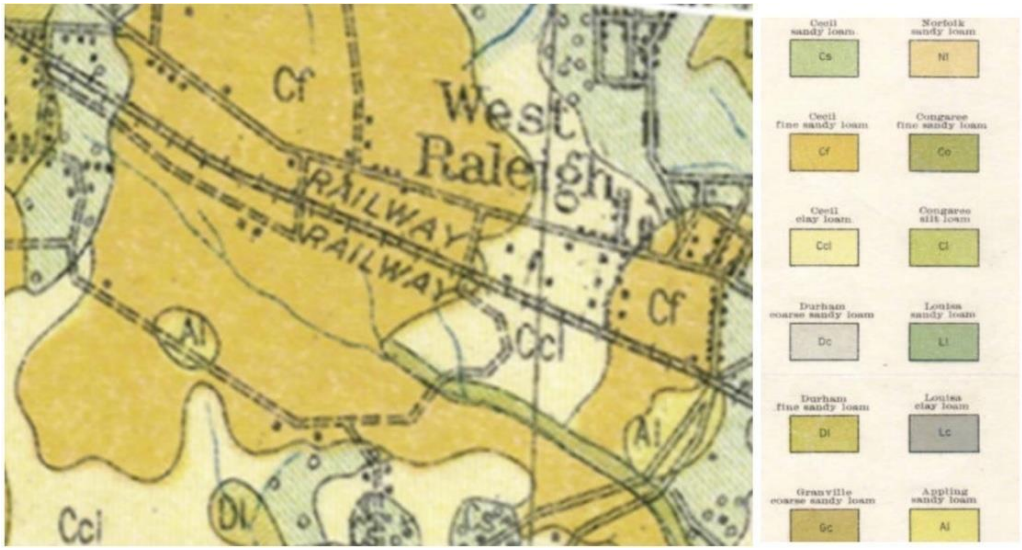


Figure 2.2 1914 soil survey of the study site (U.S. Department of Agriculture, Bureau of Soils, 1914).

Each phase had its own plant lists for revegetation. These lists identified tree, shrub, and herbaceous species to be planted in separate landscape zones such as narrow floodplains, gentle slope forests, and floodplain pools. In addition, a temporary seed mix, a riparian seed mix, and live stakes were designated for specific areas (Appendix B). Temporary seeds were included to reduce soil erosion because the resulting vegetation quickly establishes an herbaceous cover. On the other hand, the permanent vegetation included other native grasses, shrubs and trees across the different landscape zones (Harman & Starr, 2011). The planting lists were developed in accordance with natural resource reports, the geographic region, and by consulting with data and staff from the NC Natural Heritage Program, Triangle Land Conservancy, U.S. Fish and Wildlife Service, and NC Wildlife Resources Commission. Hardy species were planted to account for inconsistent future maintenance. Several fast-growing woody plants were chosen to ensure stream stabilization, with the thought that once the area was stabilized other types of plants would come in (Hall K., Personal Communication, 2023).

A five-year vegetation survey was done on Rocky Branch, which indicated that invasive exotic weeds were problematic in certain areas of the riparian buffer. Three species specifically identified within the report include *Pueraria montana* (kudzu), *Microstegium vimineum*, and *Lonicera japonica* (Japanese honeysuckle). Within each year of the vegetation report (2004–2007) it was noted that invasive cover was increasing. Some treatment done by NC State's Landscape Maintenance and Operations (LMO) (Sea Grant North Carolina, 2010a). Some treatments aggressively targeted *Pueraria montana* because it climbs and takes over the canopy, suppressing native species below. Other species that were also targeted but to a lesser extent include *Ligustrum sinense* (Chinese privet) and *Elaeagnus umbellata* (autumn olive) (Del Pinal J., Personal Communication, 2022).

2.2 Methods

The data for the current study were collected within 10-meter-long plots that extended perpendicular across the stream to the edge of the planted boundary on both sides of the riparian corridor. The width of plots varied due to include only the restored part of the stream corridor. We began the plots below the manicured garden area of the study site so as to minimize confounding data. We collected data for every third plot. We collected stem counts by species at breast height, invasive cover by species, and cover percentage by stratum (tree, shrub, and herb). The assessment protocols developed for the Carolina Vegetation Survey were applied using values of trace=1; 0-1%=2; 1-2%=3; 2-5%=4; 5-10%=5; 10-25%=6; 25-50%=7; 50-75%=8; 7595%=9; 95-100%=* (Peet et al. 2018). For each plot we plotted the four corners with the application ArcGIS Collector to map their geospatial locations (Figure 2.3). Photos of each plot were also taken at each corner. To get a comprehensive list for survivorship of planted species, we also surveyed the entire restored stream corridor, marking the presence and absence of planted species. Phase I was sampled first, followed by Phase III, and then Phase II. Phase I contained 30 plots, Phase III contained 14 plots, and Phase II contained 15 plots.

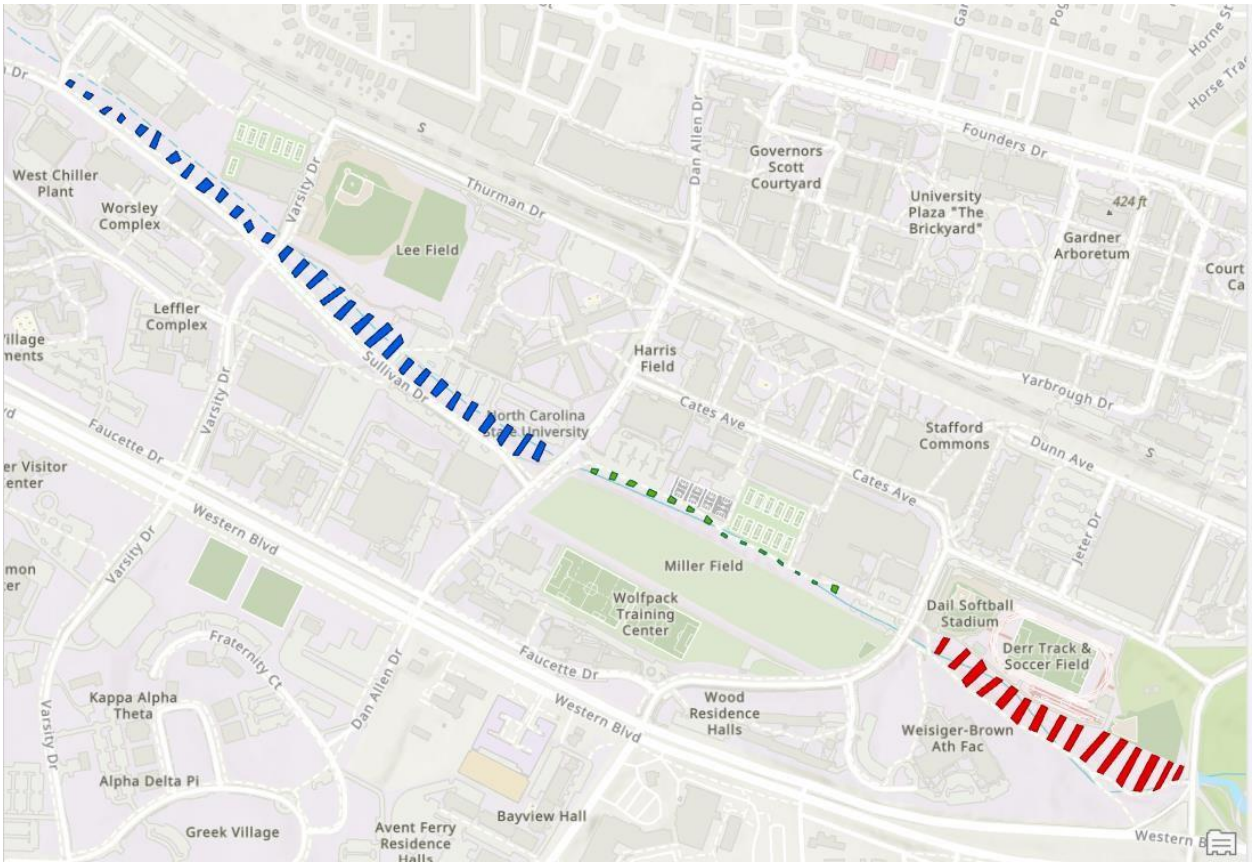


Figure 2.3 Rocky Branch Phase I (blue), Phase II (red), and Phase III (green) plots boundaries based on ArcCollector data. The section of stream in Phase III near Morrill Drive was not sampled because the stream is culverted to pass under the road.

Once data were collected, each species was labeled as planted, invasive, volunteer, or volunteer non-native. If they were included in Rocky Branch's planting list from that phase the species would be considered planted. They were labeled as invasive species if they were listed on the North Carolina Invasive Plant Council Invasive List at any level (NC Invasive Plant Council, 2023). If the species was determined to be native to North Carolina then it was designated a volunteer species. If a species was determined to be non-native to North Carolina then it was considered volunteer non-native. The nativeness of each species was determined using Vascular Plants of North America and the Biota of North America Program (Vascular Plants of North

America, n.d.; Biota of North America Program, n.d.). Each phase had different species planted, so some species can be considered either planted or volunteer if they were planted in one phase but not another. For instance, *Parthenocissus quinquefolia* (Virginia creeper) was planted in Phase III but not in Phase I or II, so it is considered a planted species in Phase III and volunteer in Phase I or II (Appendix B).

For multivariate analysis, PCORD7 software was utilized. Two indicator species analyses were conducted; the first used a main matrix with stem data and a secondary matrix with cover data. The second indicator species analysis used an invasive cover (%) main matrix and a cover secondary matrix. This analysis was done for each phase. To determine which plots to include, Sorrenson outlier analysis with a cutoff number 2.0 of standard deviations were conducted. The outliers identified were plot 5 in Phase I and 13 in Phase III (Appendix F). Plot 5 in Phase I had very little invasive cover compared to the rest of the phase. Plot 13 in Phase III had a very high amount of invasive cover from *Microstegium vimineum* compared to the rest of the phase with the species having 75-95% cover. Two NMS (non-metric multidimensional scaling) ordinations were performed using the stem data main matrix with different secondary matrices. Ordinations are a technique in which plots, species, etc. can be represented as points in a two-dimensional space; points that plot closer together are more similar to one another. This display can help determine how similar or different particular plots, phases, or species are, enabling users to better understand what is driving community composition. One was done with the secondary matrix for cover at the R^2 level 0.15 and the other was done with the secondary matrix for species data at the R^2 level 0.2. The same plots were excluded as determined by the Sorrenson outlier analysis (Appendix F). From these ordinations we can graph by the secondary matrix. This graphing was done for the second NMS ordination with the secondary matrix for species. The ordination still plots the sections, but sections where the chosen species has higher influence appear larger.

2.3 Results

2.3.1 General Results

Within the study area, invasive cover was highest in Phase II followed by Phase I and Phase III (Table 2.1). A total of 283 different plant species occurred; 54 were invasives. However, the majority of these species were volunteer plants, followed by invasive species, planted species, and non-native volunteer plants. Herbaceous plants were the most common type of designation and growth form for invasive species across all phases. While herbaceous was the highest category, the number of invasive species were relatively even across stratum. Phase II contained the highest number of species for invasive tree, shrub, herb, and vine species. Across phases the species distributions were similar in that volunteer species account for the highest species category and herb species account for the highest growth form category within each (Figure 2.4; Table 2.2). While the overall results are similar across phases, the distributions are not close enough to be considered the same distribution at the alpha 0.05 level (Chi-squared statistic = 10.65) (Appendix H).

Table 2.1 Overall invasive area within the total studied area, total area, and invasive cover.

	Invasive Area (m^2)	Studied Area (m^2)	Total Area (m^2)	Invasive Cover
Phase I	3492	6154	6154	56.7
Phase II	3552	5363	5363	66.2
Phase III	332	853	853	38.9

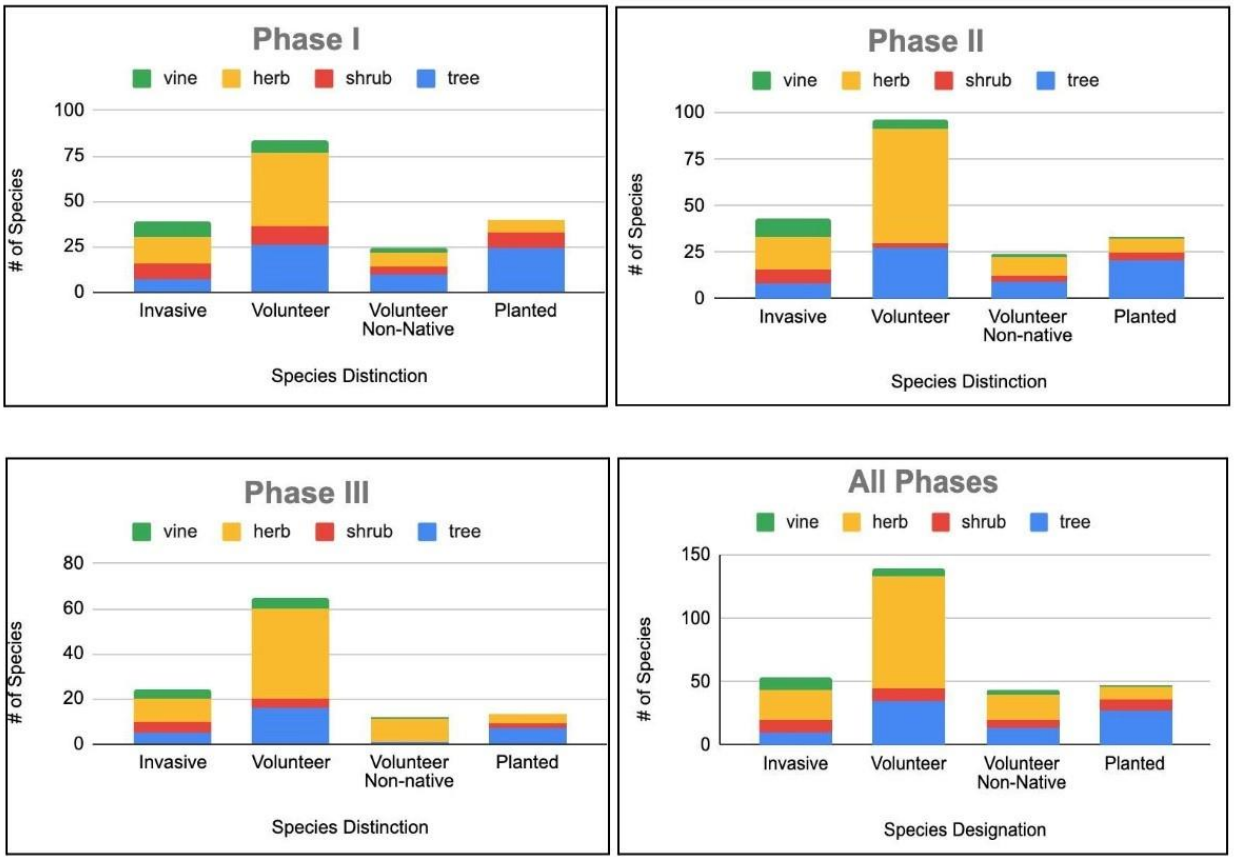


Figure 2.4 Distribution of the number of species by designation and by growth form in Phase I (top left), Phase II (top right), Phase III (bottom left), and across all phases (bottom right).

Table 2.2 Number of species within each species type and growth form across phases.

		Tree	Shrub	Herb	Vine	Totals
All Phases	Invasive	10	10	23	11	54
	Volunteer	35	10	88	7	140
	Volunteer Non-Native	14	6	20	3	43
	Planted	27	9	10	0	46
		86	35	141	21	283
		Tree	**Shrub**	**Herb**	**Vine**	**Totals**
Phase I	Invasive	7	9	14	9	39
	Volunteer	26	10	41	7	84
	Volunteer Non-Native	10	4	8	2	24
	Planted	24	9	7	0	40
		67	32	70	18	187
		Tree	**Shrub**	**Herb**	**Vine**	**Totals**
Phase II	Invasive	8	8	17	10	43
	Volunteer	27	3	61	5	96
	Volunteer Non-native	9	3	10	2	24
	Planted	21	4	7	1	33
		65	18	95	18	196
		Tree	Shrub	Herb	Vine	**Totals**
Phase III	Invasive	5	5	10	4	24
	Volunteer	16	4	40	5	65
	Volunteer Non-native	1	0	10	1	12
	Planted	7	2	4	0	13
		29	9	64	10	112

Invasive species accounted for 47.1% of stems across all phases (Figure 2.5). While the overall results are similar across phases, the distributions are not close enough to be considered the same distribution, which was shown by the results of the chi-squared test of homogeneity (Chi-squared statistic = 286.59) (Appendix I).

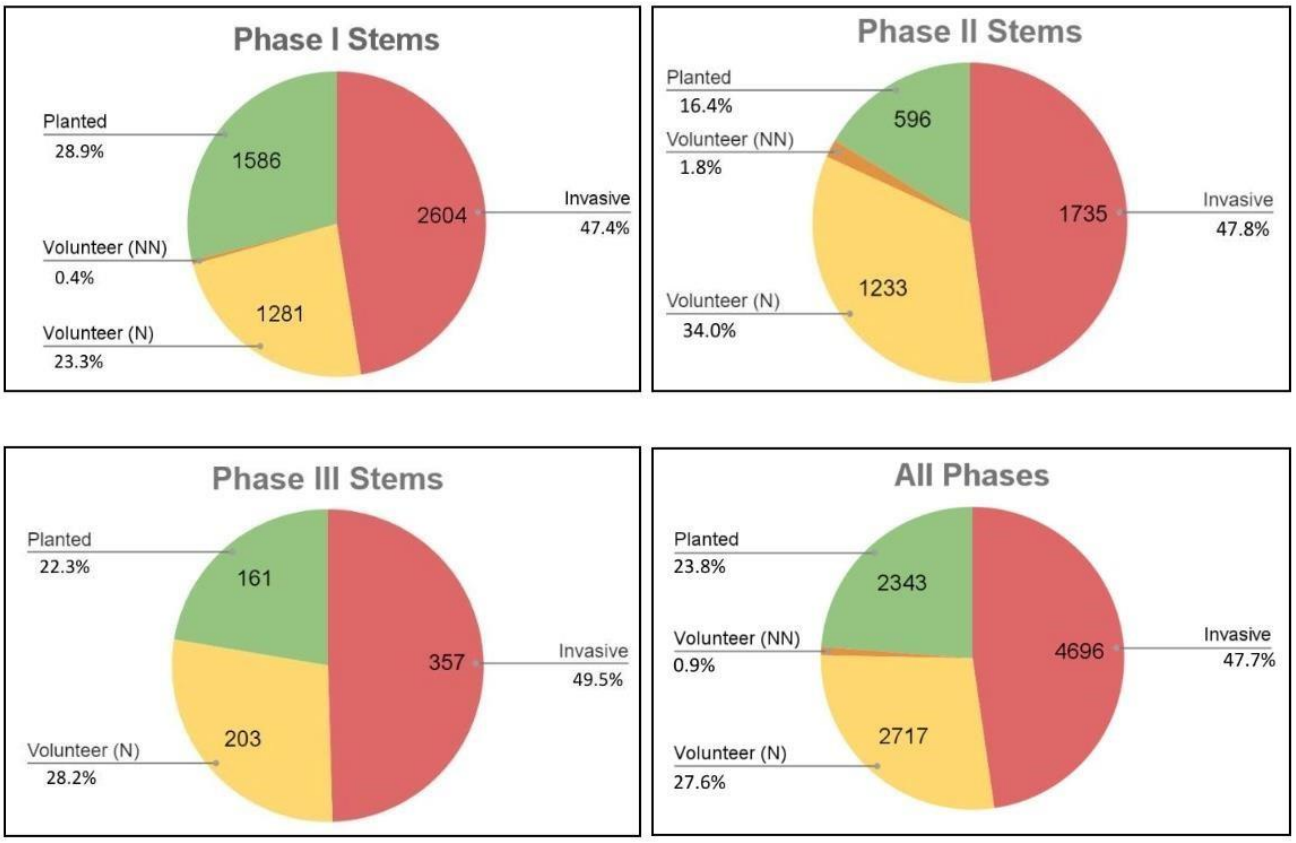


Figure 2.5 Stem counts for each plant designation in Phase I (top left), Phase II (top right), Phase III (bottom left), and across all phases (bottom right).

2.3.2 Phase Analysis

Table 2.3 Significant native and invasive indicator species for each phase. Full analysis with associated p-values for natives in Appendix J and invasives in Appendix K.

	Phase I		Phase II		Phase III	
	Common Name	Scientific Name	Common Name	Scientific Name	Common Name	Scientific Name
Native	Pawpaw	*Asimina triloba*	Box elder	*Acer negundo*	Tulip-poplar	*Liriodendron tulipifera*
	Flowering dogwood	*Benthamidia florida*	Smooth alder	*Alnus serrulata*	American elm	*Ulmus americana*
	Carolina allspice	*Calycanthus floridus*	River birch	*Betula nigra*		
	Spicebush	*Lindera benzoin*	Ironwood	*Carpinus caroliniana*		
	Black cherry	*Prunus serotina*	Hawthorn	*Crataegus spp.*		
	Laurel oak	*Quercus laurifolia*	Sweetgum	*Liquidambar styraciflua*		
	Water oak	*Quercus nigra*	Sycamore	*Platanus occidentalis*		
	Loblolly pine	*Pinus taeda*	Laurel cherry	*Prunus caroliniana*		
			Black locust	*Robinia pseudoacacia*		
Invasive	Oriental bittersweet	*Celastrus orbiculatus*	Porcelain berry	*Ampelopsis glandulosa*	Japanese stiltgrass	*Microstegium vimineum*
	English ivy	*Hedera helix*	Leatherleaf mahonia	*Berberis bealei*		
	Amur honeysuckle	*Lonicera maackii*	Thorny olive	*Elaeagnus pungens*		
	Chinese privet	*Ligustrum sinense*	Lespedeza	*Lespedeza cuneata*		
	White mulberry	*Morus alba*	Creeping lilyturf	*Liriope spicata*		
			Bristly lady's thumb	*Persicaria longiseta*		
			Chamber bitters	*Phyllanthus urinaria*		
			Mock strawberry	*Potentilla indica*		
			Callery pear	*Pyrus calleryana*		
			Japanese knotweed	*Reynoutria japonica*		
			Chinese wisteria	*Wisteria sinensis*		

Based on the species distributions, strata cover, and the native and invasive indicator species, Phase I is considered a mid-successional closed canopy plant community, Phase II is considered a mid-successional open canopy plant community, and Phase III is considered an early-successional community. The invasive species indicative of Phase I are shade-tolerant, Phase II had a mix of shade tolerance, while Phase III only had one species that is able to tolerate a wide range of light conditions (Table 2.3). When sections are plotted on an ordination (Figure 2.6), the phases group out from each other in a way that aligns with these successional stage designations. Phase III plots grouped out on the left side of the ordination with the earlysuccessional species, while Phase II plotted more in the middle, and Phase I plotted in the middle and along the right side of the ordination with the later successional species. We interpret the ordination with the horizontal axis driven by successional stage. Phase I contained more mid- and late-successional species, Phase II had a mix of early-, mid-, and late-successional species, and Phase III had early-successional species. As for the vertical axis, points that are further towards the top of the ordination were plots with higher cover in all categories (invasive, tree, shrub, and herb) (Table 2.4). The areas of highest cover within the ordination are in the uppermost right-hand corner (Figure 2.6).

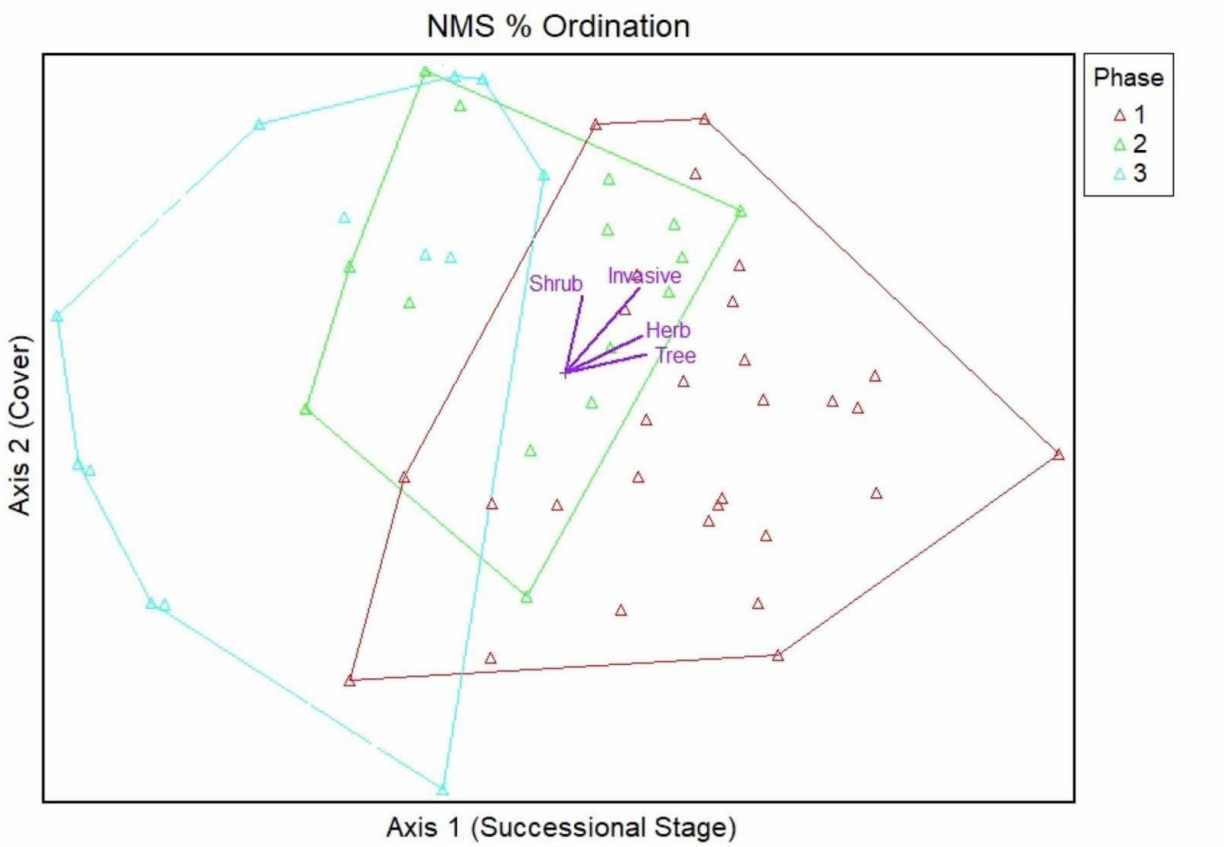


Figure 2.6 Ordination with stems as the main matrix variable and invasive, tree, shrub, and herb cover as the secondary matrix variables at $R^2 = 0.15$.

Table 2.4 Statistics table from PCORD7 with the R^2 values for the secondary matrix variables axis in regards to each axis.

Axis	1			2		
	r	r-sq	tau	r	r-sq	tau
Invasive Cover	-0.423	0.179	-0.366	-0.426	0.181	-0.299
Herb Cover	-0.431	0.186	-0.328	-0.29	0.084	-0.154
Shrub Cover	-0.201	0.04	-0.206	-0.411	0.169	-0.31
Tree Cover	-0.417	0.174	-0.345	-0.185	0.034	-0.13

2.3.3 Invasive Cover

Within the study site many invasive species of concern occurred. All of the phases had a high amount of invasive cover within them. Phase II had the highest amount followed by Phase I, then Phase III (Table 2.1). Although all phases have high percent cover, they separate based on invasive cover when plotted in ordination space (Figure 2.7). Phase I and II are the main drivers for invasive cover in this system, with *Hedera helix* being the largest contributor. Hedera helix is strongly associated with Phase I and II, *Ligustrum sinense* is strongly associated with Phase I, and Microstegium vimineum is strongly associated with Phase III. *Ligustrum lucidum*'s biplot line strongly points upward and is not associated with one particular phase (Figure 2.7).

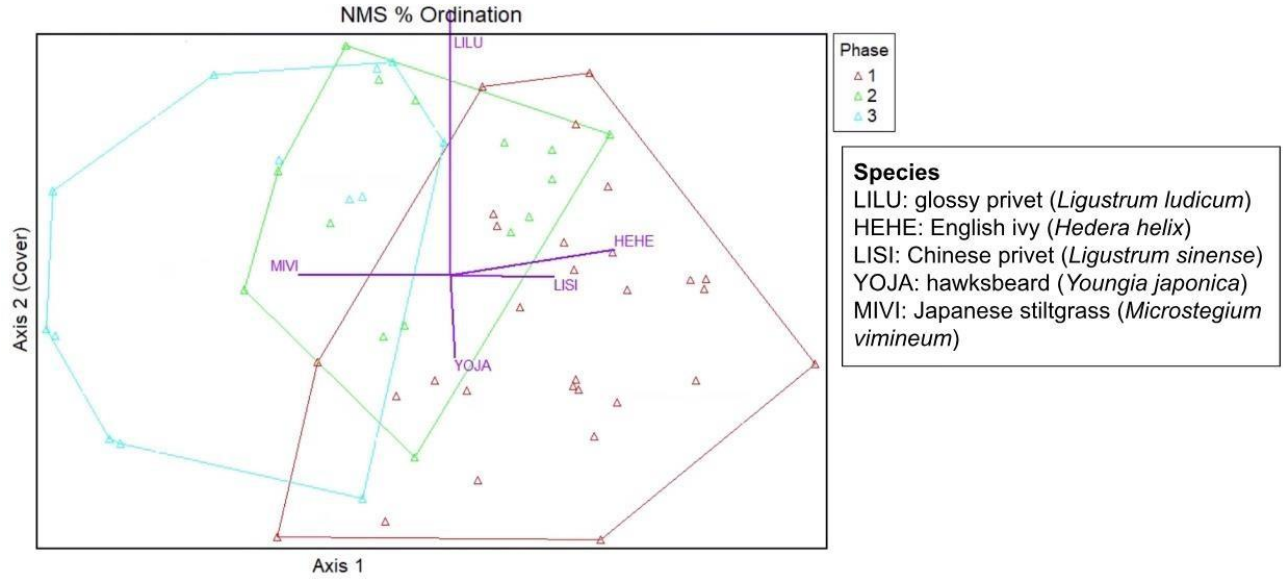


Figure 2.7 Ordination with invasive % cover per species as the main matrix variable and species as the secondary matrix variables at $R^2 = 0.2$.

Determining the highest-impact species for this site resulted from measuring the total area that each species covers, utilizing data within each plot. The five species with the highest cover are *Hedera helix*, *Ligustrum lucidum* (glossy privet), *Microstegium vimineum*, *Pyrus calleryana*

(Callery pear) and *Ligustrum sinense*. *Hedera helix* takes up the most space followed by *Ligustrum lucidum*, *Microstegium vimineum*, *Pyrus calleryana*, and *Ligustrum sinense* (Table 2.5).

Table 2.5 Five invasive species with the highest invasive cover in terms of m^2 and total percent invasive cover of the sampled area. Full invasive cover list in Appendix D.

Common Name	Scientific Name	Total Area (m^2)	Total Percent Invasive Cover
English ivy	*Hedera helix*	2189	17.7
glossy privet	*Ligustrum lucidum*	1559	12.6
Japanese stiltgrass	*Microstegium vimineum*	594	4.8
Callery pear	*Pyrus calleryana*	508	4.1
Chinese privet	*Ligustrum sinense*	408	3.3

Table 2.6 Five invasive species and their invasive cover in terms of m^2 within each phase.

	Phase	Invasive Cover (m^2)	Study Area (m^2)	Percent Cover
Hedera helix	Phase I	1288	6154	20.9
	Phase II	895	5363	16.7
	Phase III	6	853	0.7
Ligustrum lucidum	Phase I	633	6153	10.3
	Phase II	805	5363	15.0
	Phase III	104	853	12.2
Microstegium	Phase I	175	6154	2.8
	Phase II	328	5363	6.1
	Phase III	72	853	8.4
Pyrus calleryana	Phase I	100	6154	1.6
	Phase II	403	5363	7.5
	Phase III	4	853	0.5
Ligustrum sinense	Phase I	254	6154	4.1
	Phase II	149	5363	2.8
	Phase III	5	853	0.5

2.3.4 Highest Impact Invasives

2.3.4.1 English ivy (*Hedera helix*)

Hedera helix is a woody, evergreen, trailing or climbing liana (Waggy, 2010). It is an aggressive invader that threatens nearly all forested habitat types in the U.S. up to at least 3000' in elevation and it commonly invades floodplain forests across successional stages (Soll, 2005).

It usually invades during the early stages of succession and once it becomes established it can persist for centuries (Rackham, 1990 as cited in Waggy, 2010). In areas where the species is established, the vine carpets the forest floor and ascends up the trees, allowing the climbing plants to reach sufficient light for fruit production (Schnitzler, 1995). *Hedera helix* forms a thick canopy and prevents sunlight from reaching plants below. Furthermore, the vines can have negative impacts on their host trees by either reducing their vigor or making them more susceptible to blow-over (Soll, 2005). In North Carolina, *Hedera helix* is ranked a threat level one or significant threat, the highest-level threat (NC Invasive Plant Council, 2023). *Hedera helix* is a main driving force of invasion within Rocky Branch. It was found in 48 of 59 plots within the study site. The invasive cover ordination underscores its influence. This species has the highest influence in sections with the highest overall tree, shrub, herb, and invasive cover, as shown by the largest points at the upper end of the vertical axis (cover) in the ordination graph (Figure 2.8). It is particularly impactful in Phase I which aligns with the indicator species analysis as well as the significant species biplots (Table 2.5; Figure 2.7). But it also has some impact in Phase II within the uppermost, highest cover plots. It has less of an impact within Phase III, the earliest successional stage (Figure 2.8).

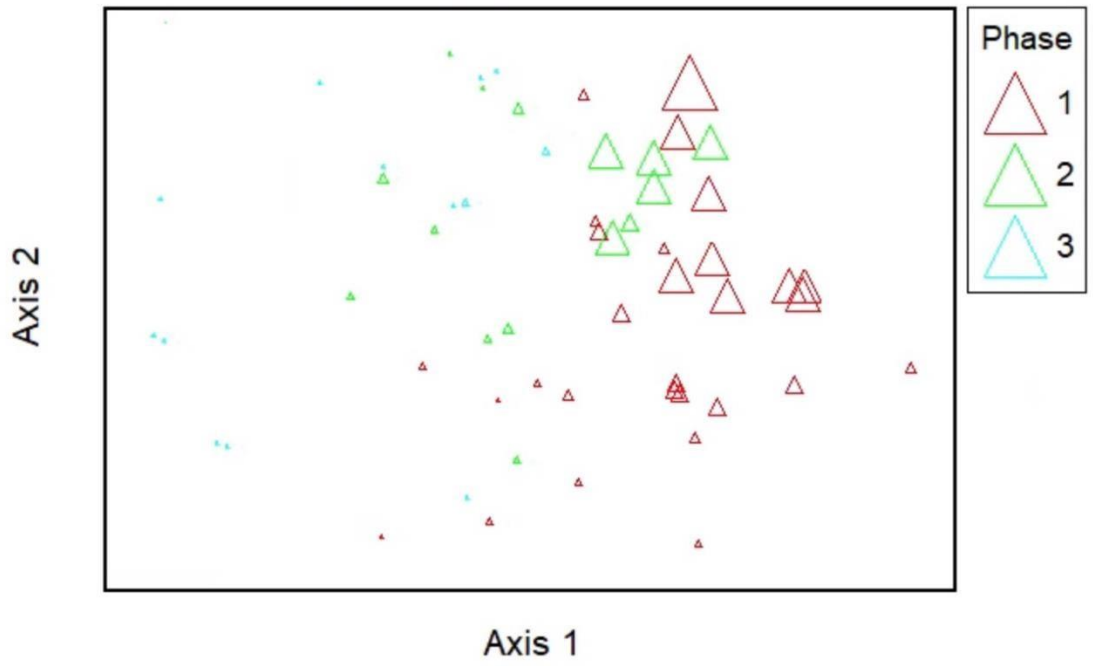


Figure 2.8 Ordination with % invasive cover per species as the primary matrix variable. The size of each section (triangle) indicates the level at which the plot's invasive cover is influenced by *Hedera helix*.

2.3.4.2 Glossy privet (*Ligustrum lucidum*)

Ligustrum lucidum is a semi-evergreen multi-stemmed shrub or small tree (Invasive Plant Atlas of the United States, n.d.). This species commonly forms dense thickets, which shades and out-competes many native species. Once the species is established it is very difficult to remove and even has the potential to develop monodominant forest stands (Center for Invasive Species and Ecosystem Health, n.d.). It can invade upland and lowland habitats; however, it is more prevalent within lowland environments due to its shade tolerance. *Ligustrum lucidum* colonizes via root sprouts and spreads widely due to the abundance of their seeds and dispersal by birds and other animals (Miller et al. 2015). Other traits that contribute to its pervasiveness include high germination rates, re-sprouting capability, rapid growth rates, low herbivory levels, and tolerance to a wide range of light levels, temperatures and soil types. All these traits contribute to

its ability to invade rapidly, altering the biodiversity and plant communities of the affected ecosystems (Fernandez et al. 2020). In North Carolina it is ranked a threat level one or significant threat (NC Invasive Plant Council, 2023). Within the ordination in Figure 2.9, we can see that *Ligustrum lucidum* is another major driving force of invasion and was found in 57 of 59 plots within the study site. The plots where the species dominates are the ones in the upper portion of the ordination, with the increasing invasive cover as you move up the vertical axis (Figure 2.6). This species is a strong indicator of invasive cover that drives Axis 2, with the highest cover in plots from all phases grouped near the top of the ordination space (Figure 2.9).

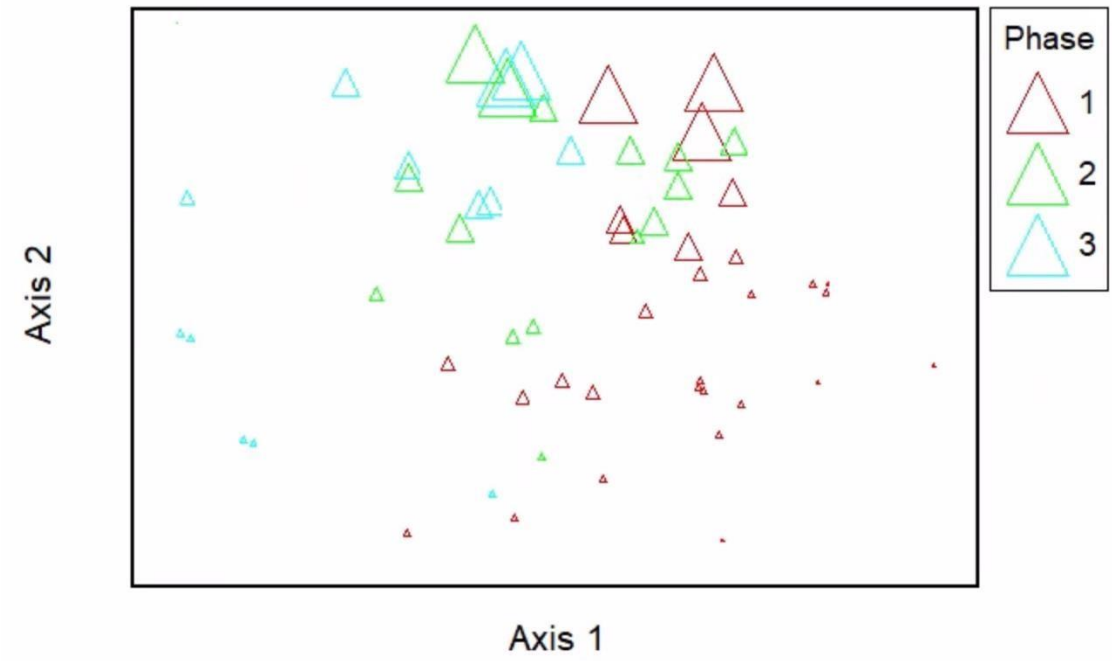


Figure 2.9 Ordination with % invasive cover per species as the primary matrix variable. The size of each section (triangle) indicates the level at which the plot's invasive cover is influenced by *Ligustrum lucidum*.

2.3.4.3 Japanese stiltgrass (*Microstegium vimineum*)

Microstegium vimineum is a sprawling, dense, mat-forming annual grass (Miller et al. 2015). It commonly invades disturbed areas and often occurs in moist environments such as on streambanks, floodplains, and forested wetlands because they are prone to natural scouring, providing an ideal environment for the species (Swearingen, 1999 as cited in U.S. Fish and Wildlife Service, 2015). Infestations from this species form thick beds and replace native herbaceous vegetation three to five years after introduction. This is accomplished by its prolific seeding, since each plant can produce 100 to 1,000 seeds (Miller et al. 2015). Invasion of *Microstegium vimineum* leads to changes in the litter composition, pH levels, and soil (Evans et al. 2006). In North Carolina it is ranked a threat level one or significant threat (NC Invasive Plant Council, 2023). The species was found in 45 of 59 plots within the study site and has particularly large impacts in Phase III, indicated by the larger sections on the left-hand side of the ordination plot. There are also a few plots in Phase II with a comparatively higher invasive presence of *Microstegium vimineum*. The species is a driver for invasive cover in areas with more open areas, with its impacts mostly seen in the left side of axis one (Figure 2.6; Figure 2.10). It often occurs in areas with low cover because it is an early-successional groundcover species.

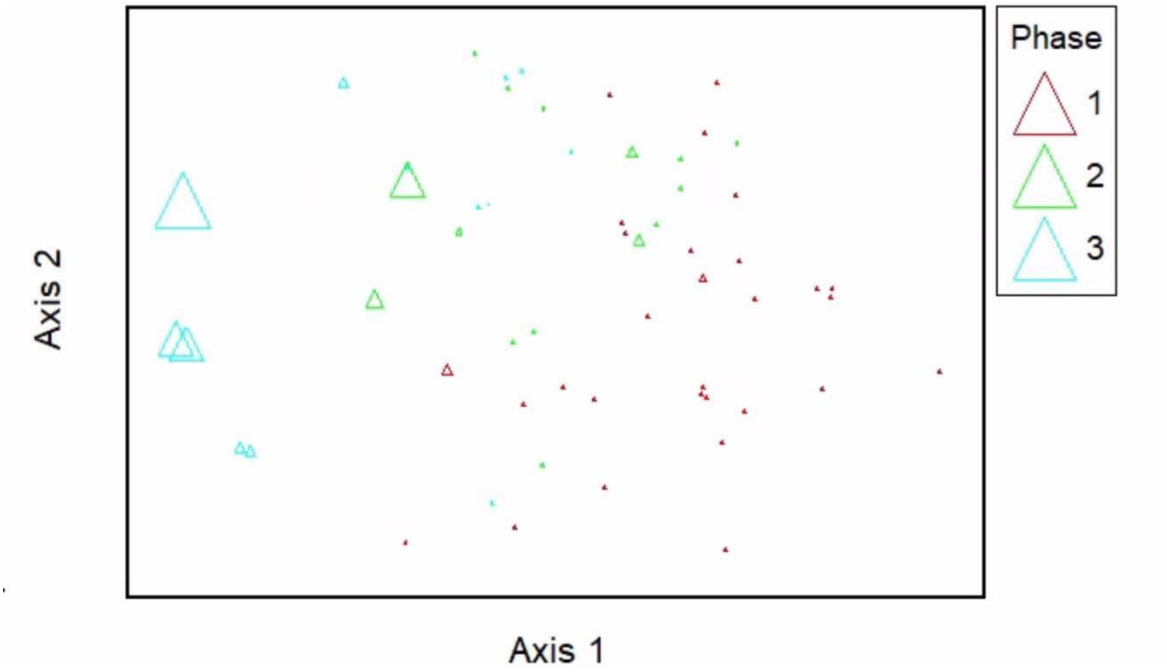


Figure 2.10 Ordination with % invasive cover per species as the primary matrix variable. The size of each section (triangle) indicates the level at which the plot's invasive cover is influenced by *Microstegium vimineum*.

2.3.4.4 Callery pear (*Pyrus calleryana*)

Pyrus calleryana is a widely planted deciduous tree that is rapidly spreading across the United States and has garnered attention as a serious invasive species (Vogt et al. 2020). It can form dense thickets and stands, formed by root sprouts. Because it can tolerate partial shade and a variety of soils, it is adaptable and thus, problematic (Miller et al. 2015). Furthermore, the species begins flowering at just a few years of age and spreads rapidly through bird dispersal (Culley & Hardiman, 2007). In North Carolina it is ranked a threat level one or significant threat (NC Invasive Plant Council, 2023). *Pyrus calleryana* has large impacts in Phase II and lesser impacts in Phase I (Figure 2.11). It is a main driver in areas with the highest tree, shrub, and herb

cover (Figure 2.6) which is denoted by the larger points near the top of the vertical axis. This species was found in 32 of 59 plots within the study site.

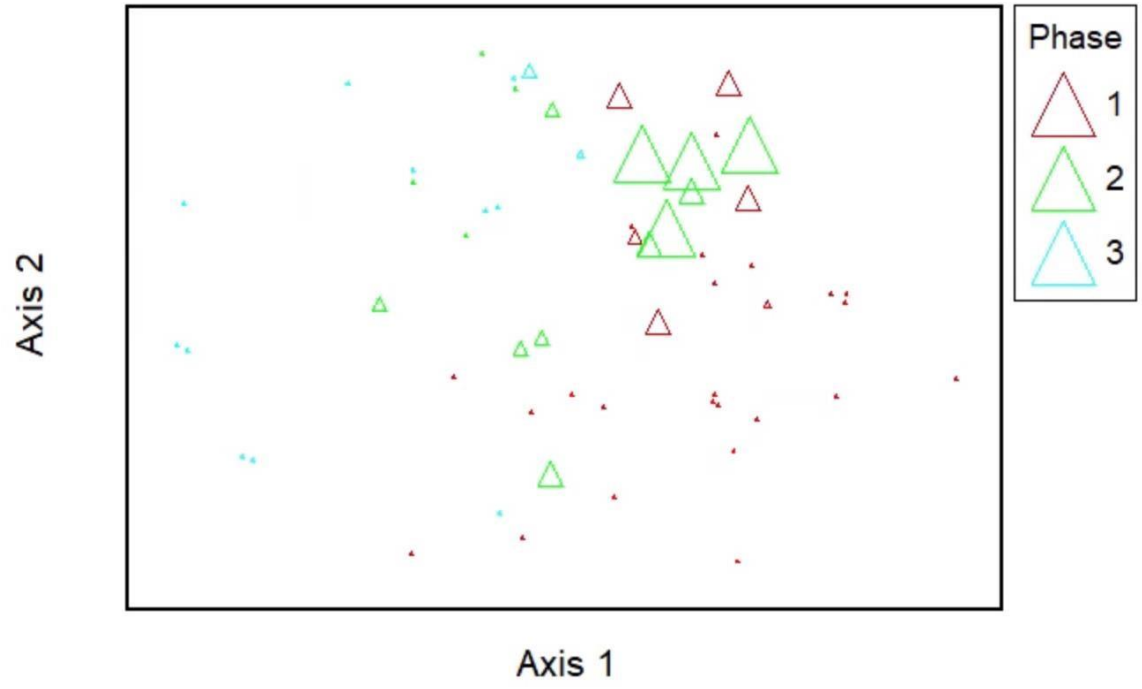


Figure 2.11 Ordination with % invasive cover per species as the primary matrix variable. The size of each section (triangle) indicates the level at which the plot's invasive cover is influenced by *Pyrus calleryana*.

2.3.4.5 Chinese privet (*Ligustrum sinense*)

Ligustrum sinense is a semi-evergreen to evergreen species that forms thickets of multistemmed plants. It is one of the most widely spread invasive plants in the Southern United States and commonly invades bottomland forests. It colonizes via root sprouts and spreads rapidly through bird and animal dispersal (Miller et al. 2015). Soil disturbances of any kind allow for colonization of *Ligustrum sinense*. This species is distinctly difficult to control because of its large seedbank and need for underground removal. Due to these characteristics it is able to displace native species and disrupt various terrestrial ecosystems (Urbatsch, n.d.). In North

Carolina it is ranked a threat level one or significant threat (NC Invasive Plant Council, 2023). *Ligustrum sinense* was found in 49 of 59 plots within the study site and was particularly impactful across Phase I, demonstrated by the larger red points and small blue and green points (Figure 2.12). This is further supported by the indicator species analysis (Table 2.3). Within the phase it appears to be largely in areas of mid to high cover by trees, shrubs, and herbs (Figure 2.6).

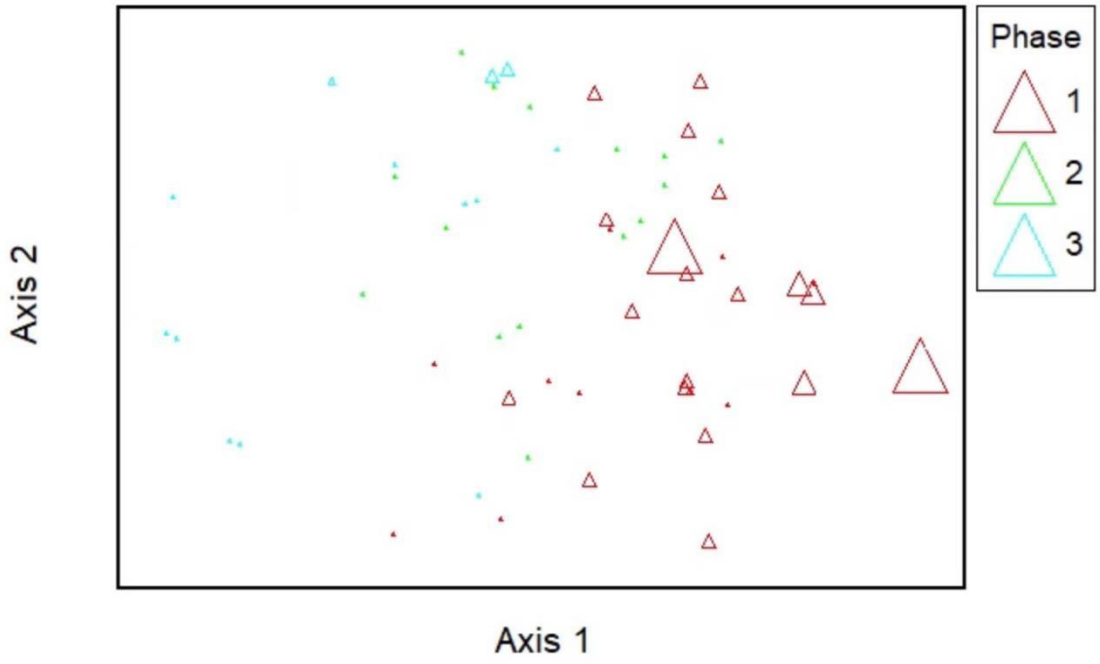


Figure 2.12 Ordination with % invasive cover per species as the primary matrix variable. The size of each section (triangle) indicates the level at which the plot's invasive cover is influenced by *Ligustrum sinense*.

2.4 Discussion

Invasive species of all growth forms (i.e. shrub, tree, vine) will invade a restoration site if given the opportunity (Figure 2.4). Moreover, invasives will dominate the plant community; in this case the invasive species comprise almost half of the stem distribution (47.1%) and over half of the overall cover (59.6%) (Figure 2.5; Table 2.1). This is true for all three phases of Rocky

Branch restoration with invasive stems covering 47.4% in Phase I, 47.7% in Phase II, and 49.5% in Phase III (Figure 2.5). The similar percentage of invasive stems across all phases demonstrates that invasive plants need to be addressed early in any project because they will invade the community and persist through stand development. The lower percentages of planted and volunteer species are due to invasive stems occupying significant space. Under different circumstances with more space available, these native species would likely be performing better within the community. Therefore, we should prioritize invasive management and control in restoration projects as the plant community develops to ensure successful establishment of the target plant community. It is interesting to note that the herbaceous cover is aligned with tree and shrub cover; thus, higher tree and shrub cover is indicative of a higher herbaceous layer as well. This is because areas with higher tree, shrub, and herbaceous cover also have higher invasive cover, suggesting that invasive species are significantly influencing cover across all strata (Figure 2.6).

The five highest-impact species within this site, and other southeastern restoration projects, are *Hedera helix*, *Ligustrum lucidum*, *Microstegium vimineum*, *Pyrus calleryana*, and *Ligustrum sinense*. These five species are unsurprising considering these are all high priority and threat level one invasive species within North Carolina (NC Invasive Plant Council, 2023). An interesting distinction is how each invades a site across different successional stages.

Hedera helix is a major driving force for invasive cover (Figure 2.8). This species is of high priority considering it covered 17.8% of the study area (2189.2 m^2) (Table 2.5). It was particularly impactful in the mid-successional closed canopy stage (Table 2.6). This aligns with their growth characteristics because they produce seeds only when they climb larger, older trees and reach openings with full sun. *Hedera helix* was also able to effectively invade Phase II since it was a mid-successional open canopy plant community. However, it did not have much impact

in the early-successional Phase III (Table 2.6). This indicates that the species is able to significantly invade in restoration sites with mid to late successional trees to climb.

Ligustrum lucidum is another high priority species that is a large driver for invasive cover and is an indicator for highly invaded plots (Figure 2.9; Figure 2.6; Appendix O). It is also a species that was planted historically and remains on the surrounding campus. It covered 1559.3 m^2 or 12.6% of the restoration site's study area (Table 2.5). Its highest impact was in Phase II, but it had significant impacts across all phases (Table 2.6). This aligns with its growth habits of forming thick understories and being tolerant to varying light levels. This equal impact is also likely why the species was not an indicator for any particular phase (Table 2.3).

Microstegium vimineum covered 593.8 m^2 or 4.8% of the study area (Table 2.5) and was primarily an issue within Phase III (Table 2.5; Figure 2.10). This species was largely an issue in the early successional phase and in areas with large canopy gaps within the other two phases. It is shade-tolerant and establishes well early on so it is surprising that it doesn't have as large of an impact comparatively within the other two phases (Fryer, 2011). However, this is likely because soil disturbance, a feature often associated with *Microstegium vimineum*, is prevalent in the narrow Phase III floodplains.

Pyrus calleryana is another species with individuals that have grown very large and take up a significant amount of space in the canopy, covering 4.1% of the study area (Table 2.5). The species has larger influence over plots from Phase II, where it's the most problematic (Figure 2.11). It is an issue in the mid-successional open canopy phase taking advantage of the openness to quickly grow up into the canopy (Table 2.6). *Pyrus calleryana* may have a foothold here because it was historically planted and remains on NC State's campus. This species is an indicator for highly invaded plots within the study site (Appendix O).

Lastly, *Ligustrum sinense* was the fifth highest impact species covering a total of 407.9 m^2 or 3.3% across the entire study area (Table 2.5). Its impact was largest in Phase I, indicated by a higher percent cover for this Phase and its biplot pointing in the direction occupied solely by Phase I plots (Table 2.6; Figure 2.12). *Ligustrum sinense* had the largest impact in the midsuccessional closed canopy stage of Rocky Branch. The shade-tolerance of the species could allow it to readily invade later successional stages of other restoration projects (U.S. Department of Agriculture, n.d.). The species is also an indicator for highly invaded plots (Appendix O).

While these species are common in restoration and are highly invasive within North Carolina, site-specific factors are also likely contributing to the level and mode of invasion. First, upstream from Phase I is a small forest patch near Gorman Street that is highly invaded by *Hedera helix* which could be a major seed source for this phase. Moreover, the area off campus west of Gorman street includes several drains and yards dominated by *Hedera helix*. Large *Ligustrum lucidum* and *Pyrus calleryana* stems on the surrounding campus serve as ready seed sources for these two invasives into the restoration project. Once again this emphasizes the importance of addressing seed sources and understanding the predisposed problems associated with a site to better understand how to manage it.

Additional species should be taken into consideration based on the successional stage. Several indicator species, or species that were indicative of that particular phase and successional stage, occur. When looking at these indicators, excluding ones that were identified as the top five highest-impact species, we observe that Phase I had *Celastrus orbiculatus* (Oriental bittersweet), *Lonicera maackii* (Amur honeysuckle), and *Morus alba* (white mulberry). These are more shadetolerant species that should be watched within closed canopy restoration projects. Phase II had many invasive indicator species; however, the three highest-impact species, as determined by cover, to target would be *Elaeagnus pungens* (thorny olive), *Reynoutria japonica* (Japanese knotweed), and *Ampelopsis glandulosa*

(porcelain berry). Since Phase II is an open canopy, the shade tolerance of these species is mixed, with *Elaeagnus pungens* and *Reynoutria japonica* being shade-tolerant while *Ampelopsis glandulosa* does not persist well in full shade and prefers more sun. While these species may not need immediate consideration, if resources permit, management to prevent and control them should also be targeted at these species in restoration projects. These are possible watchlist species based on the indicator species analysis (Table 2.3) and their overall cover (Appendix D). However, inventories should be conducted at all restoration sites to identify additional high-impact invasives that may not have been identified here, but could be invading due to other site-specific factors.

2.5 Site-Specific Recommendations

For Rocky Branch, it is important that Land Management Operations at NC State address invasive plant seed sources if possible, especially the seed source for *Hedera helix* located near Gorman street. Furthermore, an effort to remove known *Ligustrum lucidum* and *Pyrus calleryana* stems should occur across campus to reduce inputs into the site. It doesn't appear that *Microstegium vimineum* or *Ligustrum sinense* are on other parts of campus, but this should be confirmed. Invasive populations of these species should be located and mapped across NC State's campus for ease of planning and subsequent removal, similar to the DMS annual mitigation monitoring reports. A bottom-up layered approach to management has been recommended for invaded stream and wetland restoration sites. This essentially just means treating the herbaceous layer first, followed by shrub and tree. This is because a top-down layered approach – starting with trees and working your way down – creates gaps once invasive species have been removed from the canopy and overstory that allow for the fast-growing herbaceous species to invade. Therefore, it is important to establish native grasses in the herbaceous layer before removing overstory and canopy shrubs and trees (Gough, 2023). Therefore, *Hedera helix* and *Microstegium vimineum* should be targeted first for removal within

our study site because they comprise the herbaceous layer. Furthermore, it is important to note differences between particular native and invasive species and take advantage of pre-emergent spraying (e.g. annual versus perennial species) (Lovenshimer, 2023).

For *Hedera helix*, it is particularly important to first target the vines that are on trees before removing it on the ground because these tree-climbing vines are the biggest contributors to its spread. Removing *Hedera helix*, involves thoroughly wetting all leaves with herbicide in water with a surfactant. To improve the herbicide's effectiveness, a string trimmer is recommended to reduce growth and injure leaves. For larger vines, cutting them and applying herbicides directly to the surfaces or applying basal sprays, being careful to avoid the bark of the trees, has proven effective (Miller et al. 2015). Native alternatives to this species could include *Bignonia capreolata* (crossvine), *Parthenocissus quinquefolia*, and *Polystichum acrostichoide*s (Christmas fern) (City of Raleigh, n.d).

For *Microstegium vimineum*, herbicide application and mowing treatments are key to preventing seed production. Mowing should be done in late summer months because when cut early in the summer, plants regrow and flower earlier than normal (Plant Conservation Alliance's Alien Plant Working Group, 2008). Hand pulling followed by herbicide applications allows for greater plant diversity compared to herbicide treatments alone. Repeated hand pulling may be necessary to keep the desired level of diversity (Miller et al. 2015). However, the need for hand pulling can be determined on a case-by-case basis depending on the surrounding vegetation and its value to the plant community. If revegetation is done, native alternatives to this species could include *Carex* spp. (sedges), *Chasmanthium latifolium* (river oat), and *Impatiens capensis* (orange jewelweed) (Durham Master Gardeners, 2018).

After addressing these two high-priority herbaceous layer species, the understory and canopy control can start with *Ligustrum sinense* because it grows lower in the understory at

about 6–15 ft (North Carolina Extension Gardener Plant Toolbox, n.d.-a). For this species foliar spray of smaller individuals and basal spray or stem injections to larger ones is recommended (Miller et al. 2015). If revegetation is done, native alternatives to this species could include *Ilex decidua* (deciduous holly), *Ilex opaca*, *Morella cerifera*, and *Viburnum* spp. (City of Raleigh, n.d.).

Ligustrum lucidum would be the next species in the bottom-up approach as it reaches heights of 25–40 ft (Gilman & Watson, 1993). Foliar spray should be applied to dense thickets of Ligustrum lucidum; however, herbicide spray should be applied to notched bark or cut stumps for larger individuals (University of Florida Center for Aquatic and Invasive Plants, n.d.). If revegetation is done, native alternatives to this species could include *Ilex decidua* (deciduous holly), *Ilex opaca*, *Morella cerifera*, and *Viburnum* spp. (City of Raleigh, n.d.).

Pyrus calleryana would be the last species to target because it reaches heights of 50 ft (North Carolina Extension Gardener Plant Toolbox, n.d.-b). For Phase II it was found to occupy a large portion of the canopy within the plots it is found in. Foliar spray is recommended for seedlings while basal spray applications are recommended for saplings. Larger stems should be cut and herbicide should be directly applied on the stump tops (Miller et al. 2015). If revegetation is done, native alternatives to this species could include *Amelanchier arborea* (downy serviceberry), *Benthamidia florida* (flowering dogwood), and *Cercis canadensis*

(redbud) (City of Raleigh, n.d.).

If there are concerns about the removal of these invasive species destabilizing the stream via soil erosion, girdling is recommended to retain the plant's root systems until more native plants are put in and provide further stabilization (Gough, 2023). Girdling is most effective for species without resprouting capabilities. When using this technique on species that can resprout, resprouts will need to be cut repeatedly to exhaust energy stored in the roots (Pynn et al. n.d.).

Another consideration for this site is that the restoration project runs through the heart of a college campus. There is potential to engage students with invasive species removal and replanting efforts. This type of activity has already been adopted by several courses and programs. For instance, in the dendrology course, undergraduate students cut and certified staff treat *Elaeagnus umbellata* and *Elaeagnus pungens* stems at the NC State University-owned Schenck Forest as a service project. Students in a larger introductory environmental lab cut *Ligustrum sinense* stems at the Walnut Creek Wetland Park while certified volunteers and staff treated the stumps. In addition, environmental clubs or living villages (i.e. EcoVillage) that focus on sustainability have completed similar service projects, such as removing *Ampelopsis glandulosa* on Phase III of Rocky Branch (Jeffries S., Personal Communication, 2024). Other restoration sites have also utilized student assistance. For instance, students planted over 120 riparian plants, removed 900 gallons of invasive species, and stabilized 200 linear feet of stream bank at Snyder Branch Creek in Salem, Virginia (Peters & Spaulding, 2023). This project was symbiotic for the community that gained education on the ecological importance of the area, the stream channel restoration, and management crews that received assistance with managing the plant community. Engaging with students also supports a primary goal of the restoration project for Rocky Branch of serving as an outdoor learning lab (Sea Grant North Carolina, 2010). An introductory environmental science course at NC State is currently planning to engage students in a removal of *Hedera helix* in an effort to support the bottom-up approach.

In addition to the five primary target species, there is a small, robust patch of dense *Phyllostachys aurea* (golden bamboo) on one side of the floodplain. While this isn't a large concern now, the species is crowding out other species and will continue to spread densely until addressed. To avoid a more expensive removal effort in the future, this needs to be addressed soon (Higgins et al. 2000). The area should be bulldozed and root raked to remove root crowns

and rhizomes, which should be piled and burned. Repeated cutting to the ground will not yield control but can be more effective when herbicide is applied to resprouts (Miller et al. 2015).

Lastly, this study can also assist with adding species to NC State's Do Not Plant List or identify species on the planting list for campus that might have invasive tendencies/status. For example, *Ulmus parvifolia* (Chinese elm) was a species found to be problematic in this site, particularly in Phase I, and it is a species planted around campus. Another species that was also disruptive was *Liriope spicata* (creeping lilyturf) which is also planted. To prevent further invasion species like this should not be planted.

2.6 Conclusions

For stream restoration efforts, it is critical to allocate adequate funding to properly manage the site to continuously ensure that the planted and volunteer species have more time to grow and develop. Species should be dealt with on the front end to ensure plant community development by managing nearby seed sources, pre- and post-treatments of the site, and following mitigation guidelines of mapping and eradicating known invasive populations before they get out of control. Early invasive management as the plant community establishes will have the largest impact; however, continued vigilance is recommended as there are several shadetolerant species that are prone to invade later-successional stages.

Resources should be first dedicated to the highest-impact invasive species. For southeastern stream restoration projects, these include *Hedera helix*, *Ligustrum lucidum*, *Microstegium vimineum*, *Pyrus calleryana*, and *Ligustrum sinense*. These species should be the primary targets of invasive control and if these species aren’t present, effort should be made to prevent their establishment. Before a project begins, care should be taken to ensure that these species are not planted or established in or near the restoration site. If they are present, control to prevent significant seed formation is recommended (Miller et al. 2015). Additional species to

consider for control include *Elaeagnus pungens* and *Reynoutria japonica* and *Ampelopsis glandulosa* within mid-successional open canopy plant communities and *Lonicera maackii* and *Morus alba* in mid-successional closed canopy plant communities should also be considered as they can also have high-impacts and extensive coverage of a restoration site (Table 2.3; Appendix D).

If the site is older and is already heavily invaded, herbicide applications and manual removals of the targeted species should be implemented to control the population and work towards potential eradication. A bottom-up approach will ensure the herbaceous invasives don't take advantage of canopy gaps and further invade the site. Replanting should occur post treatment in order to fill back in the gaps. If soil erosion is a concern it is recommended to girdle to maintain root systems until the replantings take hold (Gough, 2023). If the site is newer and still within the seven-year mitigation monitoring period then inventorying, mapping, and treating known invasions is important. Once a project reaches long-term management no invasive monitoring or removal activities are required. However, if possible, it's recommended that these activities continue to ensure the restoration project doesn't become invaded by a predominant invasive population or stem distribution like what has occurred at Rocky Branch (Figure 2.5).

2.6 Further Research

First, the feasibility of incorporating vegetation surveys into the long-term management phase for mitigation projects – specifically with regards to continued invasive population identification and appropriate treatment measures – should be evaluated. Second, it would be beneficial to document and understand how the plant communities respond to any invasive species control, removal, or other vegetation maintenance changes implemented at Rocky Branch. Testing and comparing various invasive species removal and control approaches in different phases of the restored stream could help to determine which methods work. This effort

could also inform best practices for invasive species removal on comparable restoration sites, especially at sites experiencing invasion over a longer time. Future projects should also consider the volunteer non-native species that were identified at Rocky Branch (Appendix P) as these species were neither indicated as being native to the area nor were they listed on the North Carolina Invasive Plant Council's list. These species could become a problem down the road. Early analysis and control of these species could prevent them from becoming prominent future invasives.

REFERENCES

Brinkley, L.L., Allen, R.T., & Derrick, B.B. (1914). Soil Survey of Wake County, North Carolina (pp. 517-557). In Field Operations of the Bureau of Soils, 1914. United States Department of Agriculture.

Center for Invasive Species and Ecosystem Health. (n.d.). *Glossy privet, Ligustrum lucidum*. Retrieved February 29, 2024, from https://www.invasive.org/browse/subinfo.cfm?sub=5942

City of Raleigh. (n.d.). *Invasive Species Program*. City of Raleigh Parks, Recreation, and Cultural Resources.

https://cityofraleigh0drupal.blob.core.usgovcloudapi.net/drupalprod/COR24/invasive-species-native-alternatives.pdf

Culley, T. M., & Hardiman, N. A. (2007). The Beginning of a New Invasive Plant: A History of the Ornamental Callery Pear in the United States. *BioScience*, *57*(11), 956–964. https://doi.org/10.1641/B571108

Davis, M. A. (2003). Biotic Globalization: Does Competition from Introduced Species Threaten Biodiversity? *BioScience*, *53*(5), 481. https://doi.org/10.1641/0006-3568(2003)053[0481:BGDCFI]2.0.CO;2

Doll, B., Jenkins, J., Patterson, J., Coleman, J., Jennings, G., Buckner, C., & Mayes, D. (2004). Urban Stream Restoration Using a Natural Channel Design Approach. *Protection and Restoration of Urban and Rural Streams*. Symposium on the Protection & Restoration of Urban and Rural Streams: American Society of Civil Engineers. https://doiorg.prox.lib.ncsu.edu/10.1061/40695(2004)31

Duda, A., Lenat, D., & Penrose, D. (1978). *Water Quality Degradation in Urban Streams of the Southeast: Will Non-Point Source Controls Make Any Differences?* 151–159.

Durham Master Gardeners. (2018, November 21). *Plant List of Native Alternatives to Invasive Species*. Extension Master Gardener Volunteers of Durham County. https://durhammastergardeners.com/2018/11/21/plant-list-of-native-alternativesto-invasive-species/

Evans, C.W., Moorhead, D.J., Bargeron, C.T., & Douce, G.K. (2006). *Invasive plant responses to silvicultural practices in the South*. Bugwood Network BW-2006-03. Tifton, GA: The University of Georgia Bugwood Network. https://www.invasive.org/silvicsforinvasives.pdf

Fernandez, R. D., Ceballos, S. J., Aragón, R., Malizia, A., Montti, L., Whitworth-Hulse, J. I., Castro-Díez, P., & Grau, H. R. (2020). A Global Review of Ligustrum Lucidum (OLEACEAE) Invasion. *The Botanical Review*, *86*(2), 93–118. https://doi.org/10.1007/s12229-020-09228-w

Fryer, J. L. (2011). *Microstegium vimineum*. In *Fire Effects Information System*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. Retrieved February 29, 2024, from https://www.fs.usda.gov/database/feis/plants/graminoid/micvim/all.html

Funk, J., Cleland, E., Suding, K., & Zavaleta, E. (2008). Restoration through reassembly: plant traits and invasion resistance. *Trends in Ecology & Evolution* 23(12): 695-703. https://doi.org/10.1016/j.tree.2008.07.013

Gilman, E., & Watson, D. (1993). *Ligustrum lucidum Glossy Privet*. U.S. Forest Service.

Gosper, C. R., Stansbury, C. D., & Vivian-Smith, G. (2005). Seed dispersal of fleshy-fruited invasive plants by birds: contributing factors and management options. *Diversity and Distributions*, *11*(6), 549–558. https://doi.org/10.1111/j.1366-9516.2005.00195.x

Gough, S. (2023, November 16). *Managing Invasives Across an Urban Landscape*. NC Invasive Plant Council Annual Meeting.

Hammer, C. & Gunn, J. (2021). Planting native trees to restore riparian forests increases biotic resistance to nonnative plant invasions. *Invasive Plant Science and Management* 14(2): 126-133. https://doi-org.prox.lib.ncsu.edu/10.1017/inp.2021.11

Harman, W., & Starr, R. (2011). *Natural Channel Design: REVIEW CHECKLIST* (p. 20). U.S. Fish and Wildlife Service, Chesapeake Bay Field Office, Annapolis, MD and U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Wetlands Division.

Higgins, S. I., Richardson, D. M., & Cowling, R. M. (2000). USING A DYNAMIC LANDSCAPE MODEL FOR PLANNING THE MANAGEMENT OF ALIEN PLANT INVASIONS. *Ecological Applications*, *10*(6), 1833–1848. https://doi.org/10.1890/1051-0761(2000)010[1833:UADLMF]2.0.CO;2

Invasive Plant Atlas of the United States. (n.d.). *Glossy privet: Ligustrum lucidum*. Invasive Plant Atlas of the United States. Retrieved February 29, 2024, from https://www.invasiveplantatlas.org/subject.html?sub=5942

Isabel, C.R., Álvaro, A., & Pilar, C.D. (2014). Does stream structure affect dispersal by water? A case study of the invasive tree *Ailanthus altissima* in Spain. *Management of Biological Invasions* 5(2): 179-186. http://doi.org/10.3391/mbi.2014.5.2.11

Jennings, G. (2003). *Stream Restoration Case Studies in North Carolina* [Proceedings]. https://repository.gatech.edu/server/api/core/bitstreams/b4b08508-0416-4078-bc94f37a67c89851/content

Kolar, C. & Lodge, D. (2001). Progressing invasion biology: Predicting invaders. Trends in *Ecology & Evolution*. 16(4): 199-204. https://doi.org/10.1016/s0169-5347(01)02101-2

Kuglerová, L., Kielstra, B. W., Moore, R. D., & Richardson, J. S. (2019). Importance of scale, land-use, and stream network properties for riparian plant communities along an urban gradient. *Freshwater Biology*, *64*(3), 587–600. https://doi.org/10.1111/fwb.13244

Lovenshimer, J. (2023, November 16). *Invasive Plant Management Strategies for Stream and Wetland Restoration Sites*. NC Invasive Plant Council Annual Meeting.

Miller, J., Manning, S., & Enloe, S. (2015). *A Management Guide for Invasive Plants in Southern Forests* [General Technical Report]. United States Department of Agriculture, Forest Service, Southern Research Station. https://www.srs.fs.usda.gov/pubs/gtr/gtr_srs131.pdf

NC Invasive Plant Council. (2023). *Invasive List July 2023*. https://docs.google.com/document/d/1YY7k_an4qco-mcKQZSV1CBYbzw-6ihe_/edit?usp=sharing&ouid=106723197835414326092&rtpof=true&sd=true&usp=embed_facebook

Sea Grant North Carolina. (2010a). *ROCKY BRANCH - PHASE 1 STREAM RESTORATION 2007 FINAL MONITORING REPORT* [Monitoring Report]. North Carolina Department of Transportation.

Sea Grant North Carolina. (2010b). *Rocky Branch Stream Restoration and Greenway Project*. https://ncseagrant.ncsu.edu/ncseagrant_docs/products/2010s/rocky_branch_projectsummary.pdfNC State Biological and Agricultural Engineering Department. (n.d.). *Piedmont Riparian Species*. https://www.bae.ncsu.edu/wpcontent/uploads/2017/07/piedmont_riparian_species.pdf

NC State Biological and Agricultural Engineering Department. (n.d.). *Piedmont Riparian Species*. https://www.bae.ncsu.edu/wpcontent/uploads/2017/07/piedmont_riparian_species.pdf

New York Department of Environmental Conservation. (n.d.). *Managing Invasive Plants in Riparian Areas*. https://extapps.dec.ny.gov/docs/lands_forests_pdf/tftismg17.pdf

North Carolina Department of Environmental Quality. (2017). *Division of Mitigation Services Stream and Wetland Mitigation Plan Template and Guidance*. https://www.deq.nc.gov/mitigation-services/document-management-library/guidanceand-template-documents/mitigation-plan-components/10-mitplan-june-2017/download

North Carolina Extension Gardener Plant Toolbox. (n.d.-a). *Ligustrum sinense (Chinese Privet)*. North Carolina Extension Gardener Plant Toolbox. Retrieved February 29, 2024, from https://plants.ces.ncsu.edu/plants/ligustrum-sinense/

North Carolina Extension Gardener Plant Toolbox. (n.d.-b). *Pyrus calleryana (Bradford Pear, Callery "Bradford" Pear, Callery Pear)*. North Carolina Extension Gardener Plant Toolbox. Retrieved February 29, 2024, from https://plants.ces.ncsu.edu/plants/pyruscalleryana/#:~:text=Callery%20pear%20is%20a%20dense,is%20full%20of%20white%2 0blossoms.

Nunez-Mir, G., Liebhold, A., Guo, Q., Brockerhoff, E., Jo, I., Ordonez, K., & Fei, S. (2017). Biotic resistance to exotic invasions: its role in forest ecosystems, confounding artifacts, and future directions. *Biological Invasions* 19: 3287-3299. https://doiorg.prox.lib.ncsu.edu/10.1007/s10530-017-1413-5

Peet, R. K., Palmquist, K. A., Wentworth, T. R., Schafale, M. P., Weakley, A. S., & Lee, M. T. (2018). Carolina Vegetation Survey: an initiative to improve regional implementation of the U.S. National Vegetation Classification. *Phytocoenologia*, *48*(2), 171–179. https://doi.org/10.1127/phyto/2017/0168

Peters, C. N., & Spaulding, C. N. (2023). An on-campus stream restoration project as interdisciplinary senior capstone experience. *Journal of Environmental Studies and Sciences*, *13*(1), 115–123. https://doi.org/10.1007/s13412-022-00804-7

Plant Conservation Alliance's Alien Plant Working Group. (2008). *Fact Sheet: Japanese Stiltgrass*. https://nc-ipc.weebly.com/uploads/6/8/4/6/6846349/microstegium.pdf

Pynn, S., Beitz, P., & Moore, K. (n.d.). *Girdling | Methods for Managing Weeds in Wildlands*. Weed Control User Tool. Retrieved March 19, 2024, from https://weedcut.ipm.ucanr.edu/management-practices/girdling/#gsc.tab=0

Schnitzler, Annik. (1995). Community ecology of arboreal lianas in gallery forests of the Rhine Valley, France. Acta Oecologica. 16. 219-236.

Semedo, M.-H., & Junod, M. (2020, January 24). *Soil: the foundation of life on Earth*. John Innes Centre. https://www.jic.ac.uk/advances/soil-the-foundation-of-life-on-earth/

Shea, K. & Chesson, P. (2002). Community ecology theory as a framework for biological invasions. *Trends in Ecology & Evolution* 17(4): 170-176. https://doi.org/10.1016/S0169-5347(02)02495-3

Silver, D., & Ruth, C. (n.d.). *Riparian Plants for Stream Stabilization*. NC State and AT&T Cooperative Extension. https://henderson.ces.ncsu.edu/wpcontent/uploads/2015/06/Riparian-Plants-for-Stream-Bank-Stabilization.pdf?fwd=no

Soll, J. (2005). *Controlling English Ivy (Hedera helix) in the Pacific Northwest*. Center for Invasive Species and Human Health, Nature Conservancy. https://www.invasive.org/gist/moredocs/hedhel02.pdf

Swearingen, J.M. (1999). Japanese stilt grass: Microstegium vimineum (Trin.) Camus. National Park Service, Plant Conservation Alliance, Alien Plant Working Group.

Tickner, D., Angold, P., Gurenell, A., & Mountford, O. (2001). Riparian plant invasions: hydrogeomorphological control and ecological impacts. *Progress in Physical Geography* 25(1): 22-52. https://doi.org/10.1177/030913330102500102

The Biota of North America Program. (n.d.). *North American Vascular Flora*. The Biota of North America Program. Retrieved February 28, 2024, from http://www.bonap.org/

Tugwell, T. (2016). *Notification of Issuance of Guidance for Compensatory Stream and Wetland Mitigation Conducted for Wilmington District*. U.S. Army Corps of Engineers Wilmington District.

University of Florida Center for Aquatic and Invasive Plants. (n.d.). *Ligustrum lucidum*. Retrieved February 29, 2024, from https://plants.ifas.ufl.edu/plant-directory/ligustrumlucidum/#:~:text=For%20smaller%20infestations%20or%20areas,provide%20some%20l evel%20of%20management.

Urbatsch, L. (n.d.). *Plant Guide: CHINESE PRIVET*. U.S. Department of Agriculture Natural Resources Conservation Service.

US Army Corps of Engineers Wilmington District, & NC Department of Environmental Quality. (n.d.). *NORTH CAROLINA'S STREAM MITIGATION PROGRAM*. https://www.nawm.aswm.org/pdf_lib/nc_mitigation_program.pdf

U.S. Department of Agriculture. (n.d.). *Ligustrum spp.:* Fire Effects Information System (FEIS).

U.S. Department of Agriculture, Bureau of Soils. (1914). Soil survey of North Carolina. Retrieved February 28, 2024, https://dc.lib.unc.edu/cdm/ref/collection/ncmaps/id/301

U.S. Fish & Wildlife Service. (2020). *Japanese Stiltgrass (Microstegium vimineum) Ecological Risk Screening Summary*. https://www.fws.gov/sites/default/files/documents/Ecological-Risk-Screening-Summary-Japanese-Stiltgrass.pdf

Vascular Plants of North Carolina. (n.d.). *Vascular Plants of North Carolina*. Retrieved February 28, 2024, from https://auth1.dpr.ncparks.gov/flora/index.php

Vidra, R., Shear, T., & Wentworth, T. (2006). Testing the Paradigms of Exotic Species Invasion in Urban Riparian Forests. Natural Areas Journal 26(4): 339-350. https://doiorg.prox.lib.ncsu.edu/10.3375/0885-8608(2006)26[339:TTPOES]2.0.CO;2

Violin, C. R., Cada, P., Sudduth, E. B., Hassett, B. A., Penrose, D. L., & Bernhardt, E. S. (2011). Effects of urbanization and urban stream restoration on the physical and biological structure of stream ecosystems. *Ecological Applications*, *21*(6), 1932–1949.

https://www.jstor.org/stable/41416629

Vogt, J. T., Coyle, D. R., Jenkins, D., Barnes, C., Crowe, C., Horn, S., Bates, C., & Roesch, F. A. (2020). Efficacy of five herbicide treatments for control of *Pyrus calleryana*. *Invasive Plant Science and Management*, *13*(4), 252–257. https://doi.org/10.1017/inp.2020.36

Waggy, M. (2010). *Hedera helix* [U.S. Department of Agriculture]. Fire Effects Information System (FEIS).

Weidlich, E., Flórido, F., Sorrini, T., & Brancalion, P. (2020). Controlling invasive plant species in ecological restoration: A global review. *Journal of Applied Ecology* 57(9): 1806-1817. British Ecological Society. https://doi-org.prox.lib.ncsu.edu/10.1111/1365-2664.13656

Woods, M., Cobb, M., Hickle, K., & McEwan, R. (2019). Assessing the Efficacy of Seedling Planting as a Forest Restoration Technique in Temperate Hardwood Forests Impacted by Invasive Species. *Forests* 10(8): 699. https://doi.org/10.3390/f10080699

APPENDICES

Appendix A. Recommended planting table (NC State Biological and Agricultural Engineering Department, n.d.; Silver & Ruth, n.d.)

Tree		Shrub		Herb	
Common Name	Scientific Name	Common Name	Scientific Name	Common Name	Scientific Name
Southern sugar maple	*Acer floridanum*	Red buckeye	*Aesculus pavia*	Big bluestem	*Andropogon gerardii*
Box elder	*Acer negundo*	Painted buckeye	*Aesculus sylcatica*	River cane	*Arundinaria gigantea*
Red maple	*Acer rubrum*	Smooth alder	*Alnus serrulata*	Jack-in-the-pulpit	*Asclepias incarnata*
Yellow buckeye	*Aesculus ocandra*	Downy serviceberry	*Amelanchier arborea*	Lady fern	*Athyrium filix femina*
Cherry birch	*Betula lenta*	Shadbush serviceberry	*Amelanchier canadensis*	Beggartick	*Bidens frondosa*
River birch	*Betula nigra*	Red chokeberry	*Aronia arbutifolia*	Fringed sedge	*Carex crinata*
Ironwood	*Carpinus caroliniana*	Pawpaw	*Asimina triloba*	Bladder sedge	*Carex intumescens*
Bitternut hickory	*Carya cordiformis*	Beautyberry	*Callicarpa americana*	Hop sedge	*Carex lupulina*
Shagbark hickory	*Carya ovata*	Carolina allspice	*Calycanthus floridus*	Lurid sedge	*Carex lurida*
Sugar berry	*Celtis laevigata*	Buttonbush	*Cephalanthus occidentalis*	Broom sedge	*Carex scoparia*
Alternate leaf dogwood	*Cornus alternifolia*	Clethra	*Clethra acuminada*	Tussock sedge	*Carex stricta*
Cockspur hawthorn	*Crataegus crusgali*	Sweet pepperbush	*Clethra alnifolia*	Fox sedge	*Carex vulpinoidea*
Persimmon	*Diospyros virginiana*	Hazel-nut	*Corylus americana*	River oats	*Chasmanthium latifolium*
Green ash	*Fraxinus pennsylvanica*	Titi	*Cyrilla racemiflora*	Turtlehead	*Chelone glabra*
Silverbell	*Halesia caroliniana*	American strawberry bush	*Euonymus americanus*	Umbrella sedge	*Cypernus strigosus*
Witch-hazel	*Hamamelis virginiana*	Dwarf witch-alder	*Fathergilla gardenii*	Bottlebrush grass	*Elymus hystrix*
Black walnut	*Juglans nigra*	Marsh mallow	*Hibiscus moscheutos*	Joe-pye-weed	*Eupatorium fistulosum*
Spicebush	*Lindera benzoin*	Deciduous holly	*Ilex decidua*	Boneset	*Eupatorium perfoliatum*
Tulip-poplar	*Liriodendron tulipifera*	Inkberry	*Ilex glabra*	Common sneezeweed	*Helenium autumnale*
Sweetbay	*Magnolia virginiana*	Winterberry	*Ilex verticillata*	Purplehead sneezeweed	*Helenium flexuosum*
Umbrella tree	*Magonila tripetala*	Virginia sweetspire	*Itea virginica*	Swamp sunflower	*Helianthus angustifolius*
Water tupelo	*Nyssa aquatica*	Doghobble	*Leuocothoe axillaris*	Soft rush	*Juncus effusus*
Swamp tupelo	*Nyssa biflora*	Male-berry	*Lyonia ligustrina*	Poverty rush	*Juncus tenuis*
Black gum	*Nyssa sylvatica*	Wax myrtle	*Morella cerifera*	Rice cutgrass	*Leersia oryzoides*
Sycamore	*Platanus occidentalis*	Ninebark	*Physcocarpus opulifolius*	Cardinal flower	*Lobelia cardinalis*
Eastern cottonwood	*Populus deltoides*	Rhododendron	*Rhododendron maximum*	Longleaf lobelia	*Lobelia elongata*
Black cherry	*Prunus serotina*	Wild azalea	*Rhododendron periclymenoides*	Great blue lobelia	*Lobelia siphilitica*
Overcup oak	*Quercus lyrata*	Swamp azalea	*Rhododendron viscosum*	Bushy seedbox	*Ludwigia alternifolia*
Swamp chestnut oak	*Quercus michauxii*	Swamp rose	*Rosa palustris*	Monkeyflower	*Mimulus ringens*
Cherrybark oak	*Quercus pagoda*	American elderberry	*Sambucus canadensis*	Deertongue	*Panicum clandestinum*
Shumard oak	*Quercus shumardii*	Steeplebush	*Spiraea tomentosa*	Switchgrass	*Panicum virgatum*
Black willow	*Salix nigra*	Meadowsweet	*Spirea latifolia*	Obedient plant	*Physostegia virginiana*
Silky willow	*Salix sericea*	Steeple bush	*Spirea tomentosa*	Tearthumb	*Polygonum sagittatum*
Bald cypress	*Taxodium distichum*	Sweet leaf	*Staphlea trifolia*	Christmas fern	*Polystichum acrostichoides*
White basswood	*Tilia heterophylla*	American snowbell	*Styrax americanus*	Bigleaf mountainmint	*Pycanthemum muticum*
		Silky dogwood	*Swida amomum*	Narrowleaf mountainmint	*Pycanthemum tenuifolium*
		Horse sugar	*Symplocos tinctoria*	Maryland meadowbeauty	*Rhexia mariana*
		Highbush blueberry	*Vaccinium corymbosum*	Virginia meadowbeauty	*Rhexia virginica*
		Southern arrowwood	*Viburnum dentatum*	Cutleaf coneflower	*Rudbeckia laciniata*
		Witherod	*Viburnum nudum*	Green bulrush	*Scirpus atrovirens*
				Woolgrass	*Scirpus cyperinus*
				Soft stem bulrush	*Scripus validus*
				Indiangrass	*Sorghastrum nutans*
				Bur-reed	*Sparganium americanum*
				New York aster	*Symphytotrichum novi-belgii*
				Marsh fern	*Thelypteris palustris*
				Ironweed	*Vernonia noveboracensis*
				Yellow-root	*Xanthorhiza simplicissima*

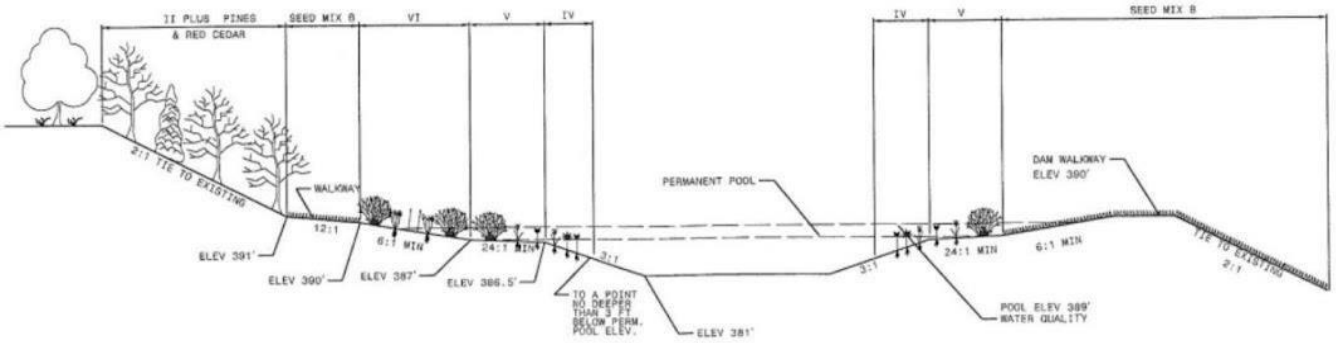
Appendix B. Rocky Branch Planting Lists for Phase I, II, and III.

PHASE I		
	Common Name	Scientific Name
NARROW FLOODPLAIN	River birch	*Betula nigra*
	Hackberry	*Celtis laevigata*
	Yellow poplar	*Liriodendron tulipifera*
	Sycamore	*Platanus occidentalis*
	Swamp chestnut oak	*Quercus michauxii*
	Pawpaw	*Asimina triloba*
	Ironwood	*Carpinus caroliniana*
	Flowering dogwood	*Cornus florida*
	Possumhaw	*Ilex decidua*
	Spicebush	*Lindera benzoin*
	Pinxter-flower	*Rhododendron periclymenoides*
	Blackhaw	*Viburnum nudum*
	Yellowroot	*Xanthorhiza simplicissima*
GENTLE SLOPE FOREST	Mockernut hickory	*Carya alba*
	Pignut hickory	*Carya glabra*
	Green ash	*Fraxinus pennsylvanicum*
	Yellow poplar	*Liriodendron tulipifera*
	Black gum	*Nyssa sylvatica*
	White oak	*Quercus alba*
	Northern red oak	*Quercus rubra*
	Black oak	*Quercus velutina*
	Downy serviceberry	*Amelanchier arborea*
	Redbud	*Cercis canadensis*
	Fringe tree	*Chionanthus virginicus*
	Flowering dogwood	*Cornus florida*
	Witch-hazel	*Hamamelis virginiana*
	Umbrella magnolia	*Magnolia tripetala*
	Sourwood	*Oxydendrum arboreum*
	Eastern sweetshrub	*Calycanthus floridus*
	American strawberry bush	*Euonymus americana*
	Wax myrtle	*Myrica cerifera*
UPLAND OAK-HICKORY	Mockernut hickory	*Carya alba*
	White oak	*Quercus alba*
	Southern red oak	*Quercus falcata*
	Northern red oak	*Quercus rubra*
	Black oak	*Quercus velutina*
	Flowering dogwood	*Cornus florida*
	Common persimmon	*Diospyros virginiana*
	American holly	*Ilex opaca*
	Sassafras	*Sassafras albidum*
	Sparkleberry	*Vaccinium arboreum*
SHRUB	Hop sedge	*Carex lupulina*
	Blunt spikerush	*Eleocharis obtusa*
	Soft rush	*Juncus effusus*
	Marsh fern	*Thelypteris palustris*
	Buttonbush	*Cephalanthus occidentalis*
	Fetterbush	*Lyonia lucida*
SEED MIX A	Giant Cane	*Arundinaria gigantea*
	Hop Sedge	*Carex lupulina*
	Virginia Wildrye	*Elymus virginicus*
	Joe Pye Weed	*Eupatorium fistulosum*
	Bottle-brush Grass	*Hystrix patula*
	Virginia Willow	*Itea virginica*
	Soft Rush	*Juncus effusus*
	Rice Cut Grass	*Leersia oryzoides*
	Cardinal Flower	*Lobelia cardinalis*
	Deertongue	*Panicum clandestinum*
	Switchgrass	*Panicum virgatum*
	Three-square Bulrush	*Scirpus americanus*
	Woolgrass	*Scirpus cyperinus*
	River Oats	*Uniola latifolia*
SEED MIX B	Annual rye	*Lolium multiflorum*
	Browntop Millet	*Panicum ramosum*
	Broomsedge	*Andropogon virginicus*
	Little bluestem	*Andropogon scoparius*
LIVE STAKES	Silky Dogwood	*Cornus amomum*
	Black Willow	*Salix nigra*
	American Elderberry	*Sambucus canadensis*

PHASE II		
	Common Name	Scientific Name
NARROW FLOODPLAIN	River birch	*Betula nigra*
	Hackberry	*Celtis laevigata*
	Yellow poplar	*Liriodendron tulipifera*
	Black gum	*Nyssa sylvatica*
	Black gum	*Nyssa sylvatica*
	Sycamore	*Platanus occidentalis*
	Sycamore	*Platanus occidentalis*
	Swamp chestnut	*Quercus michauxii*
	Bald cypress	*Taxodium distichum*
	Hawthorn	*Crataegus distichum*
	Ironwood	*Carpinus Caroliniana*
	Flowering dogwood	*Cornus florida*
	Possumhaw	*Ilex decidua*
	Spicebush	*Lindera benzoin*
	Pinxter-flower	*Rhododendron periclymenoides*
	Blackhaw	*Viburnum nudum*
	Virginia creeper	*Parthenocissus quinquefolia*
GENTLE SLOPE FOREST	Mockernut hickory	*Carya alba*
	Pignut hickory	*Carya glabra*
	Green ash	*Fraxinus pennsylvanicum*
	Spicebush	*Lindera benzoin*
	Black gum	*Nyssa sylvatica*
	White oak	*Quercus alba*
	Southern red oak	*Quercus falcata*
	Northern red oak	*Quercus rubra*
	Black oak	*Quercus velutina*
	Downy serviceberry	*Amelanchier arborea*
	Redbud	*Cercis canadensis*
	Fringe tree	*Chionanthus virginicus*
	Flowering dogwood	*Cornus florida*
	Witch-hazel	*Hamamelis virginicus*
	Umbrella magnolia	*Magnolia tripetala*
	sourwood	*Oxydendrum arboreum*
	American strawberry bush	*Euonymus americana*
	Wax myrtle	*Myrica cerifera*
FLOODPLAIN POOL	Green arrow-arum	*Peltandra virginica*
	Pickerelweed	*Pontederia latifolia*
	Broadleaf arrowhead	*Sagittaria latifolia*
	Lizard-tail	*Saururus cernuus*
	Fringe sedge	*Carex crinita*
	Hop sedge	*Carex lupulina*
	Blunt spikerush	*Eleocharis obtusa*
	Leathery rush	*Juncus coriaceus*
	Soft rush	*Juncus effusus*
	Buttonbush	*Cephalanthus occidentalis*
RIPARIAN SEED MIX	Hop sedge	*Carex lupulina*
	Virginia wildrye	*Elymus virginicus*
	Joe pye weed	*Eupatorium fishtuiosum*
	Bottle-brush weed	*Hystrix patula*
	Virginia willow	*Itea virginica*
	Soft rush	*Juncus effusus*
	Rice Cut Grass	*Leersia oryzoides*
	Cardinal flower	*Lobelia cardinalis*
	Deertounge	*Panicum clandestinum*
	Switchgrass	*Panicum virgatum*
	Three-square bulrush	*Scirpus americanus*
	Woolgrass	*Scirpus cyperinus*
	River oats	*Chasmanthium latifolium*
LIVE STAKE	Silky Dogwood	*Cornus amomum*
	Black willow	*Salix nigra*
	American elderberry	*Sambucus canadensis*
TEMP SEED	Barley	*Hordeum sp.*
	Winter rye	*Secale cereale*
	Browntop millet	*Panicum ramosum*
	Pearl millet	*Pennisetum gasucum*

PHASE III		
	Common Name	Scientific Name
FLOODPLAIN	River Birch	*Betula nigra*
	Sycamore	*Platanus occidentalis*
	Swamp chestnut	*Quercus michauxii*
	Overcup oak	*Quercus lyrata*
	Swamp white oak	*Quercus bicolor*
	Boxelder	*Acer negundo*
	Black gum	*Nyssa sylvatica*
	American strawberry bush	*Euonymus americana*
	Blackhaw	*Viburnum nudum*
	Pinxter flower	*Rhododendron periclymenoides*
	Weeping willow	*Salix babylonica*
	Fringe tree	*Chionanthus virginicus*
	Hackberry	*Celtis laevigata*
	Flowering dogwood	*Cornus flordia*
GENTLE SLOPE FOREST	Flowering dogwood	*Cornus flordia*
	pignut hickory	*Carya galbra*
	yellow poplar	*Liriodendron tulipifera*
	water oak	*Quercus nigra*
	Black Gum	*Nyssa sylvatica*
	Hawthorn	*Crataegus viridis*
	Sycamore	*Platanus occidentallis*
	Southern red oak	*Quercus falcata*
	Redbud	*Cercis canadensis*
	Fringe tree	*Chionanthus virginicus*
	White Oak	*Qurcus alba*
	Eastern Red Cedar	*Juniperous virginiana*
STREAMBANKS	Leathery rush	Juncus coriaceous
	Soft rush	Juncus effusus
	Silky dogwood	*Cornus amomum*
	Black Willow	*Salix nigra*
	American Elderberry	*Sambucus canadensis*
PARK LAWN SEED MIX	Kentucky Bluegrass	Poa pratensis
	Creeping red fescue	Festuca rubra
	Perennial Ryegrass	Lolium perenne
	Redtop	Agrostis gigantea
GRASSED FLOODPLAIN	Weeping Lovegrass	*Eragrostis curvula*
	Purpletop Lovegrass	*Eragrosris spectabilis*
JUNCUS STREAMBANKS	Soft rush	*Juncus effusus*
	Leathery rush	*Juncus spectabilis*
PERMANENT SEED MIX	Virginia wild rye	*Elymus virginicus*
	Switch grass	*Panicum virgatum*
	Creeping bentgrass	*Agrostis stolonifera*
	Begger ticks	*Bidens aristosa*
	Coreopsis	*Coreopsis lanceolata*
	Deer tounge	*Panicum candestinum*
	Big bluestem	*Andropogon gerardii*
	Soft rush	*Juncus effusus*
	Penn. Smartweed	*Polygonum pensylvanicum*
	Little bluestem	*Schizachyrium scoparium*
	Indian grass	*Sorghastrum nutans*
	Gamma	*Tripsacum dactyloides*
TEMP SEED	Barley	*Hordeum* spp.
	Winter Rye	*Secale cereale*
	Browntop millet	*Panicum ramosum*
	Pearl Millet	*Pennisetum glaucum*

Appendix C. Visual delineations of zones from the planting plans.



II GENTLE SLOPE TERRACE COMMUNITY WITH PINES AND RED CEDAR
IV EMERGENT HERBACEOUS COMMUNITY (DEEP)
V EMERGENT HERBACEOUS COMMUNITY (SHALLOW)
VI SHRUB COMMUNITY

Appendix .

D Area each invasive species covers in terms of m^2.

Appendix .

Common Name	Scientific Name	Total Area (m^2)
English ivy	*Hedera helix*	2189
Glossy privet	*Ligustrum lucidum*	1559
Japanese stiltgrass	*Microstegium vimineum*	594
Callery pear	*Pyrus calleryana*	507
Chinese privet	*Ligustrum sinense*	408
White mulberry	*Morus alba*	384
Wintercreeper euonymus	*Euonymus fortunei*	368
Kudzu	*Pueraria montana*	138
Mimosa	*Albizia julibrissin*	121
Thorny olive	*Elaeagnus pungens*	110
Tree-of-heaven	*Ailanthus altissima*	108
Golden bamboo	*Phyllostachys aurea*	106
Japanese knotweed	*Reynoutria japonica*	96
Porcelain berry	*Ampelopsis glandulosa*	79
Japanese honeysuckle	*Lonicera japonica*	69
Wisteria	*Wisteria sinensis*	68
Amur honeysuckle	*Lonicera maackii*	59
Lilyturf	*Liriope muscari*	58
Chinese elm	*Ulmus parvifolia*	55
Amur maple	*Acer ginnala*	48
Creeping lilyturf	*Liriope spicata*	39
Multiflora rose	*Rosa multiflora*	34
Oriental bittersweet	*Celastrus orbiculatus*	33
Chinaberry	*Melia azedarach*	31
Bushkiller	*Cayratia japonica*	22
Autumn olive	*Elaeagnus umbellata*	17
Winter honeysuckle	*Lonicera fragrantissima*	15
Heavenly bamboo	*Nandina domestica*	14
Youngia	*Youngia japonica*	9
Oriental lady's thumb	*Persicaria longiseta*	8
Mock strawberry	*Potentilla indica*	7
Lespedeza	*Lespedeza cuneata*	6
Johnson grass	*Sorghum halepense*	5
Princess tree	*Paulownia tomentosa*	3
Chamber bitters	*Phyllanthus urinaria*	3
Bermuda grass	*Cynodon dactylon*	3
Common hibiscus	*Hibiscus syriacus*	3
Wartremoving herb	*Murdannia keisak*	2
Leatherleaf mahonia	*Berberis bealei*	2
Asiatic dayflower	*Commelina communis*	2
Lawn marshpennywort	*Hydrocotyle sibthorpioides*	1
Chinese yam	*Dioscorea polystachya*	1
Quack grass	*Panicum repens*	1
Yellow iris	*Iris pseudacorus*	1
Beefsteak plant	*Perilla frutescens*	1
Tall fescue	*Lolium arundinaceum*	1
Redtop	*Agrostis gigantea*	1
Hardy orange	*Citrus trifoliata*	1
Common buckthorn	*Rhamnus cathartica*	1
Japanese privet	*Ligustrum japonicum*	trace
Dallis grass	*Paspalum dilatatum*	trace
Chameleon plant	*Houttuynia cordata*	trace
Chickweed	*Stellaria media*	trace
Garden star-of-bethlehem	*Ornithogalum umbellatum*	trace

Appendix .

E Sorrenson outlier analysis at the 2.0 cutoff number of standard deviations for stem main matrix data. Plots 8, 10, 12, and 13 from Phase III are outliers.

```
    Frequency distribution of average distances    N =      59 section

 Distance*   |  Frequency   (each "X" represents one entity)
-------------|-------------------------------------------------------------------------
     0.97290 |X C13
     0.95105 |X C8
     0.92920 |XX C10          C12
     0.90735 |X
     0.88551 |X
     0.86366 |X
     0.84181 |X
     0.81996 |XXX
     0.79811 |XXX
     0.77626 |XXXXXX
     0.75441 |X
     0.73256 |XXXXXXXXX
     0.71071 |XXXXXXX
     0.68886 |XXXXXXXXXXXXXX
     0.66701 |XXXXXXXX
-------------------------------------------------------------------------------------------
* Distances at left are lower end of that bin`s range.


Statistics for average distances for each of N =      59 section
Distance measure: Sorensen (Bray-Curtis)
 0.75928     = Grand mean
 0.80510E-01 = Standard deviation
     2.00000 = Cutoff number of standard deviations used to flag outliers
```

Appendix F. Sorrenson outlier analysis at the 2.0 cutoff number of standard deviations for invasive cover (%) main matrix data. Plot 5 from Phase I and plot 13 from Phase III are outliers.

```
    Frequency distribution of average distances    N =      59 section

 Distance*   |  Frequency   (each "X" represents one entity)
-------------|-------------------------------------------------------------------------
     0.90805 |X C13
     0.88410 |
     0.86015 |X A5
     0.83620 |XXXX
     0.81225 |X
     0.78830 |XXXX
     0.76435 |X
     0.74040 |X
     0.71645 |XXXX
     0.69250 |XXXXXXXXX
     0.66855 |XXXXXXXXXX
     0.64461 |XXXXXXXXX
     0.62066 |XXXXXXX
     0.59671 |XXXXX
     0.57276 |XX
-------------------------------------------------------------------------------------------
* Distances at left are lower end of that bin`s range.


Statistics for average distances for each of N =      59 section
Distance measure: Sorensen (Bray-Curtis)
 0.70058     = Grand mean
 0.78022E-01 = Standard deviation
     2.00000 = Cutoff number of standard deviations used to flag outliers
```

Appendix .

G Sorrenson outlier analysis at the 2.0 cutoff number of standard deviations for invasive cover (%) main matrix data. Plot 5 from Phase I and plot 13 from Phase III are outliers. Species *Acer floridanum*, *Quercus rubra*, *Fagus grandifolia*, *Pinus taeda*, and *Acer rubrum* are outliers.

```
   Frequency distribution of average distances    N =      93 section

 Distance*   |  Frequency   (each "X" represents one entity)
-------------|-------------------------------------------------------------------------------
     0.96490 |X ACFL
     0.93848 |XX QURU         FAGR
     0.91207 |
     0.88565 |XX PITA         ACRU                                                          |
     0.85923 |
     0.83281 |XX
     0.80639 |X
     0.77997 |XXXXXXXX
     0.75355 |XXXX
     0.72713 |XXXXXXXXXXX
     0.70071 |XXXXXXX
     0.67429 |XXXXXXXXXXXXXXX
     0.64788 |XXXXXXXXXXXXXXXXXXXX
     0.62146 |XXXXXXXXXXXX
     0.59504 |XXXXXXXX
-------------------------------------------------------------------------------------------
* Distances at left are lower end of that bin`s range.


Statistics for average distances for each of N =      93 section
Distance measure: Sorensen (Bray-Curtis)
 0.70671     = Grand mean
 0.81422E-01 = Standard deviation
     2.00000 = Cutoff number of standard deviations used to flag outliers
```

Appendix .

H Chi-squared test for homogeneity on the distribution for the number of species across each species designation at the alpha 0.05, 0.025, and 0.01 level.

Observed Data

	Invasive	Volunteer (N)	Volunteer (NN)	Planted	Row Total
Phase I	39	84	24	40	187
Phase II	43	96	22	33	194
Phase III	24	66	10	13	113
Column Total	106	246	56	73	494
Observed Row Proportion	0.2145748988	0.4979757085	0.1133603239	0.1477732794	

Expected Row Count (n_i p_j_hat)

Phase I	40.12550607	93.12145749	21.19838057	27.63360324
Phase II	41.62753036	96.60728745	21.99190283	28.66801619
Phase III	24.24696356	56.27125506	12.8097166	16.69838057

Chi-Square Statistic (Q) Calculation

Phase I	0.0315700422	0.8934674025	0.3702675034	5.534123347
Phase II	0.04525065225	0.003817497167	0.000002981283	0.6546000102
Phase III	0.002515407802	1.682004035	0.6162905562	0.8191224749
Q	10.65303191			
alpha	0.05	0.025	0.01	
Chi-Square Critical Value	9.487729	11.14329	13.2767	

Conclusion: Reject H_0 and conclude that the distribution of the # of species within each species designation (invasive, volunteer (N), volunteer (NN), and planted) designations are not equal across all phases.

Appendix .

I Chi-squared test for homogeneity on the stem distribution across phases at the alpha 0.05, 0.025, and 0.01 level.

Observed Data

	Invasive	Volunteer (N)	Volunteer (NN)	Planted	Row Total
Phase I	2604	1281	23	1586	5494
Phase II	1735	1233	65	596	3629
Phase III	357	203	0	161	721
Column Total	4696	2717	88	2343	9844
Observed Row Proportion	0.4770418529	0.2760056887	0.008939455506	0.2380130028	

Expected Row Count (n_i p_j_hat)

Phase I	2620.86794	1516.375254	49.11336855	1307.643438
Phase II	1731.184884	1001.624644	32.44128403	863.7491873
Phase III	343.9471759	199.0001016	6.44534742	171.6073751

Chi-Square Statistic (Q) Calculation

Phase I	0.1085622785	36.53548819	13.88436666	59.25344294
Phase II	0.008407599183	53.44772161	32.67657299	82.99819944
Phase III	0.4953557631	0.08039788525	6.44534742	0.6556618294
Q	286.5895246			
alpha	0.05	0.025	0.01	
Chi-Square Critical Value	9.487729	11.14329	13.2767	

Conclusion: Reject H_0 and conclude that the distribution of stems within each designation (invasive, volunteer (N), volunteer (NN), and planted (P)) are not equal across all phases.

Appendix .

J Full stem indicator analysis and their associated p-values.

Common Name	Scientific Name	Phase	Observed Indicator Value (IV)	Mean	S. Dev	p-value
Trident maple	*Acer buergerianum*	2	4.4	8.1	4.56	0.8004
Southern sugar maple	*Acer floridanum*	1	26.7	20.8	7.35	0.1854
Amur maple	*Acer ginnala*	1	9.1	11.5	5.75	0.5757
Box elder	*Acer negundo*	2	55.5	16.8	6.73	0.001
Japanese maple	*Acer palmatum*	2	13.3	7.1	3.48	0.0996
Red maple	*Acer rubrum*	1	28.3	20	6.58	0.1086
Silver maple	*Acer saccharinum*	2	6.7	5.7	2.84	0.4519
Tree-of-heaven	*Ailanthus altissima*	1	17.8	12.6	6.14	0.1644
Mimosa	*Albizia julibrissin*	2	22.4	11.8	5.44	0.0568
Smooth alder	*Alnus serrulata*	2	28.4	13.2	5.95	0.023
Downy serviceberry	*Amelanchier arborea*	2	2.9	7.1	3.65	1
Pawpaw	*Asimina triloba*	1	44.8	17.7	6.7	0.0038
Sea myrtle	*Baccharis halimifolia*	1	6.9	7.1	3.72	0.5433
Flowering dogwood	*Benthamidia florida*	1	31	14.2	6.27	0.025
River birch	*Betula nigra*	2	56.4	28.8	7.35	0.0044
Carolina allspice	*Calycanthus floridus*	1	51.7	19.3	7.12	0.002
Ironwood	*Carpinus caroliniana*	2	38	12.2	5.69	0.0032
Bitternut hickory	*Carya cordiformis*	1	17.2	10.9	5.65	0.1862
Pignut hickory	*Carya glabra*	2	6.7	5.6	2.8	0.4509
Mockernut hickory	*Carya tomentosa*	1	24.3	16.4	6.72	0.1296
Catalpa	*Catalpa speciosa*	2	4.1	7.3	3.33	1
Sugarberry	*Celtis laevigata*	2	35.1	26.7	6.48	0.11
Chinese hackberry	*Celtis sinensis*	2	5.3	7.1	3.45	0.7952
Redbud	*Cercis canadensis*	1	36.6	20.4	6.79	0.0278
Fringetree	*Chionanthus virginicus*	1	3.4	5.7	2.83	1
hawthorn	*Crataegus sp.*	2	27.2	14.2	6.41	0.0426
Buttonweed	*Diodia virginiana*	1	17.2	10.7	5.33	0.1336
thorny olive	*Elaeagnus pungens*	2	43.9	18.4	7.36	0.008
Autumn olive	*Elaeagnus umbellata*	1	8.7	10.8	5.51	0.5901
American strawberry bush	*Euonymus americanus*	1	27.6	13.4	6.09	0.0302
American beech	*Fagus grandifolia*	2	20	8.1	4.43	0.0482
White ash	*Fraxinus americana*	1	21	12.9	5.82	0.1018
Green ash	*Fraxinus pennsylvanica*	2	13	16.7	6.13	0.7079
Honey locust	*Gleditsia triacanthos*	1	10.3	8.1	4.59	0.2907
Witch-hazel	*Hamamelis virginiana*	1	20.7	11.1	5.73	0.0938
Common hibiscus	*Hibiscus syriacus*	1	6.9	7.2	3.46	0.5471
Deciduous holly	*Ilex decidua*	2	13.6	18.5	7.26	0.7429
American holly	*Ilex opaca*	2	22.5	22.1	6.99	0.3913
Winterberry	*Ilex verticillata*	1	3.4	5.7	2.83	1
Black walnut	*Juglans nigra*	1	13.2	13.6	5.97	0.4263
Eastern red cedar	*Juniperus virginiana*	3	3.2	9.2	4.9	0.9716
Golden raintree	*Koelreuteria paniculata*	1	3.4	5.6	2.81	1
Crepe myrtle	*Lagerstroemia indica*	2	6.7	5.8	2.88	0.4673
Glossy privet	*Ligustrum lucidum*	2	46.3	39.8	4.16	0.0798
Chinese privet	*Ligustrum sinense*	1	44.4	34.6	5.46	0.0584
Spicebush	*Lindera benzoin*	1	48.3	17.8	6.42	0.0022
Sweetgum	*Liquidambar styraciflua*	2	73.4	26.1	7.78	0.0002
Tulip-poplar	*Liriodendron tulipifera*	3	49.2	27.8	6.75	0.0096
Southern magnolia	*Magnolia grandiflora*	2	24.4	20.6	7.6	0.2362
Chinaberry	*Melia azedarach*	1	8.9	9.9	5.26	0.4931
Common wax myrtle	*Morella cerifera*	1	28.8	27	7.11	0.3219
White mulberry	*Morus alba*	1	41.6	29.6	6.13	0.0506
Red mulberry	*Morus rubra*	2	6.7	5.7	2.84	0.4491
Heavenly bamboo	*Nandina domestica*	3	4.2	8.1	4.53	0.8278
Black gum	*Nyssa sylvatica*	2	13.3	7	3.81	0.0942
Sourwood	*Oxydendron arboreum*	2	6.7	5.7	2.85	0.4637
Princess tree	*Paulownia tomentosa*	2	13.3	7.4	3.53	0.1064
Chinese phontinia	*Photinia serratifolia*	2	6.7	5.7	2.85	0.4637
Golden bamboo	*Phyllostachys aurea*	1	6.9	7.1	3.81	0.5485
Loblolly pine	*Pinus taeda*	1	74.7	30.1	6.58	0.0002
Chinese pistache	*Pistacia chinensis*	2	5.9	8.5	4.68	0.5649
Sycamore	*Platanus occidentalis*	2	47.7	32.5	6.34	0.0264
Laurel cherry	*Prunus caroliniana*	2	83.5	36.7	6.79	0.0002
Cherry plum	*Prunus cerasifera*	1	3.4	5.7	2.83	1
Pin cherry	*Prunus pensylvanica*	1	3.4	5.7	2.83	1
Peach	*Prunus persica*	1	3.4	5.6	2.8	1
Black cherry	*Prunus serotina*	1	57.4	28.7	5.87	0.001
Japanese cherry	*Prunus serrulata*	1	3.4	5.7	2.86	1
Callery pear	*Pyrus calleryana*	2	69.8	29.4	6.88	0.0002

Appendix .

White oak	*Quercus alba*	2	24.3	14.2	6.43	0.0742
Swamp white oak	*Quercus bicolor*	3	17.1	9.3	5.12	0.1134
Laurel oak	*Quercus laurifolia*	1	34.5	14.5	6.01	0.0116
Swamp chestnut oak	*Quercus michauxii*	1	13.8	9.1	4.94	0.2484
Water oak	*Quercus nigra*	1	44.8	18.2	7.06	0.0058
Pin oak	*Quercus palustris*	1	3.4	5.6	2.8	1
Willow oak	*Quercus phellos*	1	33.5	22.8	6.92	0.078
Red oak	*Quercus rubra*	1	15.3	13.7	5.92	0.3061
Shumard oak	*Quercus shumardii*	1	10.3	8.1	4.56	0.3875
Black oak	*Quercus velutina*	1	11.6	10.1	5.31	0.3549
Western azalea	*Rhododendron occidentale*	1	3.4	5.7	2.83	1
Pinxter-flower	*Rhododendron periclymenoides*	1	13.8	9.2	5.16	0.2384
Black locust	*Robinia pseudoacacia*	2	53.2	32.9	6.15	0.0078
Black willow	*Salix nigra*	2	23.6	21.7	7.1	0.3205
American elderberry	*Sambucus canadensis*	3	27.8	15.9	6.62	0.0612
Sassafras	*Sassafras albidum*	1	20.7	12	5.89	0.0786
Silky dogwood	*Swida amomum*	3	10.2	12.6	5.91	0.5441
Bald cypress	*Taxodium distichum*	2	26.7	9.4	5.07	0.0158
American elm	*Ulmus americana*	3	69.9	31.6	7.72	0.0006
Chinese elm	*Ulmus parvifolia*	3	8	15.6	6.27	0.9728
Mapleleaf viburnum	*Viburnum acerifolium*	1	3.4	5.6	2.84	1
Arrowwood viburnum	*Viburnum dentatum*	1	6.9	7.3	3.46	0.6269
Withe-rod	*Viburnum nudum*	1	6.9	7.2	3.59	0.5443
Japanese snowball	*Viburnum plicatum*	2	6.7	5.7	2.86	0.4447
Blackhaw	*Viburnum prunifolium*	3	11.1	5.7	2.87	0.1788
Japanese zelkova	*Zelkova serrata*	1	3.4	5.7	2.86	1

Appendix K. Full % invasive cover analysis indicator analysis and their associated p-values.

Common Name	Scientific Name	Phase	Observed Indicator Value	Mean	S-Dev	p-value
Amur maple	*Acer ginnala*	3	7.2	14.2	5.94	0.8704
Redtop	*Agrostis gigantea*	1	3.4	5.3	1.88	1
Tree-of-heaven	*Ailanthus altissima*	1	7.4	11.5	5.41	0.7724
Mimosa	*Albizia julibrissin*	3	14.6	17.9	7.12	0.6219
Porcelain berry	*Ampelopsis glandulosa*	2	60.9	39.3	6.64	0.0028
Leatherleaf mahonia	*Berberis bealei*	2	20	7.1	3.94	0.0214
Bushkiller	*Cayratia japonica*	1	3.4	5.3	1.89	1
Oriental bittersweet	*Celastrus orbiculatus*	1	44.4	28	6.93	0.0264
Hardy orange	*Citrus trifoliata*	2	6.7	5.3	1.89	0.4941
Asiatic dayflower	*Commelina communis*	3	9.7	9	4.39	0.3453
Bermuda grass	*Cynodon dactylon*	3	4.1	6.4	3.04	1
Chinese yam	*Dioscorea polystachya*	2	6.7	5.2	1.88	0.4873
Thorny olive	*Elaeagnus pungens*	2	38.7	23.5	7.51	0.0446
Autumn olive	*Elaeagnus umbellata*	1	12.1	12.8	5.81	0.4573
Wintercreeper euonymus	*Euonymus fortunei*	2	37.5	32.8	7.16	0.218
English ivy	*Hedera helix*	1	53.1	35.8	4.97	0.0042
Common hibiscus	*Hibiscus syriacus*	1	10.3	7.1	4.07	0.2933
Chameleon plant	*Houttuynia cordata*	1	3.4	5.3	1.89	1
Lawn marshpennywort	*Hydrocotyle sibthorpioides*	2	6.7	5.3	1.88	0.4921
Yellow iris	*Iris pseudacorus*	2	6.7	5.3	1.88	0.4939
Lespedeza	*Lespedeza cuneata*	2	36.8	10.5	4.58	0.0002
Japanese privet	*Ligustrum japonicum*	1	3.4	5.3	1.88	1
Glossy privet	*Ligustrum lucidum*	2	40.9	39.6	3.61	0.3049
Chinese privet	*Ligustrum sinense*	1	81.1	29.3	6.34	0.0002
Lilyturf	*Liriope muscari*	3	26.8	26.8	7.77	0.4053
Creeping lilyturf	*Liriope spicata*	2	41.4	14.5	6.04	0.0022
Tall fescue	*Lolium arundinaceum*	3	6.3	6.4	3.13	0.4949
Winter honeysuckle	*Lonicera fragrantissima*	2	13.3	6.6	3.26	0.1156
Japanese honeysuckle	*Lonicera japonica*	1	38.9	30.8	6.66	0.1146
Amur honeysuckle	*Lonicera maackii*	1	37.2	14.9	5.6	0.0038
Chinaberry	*Melia azedarach*	1	16.6	11.3	5.33	0.1448
Japanese stiltgrass	*Microstegium vimineum*	3	58.4	30.7	8.53	0.0066
White mulberry	*Morus alba*	1	58.9	34.9	5.9	0.0018
Wartremoving herb	*Murdannia keisak*	2	13.3	6.3	2.99	0.1084
Heavenly bamboo	*Nandina domestica*	1	22.6	16.5	5.42	0.119
Garden star-of-bethlehem	*Ornithogalum umbellatum*	1	3.4	5.3	1.88	1
Quack grass	*Panicum repens*	2	6.7	5.2	1.88	0.4873
Dallis grass	*Paspalum dilatatum*	3	7.7	5.3	1.89	0.2352
Princess tree	*Paulownia tomentosa*	2	13.3	6.4	3.07	0.1186
Beefsteak plant	*Perilla frutescens*	2	8.5	6.7	4.17	0.4095
Oriental lady's thumb	*Persicaria longiseta*	2	31.6	12.8	4.97	0.0058
Chamber bitters	*Phyllanthus urinaria*	2	20	7.2	4.06	0.0266
Golden bamboo	*Phyllostachys aurea*	1	6.9	6.4	3.42	0.4851
Mock strawberry	*Potentilla indica*	2	27.6	13	4.97	0.016
Kudzu	*Pueraria montana*	2	59.8	33	9.1	0.0076
Callery pear	*Pyrus calleryana*	2	80.4	28.2	6.39	0.0002
Japanese knotweed	*Reynoutria japonica*	2	20	7.4	3.87	0.0232
Common buckthorn	*Rhamnus cathartica*	2	6.7	5.3	1.89	0.4941
Multiflora rose	*Rosa multiflora*	2	18.6	19.1	6.73	0.4505
Johnson grass	*Sorghum halepense*	2	5.5	8	4.29	0.7195
Chickweed	*Stellaria media*	1	3.4	5.2	1.88	1
Chinese elm	*Ulmus parvifolia*	1	18.5	22.5	6.84	0.6689
Wisteria	*Wisteria sinensis*	2	48.9	13	5.58	0.0004
Youngia	*Youngia japonica*	1	20.2	15.8	5.18	0.159

Appendix .

L All importance values for planted species.

Common Name	Scientific Name	Sections Present	Total Sections	Stem Count	Total Stem Count	Modified IVI
Hackberry	*Celtis laevigata*	44	59	124	2343	79.87
Sycamore	*Platanus occidentalis*	44	59	123	2343	79.83
Common wax myrtle	*Morella cerifera*	29	59	364	2343	64.69
Tulip-poplar	*Liriodendron tulipifera*	31	59	139	2343	58.47
River birch	*Betula nigra*	30	59	109	2343	55.50
Carolina allspice	*Calyanthus floridus*	22	59	326	2343	51.20
Redbud	*Cercis canadensis*	25	59	91	2343	46.26
American elderyberry	*Sambucus canadensis*	23	59	141	2343	45.00
Black willow	*Salix nigra*	24	59	77	2343	43.96
Spicebush	*Lindera benzoin*	20	59	90	2343	37.74
American holly	*Ilex opaca*	21	59	33	2343	37.00
American strawberry bush	*Euonymus americanus*	20	59	46	2343	35.86
Pawpaw	*Asimina triloba*	16	59	96	2343	31.22
Green ash	*Fraxinus pennsylvanica*	18	59	15	2343	31.15
Deciduous holly	*Ilex decidua*	15	59	120	2343	30.55
Silky dogwood	*Swida amomum*	17	59	31	2343	30.14
Red oak	*Quercus rubra*	14	59	17	2343	24.45
Mockernut hickory	*Carya tomentosa*	13	59	32	2343	23.40
White oak	*Quercus alba*	13	59	27	2343	23.19
American elm	*Ulmus americana*	9	59	133	2717	20.15
Hawthorn	*Crataegus spp.*	10	59	62	2343	19.60
Withe-rod	*Viburnum nudum*	11	59	3	2343	18.77
Flowering dogwood	*Benthamidia florida*	9	59	30	2343	16.53
Ironwood	*Carpinus caroliniana*	8	59	65	2343	16.33
Sassafras	*Sassafras albidum*	7	59	40	2343	13.57
Persimmon	*Diospyros virginiana*	7	59	23	2343	12.85
Pinxter-flower	*Rhododendron periclymenoides*	7	59	21	2343	12.76
Witch hazel	*Hamamelis virginiana*	6	59	35	2343	11.66
Black oak	*Quercus velutina*	6	59	11	2343	10.64
Swamp chestnut oak	*Quercus michauxii*	6	59	5	2343	10.38
Bald cypress	*Taxodium distichum*	4	59	21	2343	7.68
Pignut hickory	*Carya glabra*	3	59	3	2343	5.21
Fringetree	*Chionanthus virginicus*	3	59	3	2343	5.21
Downy serviceberry	*Amelanchier arborea*	2	59	7	2343	3.69
Black gum	*Nyssa sylvatica*	2	59	5	2343	3.60
Swamp white oak	*Quercus bicolor*	2	59	4	2343	3.56
Sourwood	*Oxydendrum arboreum*	1	59	4	2343	1.87
Eastern red cedar	*Juniperus virginicus*	1	59	1	2343	1.74

Appendix .

M All importance values for all volunteer species.

Common Name	Scientific Name	Sections Present	Total Sections	Stem Count	Total Stem Count	Modified IVI
Laurel cherry	*Prunus caroliniana*	48	59	897	2717	114.37
Black locust	*Robinia pseudoacacia*	45	59	206	2717	83.85
Willow oak	*Quercus phellos*	42	59	63	2717	73.51
Loblolly pine	*Pinus taeda*	35	59	356	2717	72.42
Black cherry	*Prunus serotina*	38	59	135	2717	69.38
Sweetgum	*Liquidambar styraciflua*	29	59	176	2717	55.63
American elm	*Ulmus americana var. americana*	30	59	71	2717	53.46
Southern sugar maple	*Acer floridanum*	25	59	145	2717	47.71
Water oak	*Quercus nigra*	22	59	93	2717	40.71
Red maple	*Acer rubrum*	22	59	52	2717	39.20
Southern magnolia	*Magnolia grandiflora*	17	59	66	2717	31.24
American holly	*Ilex opaca*	16	59	47	2717	28.85
Box elder	*Acer negundo var. negundo*	13	59	37	2717	23.40
Laurel oak	*Quercus laurifolia*	13	59	16	2717	22.62
Bitternut hickory	*Carya cordiformis*	11	59	22	2717	19.45
Smooth alder	*Alnus serrulata*	10	59	67	2717	19.42
White ash	*Fraxinus americana*	10	59	14	2717	17.46
Sea myrtle	*Baccharis halimifolia*	9	59	7	2717	15.51
Eastern red cedar	*Juniperus virginiana*	6	59	12	2717	10.61
Honey locust	*Gleditsia triacanthos*	5	59	5	2717	8.66
Mapleleaf viburnum	*Viburnum acerifolium*	5	59	1	2717	8.51
American beech	*Fagus grandifolia var. caroliniana*	3	59	8	2717	5.38
Shumard oak	*Quercus shumardii*	3	59	3	2717	5.20
Pecan hickory	*Carya illinoinensis*	3	59	1	2717	5.12
Red elm	*Ulmus rubra*	3	59	0	2717	5.08
Arrowwood viburnum	*Viburnum dentatum*	2	59	15	2717	3.94
Winterberry	*Ilex verticillata*	2	59	14	2717	3.91
Wax myrtle	*Morella cerifera*	2	59	14	2717	3.91
Pin oak	*Quercus palustris*	2	59	1	2717	3.43
Overcup oak	*Quercus lyrata*	2	59	0	2717	3.39
Blackhaw	*Viburnum prunifolium*	1	59	19	2717	2.39
Red oak	*Quercus rubra var. rubra*	1	59	4	2717	1.84
Pin cherry	*Prunus pensylvanica*	1	59	3	2717	1.81
Red mulberry	*Morus rubra*	1	59	2	2717	1.77
Silver maple	*Acer saccranum*	1	59	1	2717	1.73
Green ash	*Fraxinus pennsylvanica*	1	59	1	2717	1.73
Leverwood	*Ostrya virginiana*	1	59	1	2717	1.73
Bald cypress	*Taxodium distichum*	1	59	0	2717	1.70
American beautyberry	*Callicarpa americana*	1	59	0	2717	1.70
Atlantic white cedar	*Chamaecyparis thyoides*	1	59	0	2717	1.70
American plum	*Prunus americana*	1	59	0	2717	1.70
Rhododendron	*Rhododendron maximum*	1	59	0	2717	1.70
Winged elm	*Ulmus alata*	1	59	0	2717	1.70

N Indicator species analysis for invasion level (highly, moderately, or less invaded plots) looking at relative abundance.

Common Name	Scientific Name	Indicator of Invasion Level	Abundance in Less Invaded	Abundance in Moderately Invaded	Abundance in Highly Invaded
Trident maple	*Acer buergerianum*	Moderately	0	54	46
Southern sugar maple	*Acer floridanum*	Highly	24	32	44
Amur maple	*Acer ginnala*	Moderately	0	95	5
Box elder	*Acer negundo*	Highly	17	37	46
Japanese maple	*Acer palmatum*	Moderately	0	100	0
Red maple	*Acer rubrum*	Moderately	20	46	34
Silver maple	*Acer saccharinum*	Highly	0	0	100
Tree-of-heaven	*Ailanthus altissima*	Moderately	0	74	26
Mimosa	*Albizia julibrissin*	Moderately	0	77	23
Smooth alder	*Alnus serrulata*	Moderately	32	46	22
Downy serviceberry	*Amelanchier arborea*	Moderately	0	60	40
Pawpaw	*Asimina triloba*	Moderately	6	62	32
Sea myrtle	*Baccharis halimifolia*	Highly	35	0	65
Flowering dogwood	*Benthamidia florida*	Moderately	12	60	28
River birch	*Betula nigra*	Less	40	35	25
Carolina allspice	*Calycanthus floridus*	Moderately	7	63	30
Ironwood	*Carpinus caroliniana*	Highly	14	21	65
Bitternut hickory	*Carya cordiformis*	Moderately	33	67	0
Pignut hickory	*Carya glabra*	Moderately	0	100	0
Pecan	*Carya illinoinensis*	Moderately	0	100	0
Mockernut hickory	*Carya tomentosa*	Highly	5	16	79
Catalpa	*Catalpa speciosa*	Less	65	35	0
Sugarberry	*Celtis laevigata*	Highly	15	29	56
Chinese hackberry	*Celtis sinensis*	Moderately	0	100	0
Redbud	*Cercis canadensis*	Moderately	4	59	37
Fringetree	*Chionanthus virginicus*	Moderately	0	100	0
Hawthorn	*Crataegus spp.*	Less	47	15	38
Persimmon	*Diospyros virginiana*	Moderately	25	69	6
Thorny olive	*Elaeagnus pungens*	Moderately	2	58	40
Autumn olive	*Elaeagnus umbellata*	Moderately	0	66	34
American strawberry bush	*Euonymus americanus*	Highly	22	23	55
American beech	*Fagus grandifolia*	Highly	0	16	84
White ash	*Fraxinus americana*	Moderately	34	40	26
Green ash	*Fraxinus pennsylvanica*	Highly	19	30	51
Honey locust	*Gleditsia triacanthos*	Highly	0	47	53
Witch hazel	*Hamamelis virginiana*	Moderately	0	60	40
Common hibiscus	*Hibiscus syriacus*	Highly	40	0	60
Deciduous holly	*Ilex decidua*	Highly	18	18	64
American holly	*Ilex opaca*	Highly	14	14	72
Winterberry	*Ilex verticillata*	Moderately	0	100	0
Black walnut	*Juglans nigra*	Moderately	29	39	33
Eastern red cedar	*Juniperus virginiana*	Moderately	0	78	22
Golden raintree	*Koelreuteria paniculata*	Moderately	0	100	0
Crepe myrtle	*Lagerstroemia indica*	Highly	0	0	100
Glossy privet	*Ligustrum lucidum*	Highly	20	29	51
Chinese privet	*Ligustrum sinense*	Highly	22	26	52
Spicebush	*Lindera benzoin*	Moderately	18	58	24
Sweetgum	*Liquidambar styraciflua*	Highly	5	30	66
Tulip-poplar	*Liriodendron tulipifera*	Highly	37	19	45
Sweetbay	*Magnolia grandiflora*	Moderately	3	61	36
Chinaberry	*Melia azedarach*	Moderately	39	61	0

Appendix .

Common wax myrtle	*Morella cerifera*	Moderately	18	51	31
White mulberry	*Morus alba*	Highly	11	34	54
Red mulberry	*Morus rubra*	Highly	0	0	100
Heavenly bamboo	*Nandina domestica*	Highly	0	43	57
Black gum	*Nyssa sylvatica*	Moderately	0	100	0
Leverwood	*Ostrya virginiana*	Moderately	0	100	0
Sourwood	*Oxydendron arboreum*	Highly	0	0	100
Princess tree	*Paulownia tomentosa*	Highly	0	0	100
Chinese photinia	*Photinia serratifolia*	Highly	0	0	100
Golden bamboo	*Phyllostachys aurea*	Highly	0	0	100
Loblolly pine	*Pinus taeda*	Moderately	21	48	31
Chinese pistache	*Pistacia chinensis*	Highly	0	6	94
Sycamore	*Platanus occidentalis*	Highly	32	28	40
Laurel cherry	*Prunus caroliniana*	Highly	21	21	58
Cherry plum	*Prunus cerasifera*	Moderately	0	100	0
Pin cherry	*Prunus pensylvanica*	Moderately	0	100	0
Peach	*Prunus persica*	Highly	0	0	100
Black cherry	*Prunus serotina*	Highly	23	27	49
Japanese cherry	*Prunus serrulata*	Moderately	0	100	0
Callery pear	*Pyrus calleryana*	Highly	12	22	66
White oak	*Quercus alba*	Highly	6	23	72
Swamp white oak	*Quercus bicolor*	Highly	26	35	39
Laurel oak	*Quercus laurifolia*	Moderately	35	47	18
Swamp chestnut oak	*Quercus michauxii*	Moderately	36	64	0
Water oak	*Quercus nigra*	Highly	4	38	58
Pin oak	*Quercus palustris*	Highly	0	0	100
Willow oak	*Quercus phellos*	Moderately	0	60	40
Red oak	*Quercus rubra*	Less	39	38	23
Shumard oak	*Quercus shumardii*	Less	46	20	34
Black oak	*Quercus velutina*	Moderately	0	73	27
Western azalea	*Rhododendron occidentale*	Moderately	0	100	0
Pinxter-flower	*Rhododendron periclymenoides*	Highly	29	29	43
Black locust	*Robinia pseudoacacia*	Highly	33	25	42
Black willow	*Salix nigra*	Less	38	35	27
American elderberry	*Sambucus canadensis*	Moderately	31	49	20
Sassafras	*Sassafras albidum*	Highly	0	9	91
Silky dogwood	*Swida amomum*	Moderately	30	70	0
Bald cypress	*Taxodium distichum*	Highly	27	18	55
American elm	*Ulmus americana*	Less	51	29	20
Chinese elm	*Ulmus parvifolia*	Moderately	14	48	38
Mapleleaf viburnum	*Viburnum acerifolium*	Highly	0	0	100
Arrowwood viburnum	*Viburnum dentatum*	Moderately	0	100	0
Withe-rod	*Viburnum nudum*	Less	53	47	0
Japanese snowball	*Viburnum plicatum*	Moderately	0	100	0
Blackhaw	*Viburnum prunifolium*	Less	100	0	0
Japanese zelkova	*Zelkova serrata*	Moderately	0	100	0

Appendix O. Full indicator species analysis for invasion level (highly, moderately, or less invaded plots) with associated p-values.

Common Name	Scientific Name	Indicator of Invasion Level	Observed Indicator Value	Mean	S. Dev	p-value
Trident maple	*Acer buergerianum*	Moderately	4	7.3	3.98	0.8262
Southern sugar maple	*Acer floridanum*	Highly	16.5	19.5	6.76	0.6009
Amur maple	*Acer ginnala*	Moderately	17.6	10.7	5.12	0.1052
Box elder	*Acer negundo*	Highly	14.3	15.7	5.92	0.4989
Japanese maple	*Acer palmatum*	Moderately	7.4	6.5	3.31	0.3601
Red maple	*Acer rubrum*	Moderately	15.4	19	5.87	0.6899
Silver maple	*Acer saccharinum*	Highly	6.2	5.4	1.88	0.4987
Tree-of-heaven	*Ailanthus altissima*	Moderately	13.7	11.8	5.45	0.2973
Mimosa	*Albizia julibrissin*	Moderately	17	11	4.89	0.0972
Smooth alder	*Alnus serrulata*	Moderately	6.8	12.1	5.2	0.9002
Downy serviceberry	*Amelanchier arborea*	Moderately	2.5	6.4	3.34	1
Pawpaw	*Asimina triloba*	Moderately	16	16.8	6.06	0.4589
Sea myrtle	*Baccharis halimifolia*	Highly	4.1	6.5	3.4	0.7487
Flowering dogwood	*Benthamidia florida*	Moderately	8.9	13.3	5.57	0.7772
River birch	*Betula nigra*	Less	18	27.3	6.73	0.9778
Carolina allspice	*Calycanthus floridus*	Moderately	18.7	18.1	6.11	0.3709
Ironwood	*Carpinus caroliniana*	Highly	16.3	11.4	5.15	0.1704
Bitternut hickory	*Carya cordiformis*	Moderately	9.9	10	5.02	0.4051
Pignut hickory	*Carya glabra*	Moderately	3.7	5.4	1.85	1
Pecan	*Carya illinoinensis*	Moderately	3.7	5.5	1.87	1
Mockernut hickory	*Carya tomentosa*	Highly	24.7	15.5	6.19	0.0834
Catalpa	*Catalpa speciosa*	Less	5.4	6.5	3.18	0.5685
Sugarberry	*Celtis laevigata*	Highly	42.1	25.4	5.73	0.0142
Chinese hackberry	*Celtis sinensis*	Moderately	7.4	6.5	3.34	0.3631
Redbud	*Cercis canadensis*	Moderately	21.9	19.9	6.15	0.2957
Fringetree	*Chionanthus virginicus*	Moderately	3.7	5.4	1.86	1
Hawthorn	*Crataegus spp.*	Less	9.5	13.3	5.73	0.7159
Persimmon	*Diospyros virginiana*	Moderately	7.7	9.8	4.94	0.6069
Thorny olive	*Elaeagnus pungens*	Moderately	15.1	17.8	6.59	0.6097
Autumn olive	*Elaeagnus umbellata*	Moderately	9.8	10.3	5.17	0.4081
American strawberry bush	*Euonymus americanus*	Highly	6.9	12.6	5.55	0.9186
American beech	*Fagus grandifolia*	Highly	10.4	7.2	4.05	0.3133
White ash	*Fraxinus americana*	Moderately	6	12.1	5.16	0.971
Green ash	*Fraxinus pennsylvanica*	Highly	15.8	15.8	5.48	0.4031
Honey locust	*Gleditsia triacanthos*	Highly	3.5	7.2	4.06	0.934
Witch hazel	*Hamamelis virginiana*	Moderately	11.1	10.3	4.93	0.3107
Common hibiscus	*Hibiscus syriacus*	Highly	3.7	6.4	3.3	0.8542
Deciduous holly	*Ilex decidua*	Highly	20	17.5	6.44	0.2973
American holly	*Ilex opaca*	Highly	44.8	20.7	6.12	0.005
Winterberry	*Ilex verticillata*	Moderately	3.7	5.4	1.86	1
Black walnut	*Juglans nigra*	Moderately	7.1	13.4	5.16	0.9774
Eastern red cedar	*Juniperus virginiana*	Moderately	8.7	8.5	4.55	0.4001
Golden raintree	*Koelreuteria paniculata*	Moderately	3.7	5.4	1.87	1
Crepe myrtle	*Lagerstroemia indica*	Highly	6.2	5.5	1.89	0.5047
Glossy privet	*Ligustrum lucidum*	Highly	51.2	39	4	0.007
Chinese privet	*Ligustrum sinense*	Highly	49.1	33.4	5.32	0.0108
Spicebush	*Lindera benzoin*	Moderately	19.3	17.4	5.79	0.2847
Sweetgum	*Liquidambar styraciflua*	Highly	37	24.4	6.9	0.0558
Tulip-poplar	*Liriodendron tulipifera*	Highly	30.7	27	6.13	0.234
Sweetbay	*Magnolia grandiflora*	Moderately	20.3	19.7	7.09	0.3967
Chinaberry	*Melia azedarach*	Moderately	9	9.3	4.65	0.4829

Common wax myrtle	*Morella cerifera*	Moderately	24.5	26.2	6.45	0.5173
White mulberry	*Morus alba*	Highly	33.9	29	5.8	0.1832
Red mulberry	*Morus rubra*	Highly	6.2	5.5	1.87	0.5157
Heavenly bamboo	*Nandina domestica*	Highly	3.6	7.2	4.18	0.9342
Black gum	*Nyssa sylvatica*	Moderately	7.4	6.6	3.33	0.4775
Leverwood	*Ostrya virginiana*	Moderately	3.7	5.5	1.87	1
Sourwood	*Oxydendron arboreum*	Highly	6.2	5.4	1.87	0.5043
Princess tree	*Paulownia tomentosa*	Highly	12.5	6.5	3.21	0.1254
Chinese photinia	*Photinia serratifolia*	Highly	6.2	5.4	1.87	0.5043
Golden bamboo	*Phyllostachys aurea*	Highly	12.5	6.6	3.4	0.126
Loblolly pine	*Pinus taeda*	Moderately	30.5	29.3	6	0.3487
Chinese pistache	*Pistacia chinensis*	Highly	11.7	8.1	4.07	0.1896
Sycamore	*Platanus occidentalis*	Highly	29.8	31.7	5.8	0.5689
Laurel cherry	*Prunus caroliniana*	Highly	50.7	35	6.25	0.02
Cherry plum	*Prunus cerasifera*	Moderately	3.7	5.5	1.88	1
Pin cherry	*Prunus pensylvanica*	Moderately	3.7	5.5	1.88	1
Peach	*Prunus persica*	Highly	6.2	5.5	1.87	0.5219
Black cherry	*Prunus serotina*	Highly	37	27.9	5.41	0.067
Japanese cherry	*Prunus serrulata*	Moderately	3.7	5.5	1.88	1
Callery pear	*Pyrus calleryana*	Highly	45.1	28	6.23	0.0176
White oak	*Quercus alba*	Highly	18	14.1	5.9	0.2442
Swamp white oak	*Quercus bicolor*	Highly	4.9	8.6	4.53	0.8158
Laurel oak	*Quercus laurifolia*	Moderately	10.5	13.4	5.1	0.7221
Swamp chestnut oak	*Quercus michauxii*	Moderately	7.1	8.5	4.58	0.6261
Water oak	*Quercus nigra*	Highly	14.5	17	6.4	0.5665
Pin oak	*Quercus palustris*	Highly	6.2	5.4	1.85	0.4969
Willow oak	*Quercus phellos*	Moderately	26.5	22.3	6.43	0.2184
Red oak	*Quercus rubra*	Less	7	12.7	5.23	0.9394
Shumard oak	*Quercus shumardii*	Less	3.8	7.2	4.18	1
Black oak	*Quercus velutina*	Moderately	8.1	9.3	4.65	0.5281
Western azalea	*Rhododendron occidentale*	Moderately	3.7	5.4	1.86	1
Pinxter-flower	*Rhododendron periclymenoides*	Highly	2.7	8.4	4.44	1
Black locust	*Robinia pseudoacacia*	Highly	29	31.9	5.56	0.6519
Black willow	*Salix nigra*	Less	15.7	21.1	6.47	0.7928
American elderberry	*Sambucus canadensis*	Moderately	10.3	15.6	5.85	0.8376
Sassafras	*Sassafras albidum*	Highly	17	11.4	5.38	0.1466
Silky dogwood	*Swida amomum*	Moderately	10.3	11.7	5.22	0.5517
Bald cypress	*Taxodium distichum*	Highly	4.5	8.7	4.57	0.8422
American elm	*Ulmus americana*	Less	42.2	29.8	7.17	0.0656
Chinese elm	*Ulmus parvifolia*	Moderately	10.6	14.7	5.63	0.7391
Mapleleaf viburnum	*Viburnum acerifolium*	Highly	6.2	5.5	1.87	0.5203
Arrowwood viburnum	*Viburnum dentatum*	Moderately	7.4	6.5	3.15	0.3533
Withe-rod	*Viburnum nudum*	Less	4.4	6.5	3.29	0.7886
Japanese snowball	*Viburnum plicatum*	Moderately	3.7	5.5	1.88	1
Blackhaw	*Viburnum prunifolium*	Less	8.3	5.4	1.86	0.213
Japanese zelkova	*Zelkova serrata*	Moderately	3.7	5.5	1.88	1

Appendix P. Master list of species present at Rocky Branch.

Common Name	Scientific Name	Species Type	Phases Present	Sections Present (out of 122 for planted, 59 otherwise)	Total Stems
Rhomboid mercury	*Acalypha virginica*	V	II, III	16	
Trident maple	*Acer buergerianum*	VNN	I, II	6	6
Southern sugar maple	*Acer floridanum*	V	I, II	25	145
Amur maple	*Acer ginnala*	I	I, III	7	32
Box elder	*Acer negundo*	V	I, II	13	37
Japanese maple	*Acer palmatum*	VNN	II	2	3
Red maple	*Acer rubrum*	V	I, II, III	22	52
Silver maple	*Acer saccharinum*	V	II	1	1
Redtop	*Agrostis gigantea*	I	I	2	
Tree-of-heaven	*Ailanthus altissima*	I	I, II	7	52
Mimosa	*Albizia julibrissin*	I	I, II, III	13	15
Wild garlic	*Allium canadense*	V	I	3	
Smooth alder	*Alnus serrulata*	V	I, II, III	10	67
Annual ragweed	*Ambrosia artemisiifolia*	V	I, II	3	
Downy serviceberry	*Amelanchier arborea*	P	I, II	2	7
Porcelain berry	*Ampelopsis glandulosa*	I	I, II, III	50	
Broomsedge	*Andropogon virginicus*	P/V	I, III	14	
American groundnut	*Apios americana*	V	I, II	4	
Indian hemp	*Apocynum cannabinum*	V	I	3	
Red chokeberry	*Aronia arbutifolia*	V	II	1	
Giant cane	*Arundinaria sp.*	P	I, II	4	
Pawpaw	*Asimina triloba*	P	I	16	96
Ebony spleenwort	*Asplenium platyneuron*	V	I, II, III	13	
Lady fern	*Athyrium filix-femina*	V	I	1	
Common carpetgrass	*Axonopus fissifolius*	V	II	1	
Sea myrtle	*Baccharis halimifolia*	V	I, II, III	9	7
Flowering dogwood	*Benthamidia florida*	P	I	9	30
Leatherleaf mahonia	*Berberis bealei*	I	II	2	
River birch	*Betula nigra*	P	I, II	30	109
Devil's beggarticks	*Bidens frondosa*	V	I, II, III	4	
Smallspike false nettle	*Boehmeria cylindrica*	V	II	1	
American beautyberry	*Calicarpa americana*	V	I	1	
Marsh marigold	*Caltha palustris*	V	III	1	
Carolina allspice	*Calycanthus floridus*	P	I	22	326
Marsh bellflower	*Campanula aparinoides*	V	II	1	
Trumpet vine	*Campsis radicans*	V	I, II, III	11	
Eastern woodland sedge	*Carex blanda*	V	I, II, III	4	
Oval-headed sedge	*Carex cephalophora*	V	II	1	
Frank's sedge	*Carex frankii*	V	II	1	
Slough sedge	*Carex obnupta*	V	II	1	
Long-stalked sedge	*Carex pedunculata*	V	II	1	
Broad leaf sedge	*Carex platyphylla*	V	II	1	
Eastern star sedge	*Carex radiata*	V	II	1	
Eastern rough sedge	*Carex scabrata*	V	II	1	
Ironwood	*Carpinus caroliniana*	P	I, II	8	65
Bitternut hickory	*Carya cordiformis*	V	I, II	11	22
Pignut hickory	*Carya glabra*	P	I, II	3	3
Pecan hickory	*Carya illinoinensis*	V	I	3	
Mockernut hickory	*Carya tomentosa*	P	I, II	13	32
Northern catalpa	*Catalpa speciosa*	VNN	I	3	11
Bushkiller	*Cayratia japonica*	I	I, II, III	1	
Oriental bittersweet	*Celastrus orbiculatus*	I	I, II	29	
Hackberry	*Celtis laevigata*	P	I, II, III	44	124
Chinese hackberry	*Celtis sinensis*	VNN	I, II	3	3
Buttonbush	*Cephalanthus occidentalis*	P	II	1	
Redbud	*Cercis canadensis*	P	I, II, III	25	91
Southern chervil	*Chaerophyllum tainturieri*	V	I	5	
Atlantic white cedar	*Chamaecyparis thyoides*	V	III	1	
Northern sea oat	*Chasmanthium latifolium*	P	I, II, III	32	
Chinese fringetree	*Chionanthus retusus*	VNN	II	2	
Fringetree	*Chionanthus virginicus*	P	I, II, III	3	3
Stout woodreed	*Cinna arundinacea*	V	I, II	2	
Hardy orange	*Citrus trifoliata*	I	II	1	
Chinese clematis	*Clematis chinensis*	VNN	I, II	15	
Asiatic dayflower	*Commelina communis*	I	I, II, III	5	
Blue mistflower	*Conoclinium colestinum*	V	II	1	
Redflower ragleaf	*Crassocephalum crepidioides*	VNN	I, III	3	
Black hawthorn	*Crataegus douglasii*	P	II	1	4

Parsley hawthorn	*Crataegus marshallii*	P	I	4	32
Chinese hawthorn	*Crataegus pinnatifida*	VNN	II	2	5
Green hawthorn	*Crataegus viridis*	P	II	6	26
Bermuda grass	*Cynodon dactylon*	I	II, III	2	
Nut grass	*Cyperus rotundus*	VNN	II	4	
Orchard grass	*Dactylis glomerata*	VNN	III	1	
Poverty grass	*Danthonia spicata*	V	II	3	
Panicledleaf ticktrefoil	*Desmodium paniculatum*	V	I	1	
Deertongue	*Dichanthelium clandestinum*	P	I, II, III	29	
Fewanther obscuregrass	*Dichanthelium oligosanthes*	V	I	1	
Carolina ponyfoot	*Dichondra carolinensis*	V	III	3	
Hairy crabgrass	*Digitaria sanguinalis*	VNN	II, III	5	
Buttonweed	*Diodia virginiana*	V	III	1	
Chinese yam	*Dioscorea polystachya*	I	II	1	
Persimmon	*Diospyros virginiana*	P	I	7	23
Autumn fern	*Dryopteris erythrosora*	VNN	I, II	5	
Thorny olive	*Elaeagnus pungens*	I	I, II, III	21	233
Autumn olive	*Elaeagnus umbellata*	I	I, II	7	26
Needle spikerush	*Eleocharis acicularis*	V	I, III	2	
Indian goosegrass	*Eleusine indica*	VNN	III	1	
Bottlebrush grass	*Elymus hystrix*	P	I, III	4	
Virginia wildrye	*Elymus virginicus*	P	I, II, III	22	
American burnweed	*Erechtites hieraciifolia*	V	I, II, III	12	
Daisy fleabane	*Erigeron annuus*	V	I, II, III	5	
Hairy fleabane	*Erigeron bonariensis*	V	II	1	
Horseweed	*Erigeron canadensis*	V	II, III	12	
American strawberry bush	*Euonymus americanus*	P	I, II	20	46
Wintercreeper euonymus	*Euonymus fortunei*	I	I, II, III	37	
Dogfennel	*Eupatorium capillifolium*	V	II	7	
Late boneset	*Eupatorium serotinum*	V	I, II	5	
Spotted spurge	*Euphorbia maculata*	V	III	1	
Joe pye weed	*Eutrochium fistulosum*	P	I	5	
American beech	*Fagus grandifolia*	V	II	3	8
White ash	*Fraxinus americana*	V	I, II	10	14
Green ash	*Fraxinus pennsylvanica*	P/V	I, II, III	19	16
Cleavers	*Galium aparine*	V	I, III	4	
Pennsylvania everlasting	*Gamochaeta pensylvanica*	VNN	II	3	
Honey locust	*Gleditsia triacanthos*	V	I, II	5	5
Fowl mannagrass	*Glyceria striata*	V	I, II	3	
Witch hazel	*Hamamelis virginiana*	P	I	6	35
English ivy	*Hedera helix*	I	I, II, III	48	
Common hibiscus	*Hibiscus syriacus*	I	I	3	6
Chameleon plant	*Houttuynia cordata*	I	I	1	
Lawn marshpennywort	*Hydrocotyle sibthorpioides*	I	II	1	
Deciduous holly	*Ilex decidua*	P	I, II	15	120
American holly	*Ilex opaca*	P/V	I, II, III	37	80
Winterberry	*Ilex verticillata*	V	I	2	14
Orange jewelweed	*Impatiens capensis*	V	I, II, III	21	
White morning-glory	*Ipomoea lacunosa*	V	II	4	
Common morning-glory	*Ipomoea purpurea*	VNN	III	1	
Yellow iris	*Iris pseudacorus*	I	II	1	
Virginia sweetspire	*Itea virginica*	P	I	2	
Black walnut	*Juglans nigra*	V	I, II	18	11
Soft rush	*Juncus effusus*	P	II, III	3	
Poverty rush	*Juncus tenuis*	V	I, II, III	8	
Eastern red cedar	*Juniperus virginiana*	V	I, II, III	13	7
Golden raintree	*Koelreuteria paniculata*	VNN	I	5	1
Crepe myrtle	*Lagerstroemia indica*	VNN	I, II	1	1
Rice cut grass	*Leersia oryzoides*	P	I	1	
Whitegrass	*Leersia virginica*	V	I, II, III	17	
Virginia pepperweed	*Lepidium virginicum*	V	I, III	2	
Lespedeza	*Lespedeza cuneata*	I	I, II	7	
Japanese privet	*Ligustrum japonicum*	I	I	1	
Glossy privet	*Ligustrum lucidum*	I	I, II, III	57	2848
Chinese privet	*Ligustrum sinense*	I	I, II, III	49	817
Spicebush	*Lindera benzoin*	P	I	20	90
Sweetgum	*Liquidambar styraciflua*	V	I, II, III	29	176
Tulip-poplar	*Liriodendron tulipifera*	P	I, II, III	31	139

Lilyturf	*Liriope muscari*	I	I, II, III	26	
Creeping lilyturf	*Liriope spicata*	I	I, II	10	
Tall fescue	*Lolium arundinaceum*	I	I, III	2	
Perennial ryegrass	*Lolium perenne*	P	III	1	
Winter honeysuckle	*Lonicera fragrantissima*	I	II	2	
Japanese honeysuckle	*Lonicera japonica*	I	I, II, III	36	
Amur honeysuckle	*Lonicera maackii*	I	I, II	12	
Netted chain fern	*Lorinseria areolata*	V	I	1	
Marsh seedbox	*Ludwigia palustris*	V	II	2	
Hairy wood-rush	*Luzula pilosa*	VNN	II	3	
Southern magnolia	*Magnolia grandiflora*	V	I, II, III	17	66
Japanese mazus	*Mazus pumilus*	VNN	II	1	
Chinaberry	*Melia azedarach*	I	I, II	6	9
Lemon balm	*Melissa officinalis*	VNN	III	1	
Japanese stiltgrass	*Microstegium vimineum*	I	I, II, III	45	
Common wax myrtle	*Morella cerifera*	P/V	I, II, III	31	378
White mulberry	*Morus alba*	I	I, II, III	43	214
Red mulberry	*Morus rubra*	V	II	1	2
Nimbleweed	*Muhlenbergia schreberi*	V	II	3	
Wartremoving herb	*Murdannia keisak*	I	II	4	
Muscadine	*Muscadinia rotundifolia*	V	I, II, III	9	
Heavenly bamboo	*Nandina domestica*	I	I, II, III	15	7
Black gum	*Nyssa sylvatica*	P	II	2	5
Garden star-of-bethlehem	*Ornithogalum umbellatum*	I	I	1	
Leverwood	*Ostrya virginiana*	V	I	1	1
Creeping woodsorrel	*Oxalis corniculata*	V	II, III	4	
Slender yellow woodsorrel	*Oxalis dillenii*	V	II, III	7	
Sourwood	*Oxydendron arboreum*	P	II	1	4
Witchgrass	*Panicum capillare*	V	II	1	
Quack grass	*Panicum repens*	I	II	1	
Switchgrass	*Panicum virgatum*	P	II	1	
Virginia creeper	*Parthenocissus quinquefolia*	V/P	I, II, III	45	
Dallis grass	*Paspalum dilatatum*	I	III	1	
Yellow passionflower	*Passiflora lutea*	V	I	1	
Princess tree	*Paulownia tomentosa*	I	II	2	2
Beefsteak plant	*Perilla frutescens*	I	II, III	3	
Swamp smartweed	*Persicaria hydropiperoides*	V	I, III	2	
Oriental lady's thumb	*Persicaria longiseta*	I	I, II, III	10	
Dotted smartweed	*Persicaria punctata*	V	II, III	4	
Jumpseed	*Persicaria virginiana*	V	I	1	
Reed canary grass	*Phalaris arundinacea*	V	II, III	2	
Chinese photina	*Photinia serratifolia*	VNN	II	1	37
Chamber bitters	*Phyllanthus urinaria*	I	II	3	
Golden bamboo	*Phyllostachys aurea*	I	I	2	174
Pokeweed	*Phytolacca americana*	V	I, II, III	18	
Loblolly pine	*Pinus taeda*	V	I, II, III	35	356
Chinese pistache	*Pistacia chinensis*	VNN	I, II	3	10
Ribwort plantain	*Plantago lanceolata*	VNN	I	1	
Blackseed plantain	*Plantago rugelii*	V	II	1	
Sycamore	*Platanus occidentalis*	P	I, II, III	44	123
Annual bluegrass	*Poa annua*	VNN	I, II	2	
Christmas fern	*Polystichum acrostichoides*	V	I, II	11	
Pickerelweed	*Pontederia cordata*	P	I	1	
Mock strawberry	*Potentilla indica*	I	I, II, III	10	
Self-heal	*Prunella vulgaris*	V	II	2	
American plum	*Prunus americana*	V	I	1	
Laurel cherry	*Prunus caroliniana*	V	I, II, III	48	897
Cherry plum	*Prunus cerasifera*	VNN	I	1	2
Japanese apricot	*Prunus mume*	VNN	II	1	
Pin cherry	*Prunus pensylvanica*	V	I	1	3
Peach	*Prunus persica*	VNN	I	2	4
Black cherry	*Prunus serotina*	V	I, II, III	38	135
Japanese cherry	*Prunus serrulata*	VNN	I	1	1
Kudzu	*Pueraria montana*	I	I, II	29	
Callery pear	*Pyrus calleryana*	I	I, II, III	32	221
White oak	*Quercus alba*	P	I, II	13	27
Swamp white oak	*Quercus bicolor*	P	III	2	4
Laurel oak	*Quercus laurifolia*	V	I, II	13	16

Overcup oak	*Quercus lyrata*	V	I, II	2	
Swamp chestnut oak	*Quercus michauxii*	P	I	6	5
Water oak	*Quercus nigra*	V	I, II	22	93
Pin oak	*Quercus palustris*	V	I, II	2	1
Willow oak	*Quercus phellos*	V	I, II, III	42	63
Red oak	*Quercus rubra*	P/V	I, II, III	16	20
Shumard oak	*Quercus shumardii*	V	I	3	3
Black oak	*Quercus velutina*	P	I, II	6	11
Little-leaf buttercup	*Ranunculus abortivus*	V	I, II	4	
Japanese knotweed	*Reynoutria japonica*	I	II	3	
Common buckthorn	*Rhamnus cathartica*	I	II	1	
Rhododendron	*Rhododendron maximum*	V	I	1	
Western azalea	*Rhododendron occidentale*	VNN	I	1	1
Pinxster-flower	*Rhododendron periclymenoides*	P	I	7	21
Black locust	*Robinia pseudoacacia*	V	I, II, III	45	206
Multiflora rose	*Rosa multiflora*	I	I, II, III	17	
American blackberry	*Rubus allegheniensis*	V	I, III	5	
Sawtooth blackberry	*Rubus argutus*	V	I	5	
Southern dewberry	*Rubus trivalis*	V	I, II, III	33	
Orange coneflower	*Rudbeckia fulgida*	V	III	1	
Clustered dock	*Rumex conglomeratus*	VNN	I, II, III	11	
Dwarf palmetto	*Sabal minor*	V	II	1	
Black willow	*Salix nigra*	P	I, II, III	24	77
Lyreleaf sage	*Salvia lyrata*	V	II	2	
Nettleleaf sage	*Salvia urticifolia*	V	III	1	
American elderberry	*Sambucus canadensis*	P	I, II, III	23	141
Canadian black snakeroot	*Sanicula canadensis*	V	I, II, III	5	
Sassafras	*Sassafras albidum*	P	I	7	40
Lizard's tail	*Saururus cernuus*	P	II	1	
Annual blue-eyed grass	*Sisyrinchium angustifolium*	V	II	1	
Saw greenbrier	*Smilax bona-nox*	V	I	1	
Cat greenbrier	*Smilax glauca*	V	I, II	5	
Smooth carrionflower	*Smilax herbacea*	V	I	1	
Smilax	*Smilax rotundifolia*	V	I, II, III	26	
Carolina horsenettle	*Solanum carolinense*	V	I, II, III	10	
Tall goldenrod	*Solidago altissima*	V	I, II	3	
Silverrod	*Solidago bicolor*	V	II	1	
Bluestem goldenrod	*Solidago caesia*	V	I, II, III	6	
Canada goldenrod	*Solidago canadensis*	V	I, II, III	5	
Giant goldenrod	*Solidago gigantea*	V	I, II	3	
Wrinkleleaf goldenrod	*Solidago rugosa*	V	II	1	
Johnson grass	*Sorghum halepense*	I	I, II, III	5	
Heartleaf hedgenettle	*Stachys cordata*	V	II, III	2	
Chickweed	*Stellaria media*	I	I	1	
Japanese snowbell	*Styrax japonicus*	VNN	II	1	
Silky dogwood	*Swida amomum*	P	I, II, III	17	31
Panicled aster	*Symphyotrichum lanceolatum*	V	I, II, III	6	
Calico aster	*Symphyotrichum lateriflorum*	V	I, II, III	6	
Purplestem aster	*Symphyotrichum puniceum*	V	I, III	2	
Bald cypress	*Taxodium distichum*	V	II, III	5	21
Poison ivy	*Toxicodendron radicans*	V	I, II, III	42	
White clover	*Trifolium repens*	VNN	II, III	2	
Society garlic	*Tulbaghia violacea*	VNN	I	1	
Winged elm	*Ulmus alata*	V	II	1	
American elm	*Ulmus americana*	V	I, II, III	39	204
Chinese elm	*Ulmus parvifolia*	I	I, II, III	22	38
Red elm	*Ulmus rubra*	V	I, II	3	
Common speedwell	*Veronica officinalis*	VNN	II	1	
Mapleleaf viburnum	*Viburnum acerifolium*	V	I	1	5
Arrowwood viburnum	*Viburnum dentatum*	V	I	2	15
Withe-rod	*Viburnum nudum*	P	I	11	3
Japanese snowball	*Viburnum plicatum*	VNN	I, II	3	1
Blackhaw	*Viburnum prunifolium*	V	III	1	19
Common vetch	*Vicia sativa*	VNN	I	1	
Common violet	*Viola sororia*	V	I, II, III	16	
Wisteria	*Wisteria sinensis*	I	I, II	9	
Shrub yellowroot	*Xanthorhiza simplicissima*	V	II	1	
Youngia	*Youngia japonica*	I	I, II	15	
Japanese zelkova	*Zelkova serrata*	VNN	I	2	2
Atamasco-lily	*Zephyranthes atamasco*	V	III	1	