An Evaluation of Forest Impacts Compared To Benefits Associated with Stream Restoration

Prepared For:

Chesapeake Bay Trust
Restoration Research Award Program

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I. Introduction

Stream restoration has become a growing practice in the Mid-Atlantic region, particularly as restoration offers benefits such as bank stabilization and reductions in sediment and nutrient loads to downstream waterways. To achieve project goals, restoration design approaches often include reconnection of a stream to its floodplain. At present, restoration benefits in terms of water quality and habitat improvement are receiving attention; however, it is less well known whether benefits outweigh the potential impacts to forest communities when a stream is reconnected to the floodplain. Maryland Department of Natural Resources' guidelines for stream restoration projects (DNR 2015) emphasize the importance of minimizing impacts to existing forest resources.

While scientists are always reluctant to place a value on the importance of one habitat type over another, there is a consensus in ecological literature that the rarer or more unique a habitat, the higher its conservation priority. Therefore, given the scarcity of fully functioning floodplains in urbanized portions of the Chesapeake Bay watershed, converting upland forest to riparian or floodplain forest should represent a net gain to species diversity and the overall ecological health of the watershed. In practice, however, these benefits may not be fully realized due to habitat fragmentation and anthropogenic structures within watersheds, both of which pose serious impediments to normal dispersal of native species. The purpose of this study was to measure the response of upland forest to reestablishment of a floodplain flooding regime and resulting changes in the local ecological community, if any.

This study addresses the question outlined in *Section 8(a) of the CBT 2017 Request for Proposals: Resource trade-offs in different types of restoration projects with focus on (a) tree trade-offs in stream restoration projects*. Specifically:

- What are the impacts of stream restoration on biological communities found on the floodplain?
- Does reconnection of the floodplain to the stream alter the functional composition and diversity of plant communities?
- Do invasive species increase or decrease after the floodplain is hydrologically reconnected to the stream?
- Are soil nutrient stocks in the floodplain altered in response to reconnection to the stream? Or to changes in plant functional composition?

II. Literature Review

A primary design approach for stream restoration is reconnecting the stream to its floodplain. Reconnection of side channels contributes to improved hydro-geomorphological linkages. According to Meyer, et al. (2013), hydro-geomorphological conditions largely influence communities that colonize the floodplain after disturbance from stream restorations.

Further research suggests hydro-geomorphological restoration results in different community assemblages because floodplain vegetation has strong reactions to a changing habitat, such as the addition of niches within the community (Januschke, et al. 2014). Creation of additional habitat as a result of stream restoration (Jähnig, et al. 2009) is believed to be a driving factor in the increase of floodplain vegetation found along restored stream edges.

One method used to examine effects of stream restoration on floodplain vegetation is to examine restored versus non-restored sections of the stream. Januschke, et al (2011) used this method to analyze impact of stream restoration in Germany and found riparian habitat diversity doubled in restored sections of the stream compared to non-restored areas. Species richness also increased in restored sections (Januschke, et al, 2011). A more recent study analyzed several taxonomic groups of biota, including floodplain vegetation, and found that floodplain vegetation responded positively to restoration (Pilotto, et al, 2018). In addition to increase in species richness, floodplain vegetation has been found to have high recolonization rates.

Over a five year interval, one group of researchers examined biotic communities in and around several restored streams in Germany; and found riparian assemblages colonized and improved more rapidly than aquatic assemblages (Lorenz, et al., 2018). A few years prior, a study found similar results with high immigration rates of floodplain vegetation in restored streams 3-5 years post-restoration and 7-9 years post-restoration (Januschke et al., 2014). High colonization rates are common among the majority of vegetation, both native and exotic. Paillex et al. (2017) detected a significantly better ecological state for riparian vegetation in restored reaches of the stream; however, a large presence of invasive plant species was also found in these restored areas, counteracting much of the ecological benefit.

When considering the success of post-restoration floodplain vegetation recolonizing, it is important to understand species composition and the amount of native versus non-native species present. A graduate student from North Carolina State University designed a study to determine the extent of invasion by exotic plants in restored streams versus undisturbed, reference streams (Malone, 2011). Restored streams had 34% exotic species cover whereas reference areas only had 10% exotic cover. With a high density of exotic plants, restored riparian areas are far from their ecological potential.

The outcome of stream restoration projects varies greatly depending on region, project goals, budget, and construction company. Largely due to differences in restoration projects, researchers have found varying results in riparian plant communities post-restoration. One study conducted near Baltimore found notably low numbers of exotic tree species near restored stream sections (Beauchamp, et al., 2015). A possible explanation for these results is the priority and planting preference by construction companies to plant native species after restoration (Beauchamp et al., 2015). Time after restoration is another important factor to consider when analyzing riparian vegetation. Meyer et al. (2013) found few changes in riparian vegetation over their study interval and suggest further research should begin immediately following a stream restoration project to understand vegetation dynamics over time.

III. Study Design

Stream restoration projects often include reconnecting a stream to its floodplain. At present, little is known about potential impacts to surrounding forest communities from such reconnections. Versar staff, in consultation with Dr. Verl Emrick at the *Virginia Tech Conservation Management Institute*, developed a study design to evaluate impacts of stream restoration projects, which include an adjacent floodplain, on biological communities found within that floodplain. Specifically, we evaluated woody (including trees) and herbaceous plant communities. Data from four stream restoration projects and three different site treatments were collected, analyzed, and compared.

Versar coordinated with stream management staff and professionals, familiar with Harford, Anne Arundel, and Howard Counties, to identify potential stream restoration project locations that were suitable for this study. Several locations – "**study sites**" - were considered so that research elements could be replicated across a variety of environmental surroundings and watersheds. At selected study sites, three different "**site treatments**" were identified to be able to detect differences that might affect biological communities. Three "**plots**" were then identified within each site treatment to provide additional statistical power to this study.

III.A Study Site, Site Treatment, & Plot Selection

After initial consultation with stream managers/professionals, candidate study sites were reviewed further using aerial photographs and spatial data in *ArcGIS* software. Analysts evaluated suggested study sites and field crews identified those with each of these attributes:

- Distinct stream reaches characterized by three site treatments (See Table 1)
- Need to be of similar size to each other
- Be between 200-350 meters in length,
- Have a floodplain wide enough for vegetation plots, ≥100 meters
- Was/is forested pre- and post-restoration,
- Is situated in an urban environment, and
- The catchment area is predominantly impervious.

Three study sites were selected for Year One of the study; Church Creek and Dividing Creek in Anne Arundel County, and Red Hill Branch in Howard County. For Year Two, Church Creek was not sampled, and Wheel Creek in Harford County was the third site (See Figure 1). This decision was made collaboratively, between Versar and the Chesapeake Bay Trust, to diversify the areas selected for study.
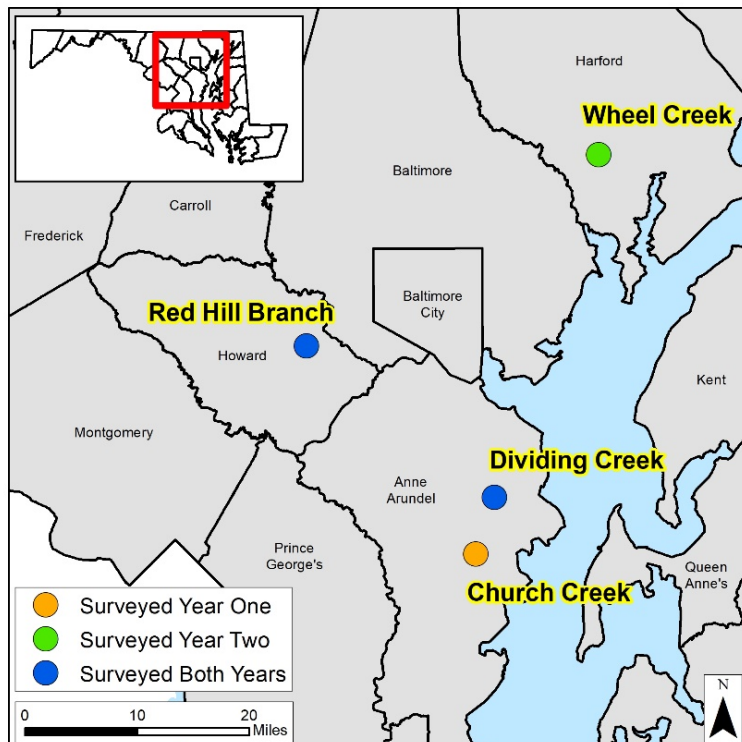
Figure 1. *Location of Selected Study Sites*

At the conclusion of study site selection, 10-meter study plots were tentatively determined using *ArcGIS* software and random coordinate selection. Plot locations were based on their physical characteristics and must be situated within the floodplain. Plots that were too far up slope, in standing water, or too close to a stream or property boundary were rejected. Three plots were delineated for each site treatment, for a total of nine plots at each study site (See Figure 2).
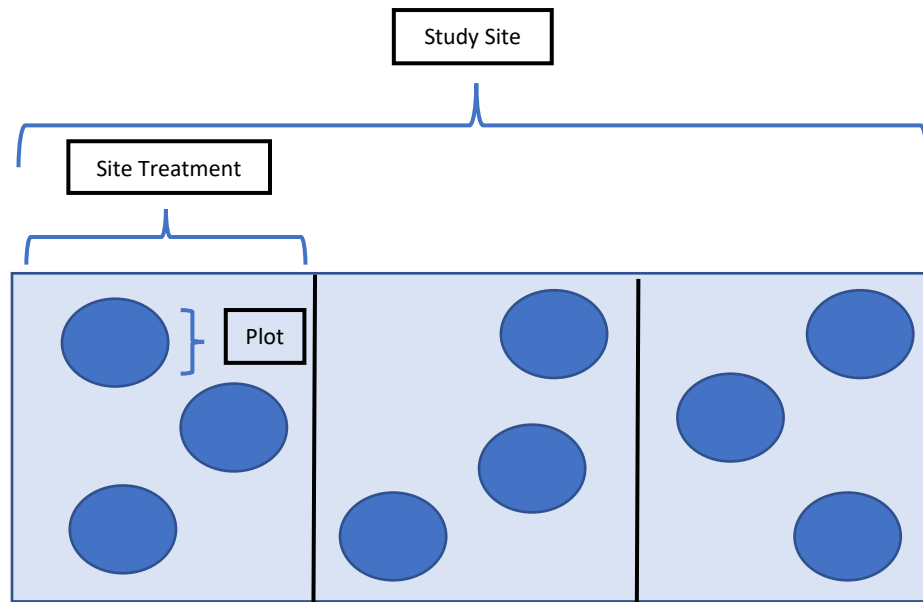
Figure 2. *Diagrammatic Representation of Sampling Plot Selection.*

Versar staff then conducted field evaluations to verify that each selected study site included the three treatments defined in Table 1. After field evaluation of the study sites verified that each supported the three site treatments, minor adjustments to each initial GPS plot location was made if there were physical restrictions not accounted for in GIS analysis. Such restrictions included large patches of thorn bushes, rendering the area unable to be thoroughly sampled. After necessary adjustments, field crews marked all tentative study plots using a piece of metal rebar, and used a pre-measured rope to outline the plot. New plot coordinates were recorded using *Trimble* GPS devices.

Table 1. Site Treatment Criteria	
Site Treatment	**Defining Criteria**
Restoration (RES)	Must provide connection to its forested floodplain[1]
	Must have reference and control treatment reaches nearby
	Restoration reach must be long enough for sample plots
Reference (REF)	Must provide connection to its forested floodplain[1]
	Stream and floodplain in good natural condition
	Similar physical/topographic setting as restoration treatment[2]
	Stream characteristics similar to restoration treatment
Control (CON)	Situated next to, but not connected to, a forested floodplain
	Similar physical/topographic setting as restoration treatment[2]
	Stream characteristics similar to restoration treatment
	Is severely incised

[1] Floodplain must be wide enough for three plots (See Figure 7)
[2] Including roughly the same length and floodplain area as restoration treatment

III.B Study Site Descriptions

Church Creek (CC) restoration took place during 2015 and into early 2016. This study site is situated north of MD 665, on either side of MD 2, in Annapolis. The South River Federation (now Arundel Rivers), in cooperation with Anne Arundel County, undertook restoration of this portion of Church Creek near the County's current biological, physical, and chemical monitoring stations. This work consisted of 1,500 linear feet of stream restoration, step-pool storm conveyance, riffle weirs, and grade control structures to improve habitat and increase floodplain connectivity.

Figure 3. *Church Creek Study Site*

Figure 4. Dividing Creek Study Site

Dividing Creek (DC) restored approximately 1,100 linear feet of low-quality stream and retrofitted two outdated stormwater management facilities, was completed in 2016. It is located on the Anne Arundel Community College main campus, just west of the west Ring Road entrance off College Parkway. The project also created 150 linear feet of step pool conveyance to help stabilize an outfall for an adjacent pond retrofit. At the conclusion of restoration, Anne Arundel County Public School's *Office of Environmental Literacy and Outdoor Education Program* planted native trees, shrubs, and herbaceous plants in spring 2016.
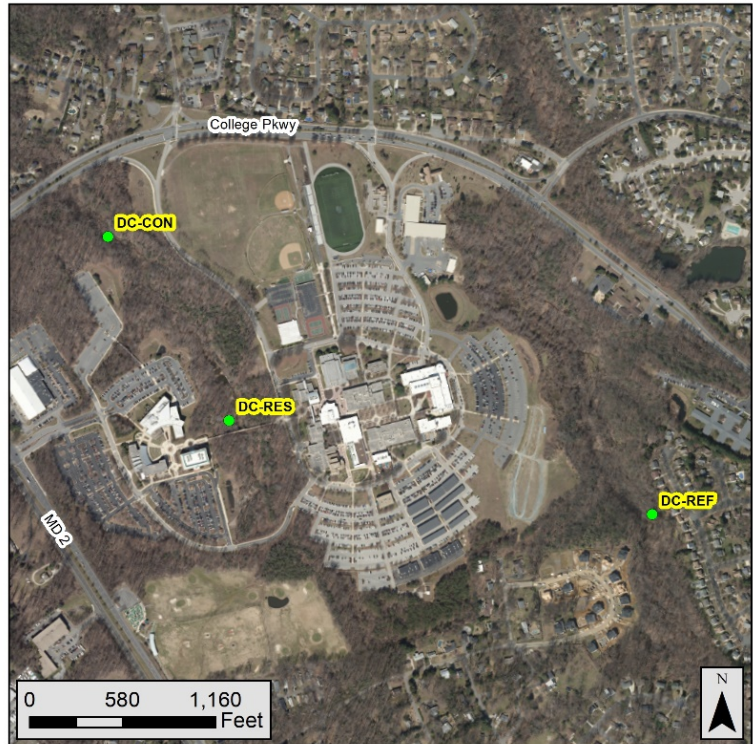
Restoration of **Red Hill Branch (RH)** took place in 2011. The study site is situated in the SE quadrant of US 29 and MD 100, along the south perimeter of Meadowbrook Park, in Ellicott City. The stream was restored by stabilizing and re-vegetating 3,165 linear feet of stream bank to reduce excess nutrient and sediment loading. Red Hill Branch was continuously monitored before and after restoration by Howard County Bureau of Environmental Services, Maryland DNR, Versar, and KCI.

Figure 5. Red Hill Branch Study Site.

Figure 6. *Wheel Creek Study Site*

Wheel Creek (WC) restoration took place from December 2015 through February 2016. Several stream restoration projects have occurred along Wheel Creek. The study site used for this project is located in the west quadrant of S Tollgate Road and W Wheel Creek Road, in Belair. This site has been continuously monitored by Harford County DPW, Maryland DNR, USGS, Versar, and KCI.

IV. Data Collection Methods

The goal of data collection was to gather a wide variety of data that could be used for various analyses. Versar's scientists focused their analysis on overall counts and diversity of woody and herbaceous plants found across different site treatments and study sites. Invasive species cover was also analyzed for connections between invasive species and stream restoration projects. Virginia Tech's *Conservation Management Institute* conducted additional analyses on plant functional groups and their connection with soil nutrients found across treatments and study sites. All data collected are provided in digital form in the Data Appendix.

Field crews navigated to the selected study sites using GPS coordinates and maps, produced using GIS software. Once at the sites, crews adjusted their coordinates as needed so that the habitat surveyed did not include any portion of a waterbody. They installed a piece of metal rebar into the center of the plot, marked a waypoint in GPS, and recorded coordinates on a *CBT Vegetation Survey Data Sheet* (See Data Appendix). Immediately following this set-up, crews began taking pictures of each plot. One photo was taken outside of the plot facing into the plot to capture the four-meter plot area. While standing over the center rebar, photos were taken in the four cardinal directions. These five pictures in total were used to create a photo log for reference and use the following year. After taking photos, field crews recorded the bearing, photo numbers, and camera used, on a field datasheet

After taking pictures of the plot, field crews delineated 4-meter sub-plots and 10-meter plots. Using a pre-measured rope, crews placed one end of the rope around the center rebar using a carabiner and stretched the rope across the plot. The rope indicated 4-meter and 10-meter lengths, and crews marked dashed lines at these points around the plot. The result was a plot resembling the image in Figure 7. Crews used a compass to determine the

four cardinal directions and placed wired flags at these points along the edge of the 10-meter plot.
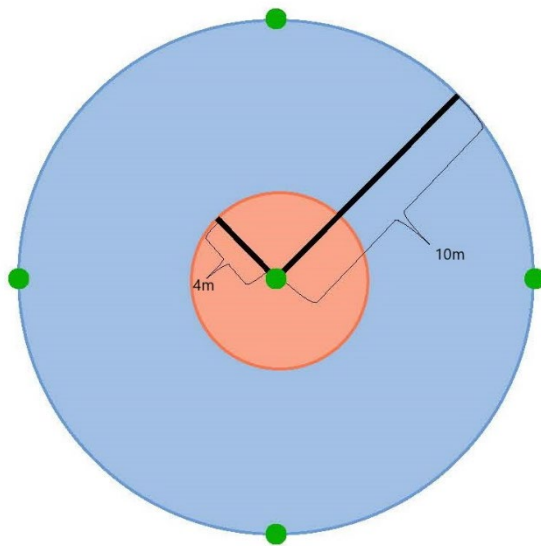
Figure 7. *Layout of 4-meter sub-plots and 10-meter Plots at Each Treatment Area. Green Dots Represent the Center and Four Cardinal Directions on the Plot.*

Photos were then taken for use to analyze canopy density. Photos were taken at the center rebar looking straight up and at each of the wired flags, used to indicate cardinal directions, while facing the center of the plot (Figure 7). In 2017, these pictures were taken on digital cameras, saved, and photo numbers recorded on a *CBT Vegetation Survey Data Sheet*. In 2018, field crews used a phone application called *CanopyApp* to take pictures of the canopy. There were five pictures taken at each plot, all canopy photos taken during the study can be found in the Data Appendix.

While at each study site, field crews collected a variety of data, including identification of woody and herbaceous plant species present. Among woody vegetation, crews differentiated species of trees from other woody species. Trees were evaluated for diameter at breast height (DBH), tree height, crown condition, and overall condition. Finally, crews collected soil samples and took photos of the plot and canopy cover.

Staff also conducted an herbaceous species survey by recording a list of species found and rating overall density of each species. In addition, overall species composition and basal area were evaluated for woody vegetation.

Field crews then identified herbaceous plants in the 4-meter sub-plot. Every plant species encountered in a sub-plot was identified to species level and recorded on the datasheet. Crews also recorded a "Vegetal Cover Code" which indicated the abundance of each species within the sub-plot (See Table 2). For woody plants found in the sub-plot, a stem count number was included along with the "Vegetal Cover Code".

Table 2. Herbaceous Species Cover Codes			
% Coverage	Value	% Coverage	Value
0-1	+	25-50	3
1-5	1	50-75	4
5-25	2	75-100	5

All trees in both 4-meter sub-plots and 10-meter plots were identified to species level. Those tree specimens found to be ≥ 5 cm DBH were measured for DBH. Crews determined if the tree was found in the 4-meter sub-plot or in the 10-meter plot and recorded all data on the datasheet. Overall and crown conditions were also determined using the rating scales shown in Table 3 and Table 4 and recorded on the datasheet.

Table 3. Overall Tree Condition	
Condition	**Value**
Good; no symptoms of disease/ other effects on growth and vitality	1
Slightly Affected; some symptoms	2
Severely Affected; symptoms that substantially affect the tree's growth and vitality	3
Dead/dying; damage that is or will lead to death, or the tree has fallen	4

Table 4. Crown Condition/Health	
Condition	**Value**
Good; dense, no dieback	1
Moderate; dense, visible dieback	2
Poor; less dense	3
Significant dieback	4
Dying; sparse, high dieback	5
Dead; already killed	6

Using a range finder, field crews measured their distance from each tree. Then, using a clinometer, they measured the angles to the base and to the top of the trunk. These measurements were used to calculate the height of the tree. Measurement data were noted on the datasheet. Field crews took tree core samples from one individual of each tree species found within the plot. Crews used a forestry grade increment borer to remove cores, which were cored at 4.5 ft above the ground. Cores were then placed into plastic straws, labeled and preserved for further analysis (tree cores obtained in 2018 only). In addition to tree cores, herpetological fauna seen or heard while sampling, were recorded. For additional information on tree core processing, herpetological fauna, and resulting data (See Data Appendix).

At each plot, five soil samples were taken, one at the center and four cardinal points. Soil samples were mixed in a bucket, creating one sample >50 grams. The combined soil samples were then sent to Penn State's lab for nutrient analysis. Impervious surface area for each catchment (measured from the downstream study plot) was determined from photointerpretation of 1:2000 scale aerial photographs in *ArcGIS*. Tree canopy percent was obtained by classifying field canopy images into canopy/non-canopy areas using *ArcGIS' Image Analyst* extension.

V. Data Management and Analysis

Versar staff collected and organized field datasheets for QA/QC procedures. Once all field forms were checked, data were entered into an Access database. The database was structured to align with field datasheets with a section for each field survey collection (i.e. 4-meter sub-plot, woody vegetation, photo documentation, etc.).

After all data were entered, additional Versar staff applied additional QA/QC review by cross referencing field forms and the database. From this database, spreadsheets were exported for further analysis.

Versar conducted preliminary analyses including calculating total number of species present, number of invasive species present, and overall difference between treatment types. Data were sent to Verl Emerick at the Virginia Tech *Conservation Management Institute* for statistical analysis on soil chemistry results and additional analysis on plant functional groups. The main results of analyses are summarized in the *Results and Discussion* section of this report. All other data collected in the field including site photos, canopy photos, and raw data can be found in the Data Appendix.

VI. Results & Discussion

Results and findings presented in this section are based on data collected by Versar in 2017 and 2018 at the four restoration study site locations across Maryland. Each study site evaluated for this project contains a completed reach of restored stream. Field staff examined and surveyed woody and herbaceous vegetation across these four study sites in the two-year study period.

A total of 32 tree species were found across all years, study sites, treatments, and plots. Of the study sites, Wheel Creek had the greatest number of trees per treatment, the most species per treatment, and the highest overall basal area (See Table 5). In contrast, Red Hill Branch had the fewest trees per treatment, was the least diverse, and had the lowest basal area (See Figure 8). Red Maple (*Acer rubrum)* was the dominant species across all plots, being found in 28 out of 36 plots studied over the study period. Red Maple was common at Church Creek, Dividing Creek, and Wheel Creek, but not common at Red Hill Branch. At Red Hill Branch, the dominant species was Black Walnut (*Juglans nigra)* with 19.5 observations (average of 2017 and 2018) (See Appendix A). At Church Creek, Dividing Creek, and Wheel Creek, the common species after Red Maple were American Hornbeam (*Carpinus caroliniana*), American Beech (*Fagus grandifolia),* Sweetgum *(Liquidambar styraciflua*), and Tulip Tree *(Liriodendron tulipifera)*. These species are all native to Maryland and are commonly found across the state. Of all tree species found across the plots, there was only one invasive tree species, Chinese Wisteria (*Wisteria sinensis*). This species was only found in one of the 36 plots studied; at a reference plot located at Dividing Creek. Four individuals were found in 2017 and the same four persisted in 2018. All other tree species found were native to Maryland.

Red Maple was observed most frequently across all treatment types but was found more at control treatments than in reference and restoration treatments (See Appendix A). Besides Red Maple, Sweetgum and Black Walnut were the dominant species found at Dividing Creek and Red Hill Branch, respectively. Several species were more common at reference treatments including American Hornbeam, American Witch-Hazel (*Hamamelis virginiana*), and Black Willow (*Salix nigra*).

Overall, it appears that location was the driving factor for species present at each study site. For example, Sweetgum was only found at Church Creek and Dividing Creek, both of which are in the Coastal Plain region. Sweetgum is known to be a mid-succession tree found in the Coastal Plain region of Maryland and is much less common in the Piedmont region (MBP 2020). Observations and counts of Sweetgum appear to align with the geographic province of study sites rather than the site treatment. This trend was common among other tree species and other study sites as well, but Sweetgum was one of the most notable examples.

Table 5. Summary of Woody Vegetation Data				
Study Site	**Treatment**	**# of Trees per Treatment**	**# of Species per Treatment**	**Total Basal Area (cm²)**
Church Creek	Control	29	4	838
	Reference	37	9	1129
	Restoration	23	9	630
Dividing Creek*	Control	35	9	860
	Reference	40.5	8	874
	Restoration	38	8	873
Red Hill Branch*	Control	11	5	280
	Reference	16	7.5	388
	Restoration	16.5	4.5	418
Wheel Creek	Control	67	13	1191
	Reference	87	10	1484
	Restoration	41	7	768

*These sites were sampled in 2017 and 2018, so an average of the two years was used for this table

As indicated in Figure 8 (# of species) and Figure 9 (basal area), there is no consistent pattern across study sites. The species count is highest in the control treatment at Wheel Creek, while it is lowest in the control treatment at Church Creek. The restoration treatment matches the reference treatment for number of species at Church Creek and Dividing Creek, while it is lower than either reference or control at Red Hill Branch and Wheel Creek (See Appendix B).

If it is assumed, for preliminary analysis, that species composition at the study sites is drawn from the same underlying pool, (which has not been tested and may not be true), the average and standard deviation species count for the control treatment is 7.8 +/- 3.6; the reference treatment 8.6 +/- 0.96; and the restoration treatment 7.1 +/- 1.7. Because the means are within one (1) standard deviation, it is unlikely that the treatment type could be demonstrated to have any effect on species diversity.

Number of Tree Species per Treatment

Figure 8. *Graph of Tree Species Per Treatment*
    These sites were sampled in 2017 and 2018, so an average of the two years was used

Total Basal Area

Figure 9. *Graph of Total Basal Area Per Treatment*
    These sites were sampled in 2017 and 2018, so an average of the two years was used

For herbaceous plants, Dividing Creek had the highest number of herbaceous species per treatment, Wheel Creek had the fewest (See Table 6). In general, across all study sites, the restoration treatment had more herbaceous plant species than the reference or control treatments, with a total of 117 species found. There was a total of 181 herbaceous plant species found across all sites and all years (See Appendix C).

Overall, common herbaceous species found were Oriental Bittersweet (*Celastrus orbiculatus),* Common Spicebush (*Lindera benzoin),* Japanese Honeysuckle *(Lonicera japonica),* Japanese Stiltgrass *(Microstegium vimineum),* Virginia Creeper *(Parthenociussus quinquefolia)*, and Glaucous Greenbrier (*Smilax glauca)*. Of these, *C. orbiculatus*, *L. japonica*, and *M. vimineum* all are non-native and invasive species in Maryland. The dominant herbaceous species across all study sites and treatments was Japanese Stiltgrass, which was found at 22 of 27 plots in 2018. Japanese Stiltgrass created particularly heavy ground cover at Dividing Creek and Red Hill Branch.

This is a stark contrast to woody vegetation which found very few invasive species. These results were expected due in part to the ability of herbaceous plants to colonize and persist more rapidly than woody vegetation, but it is still a crucial result of this study.

Table 6. Summary of Herbaceous Plant Data			
Study Site	**Treatment**	**# of Species per Treatment****	**Average # of Species per Plot**
Church Creek	Control	28	9.3
	Reference	45	15.0
	Restoration	46	15.3
Dividing Creek*	Control	31.5	13.7
	Reference	47	18.7
	Restoration	48.5	21.7
Red Hill Branch*	Control	32.5	13.0
	Reference	27.5	13.7
	Restoration	22.5	10.0
Wheel Creek	Control	26	8.7
	Reference	26	8.7
	Restoration	35	11.7

*These sites were sampled in 2017 and 2018, so an average of the two years was used

** This includes woody species that were found inside the 4-meter sub-plots

Herbaceous plants were split into four functional groups for additional analyses. The following is a list of plant functional groups and definitions:

- **C3 Grasses –** perennial grasses with a more "primitive" carbon pathway during photosynthesis. These plants are adapted to cool season establishment and grow in either dry or wet environments. They have lower light and temperature requirements, thus have a lower productivity than C4 grasses. Examples include: sedges, fescues, rushes, cattails.
- **C4 Grasses –** perennial grasses with a more complicated carbon pathway. They are adapted to warm or hot season conditions, with higher temperature and light requirements and have a higher productivity than C3 grasses. Examples include: Japanese Stiltgrass (invasive), little bluestem, switchgrass
- **Forbs –** herbaceous plants that are not grasses. Compared to grasses, forbs produce a more persistent seed bank and tend to be heartier species. Examples include: milkweed, boneset, dandelions, goldenrod.
- **Legumes –** herbaceous plants that are important due to their symbiotic relationship with nitrogen-fixing bacteria that contribute nitrogen to surrounding soil. Legumes produce a pod as their fruit. Examples include clovers, kudzu, and vetches.
- **Woody Plants –** plants that produce wood as their structural tissue – usually trees or shrubs. Woody plants may enhance productivity and participate in carbon storage in an ecosystem.

Japanese Stiltgrass is one of the dominant plants found across all study sites and is categorized as a C4 plant. C4 plants are described as having higher productivity than C3 plants, which can explain in part why Japanese Stiltgrass was found in high quantities across study sites. It is important to note that Japanese Stiltgrass is a major invasive species across Maryland and is found in more places than our selected study sites; however, this study found Japanese Stiltgrass was the only herbaceous species that comprised 75-100% of ground cover of any study plot.
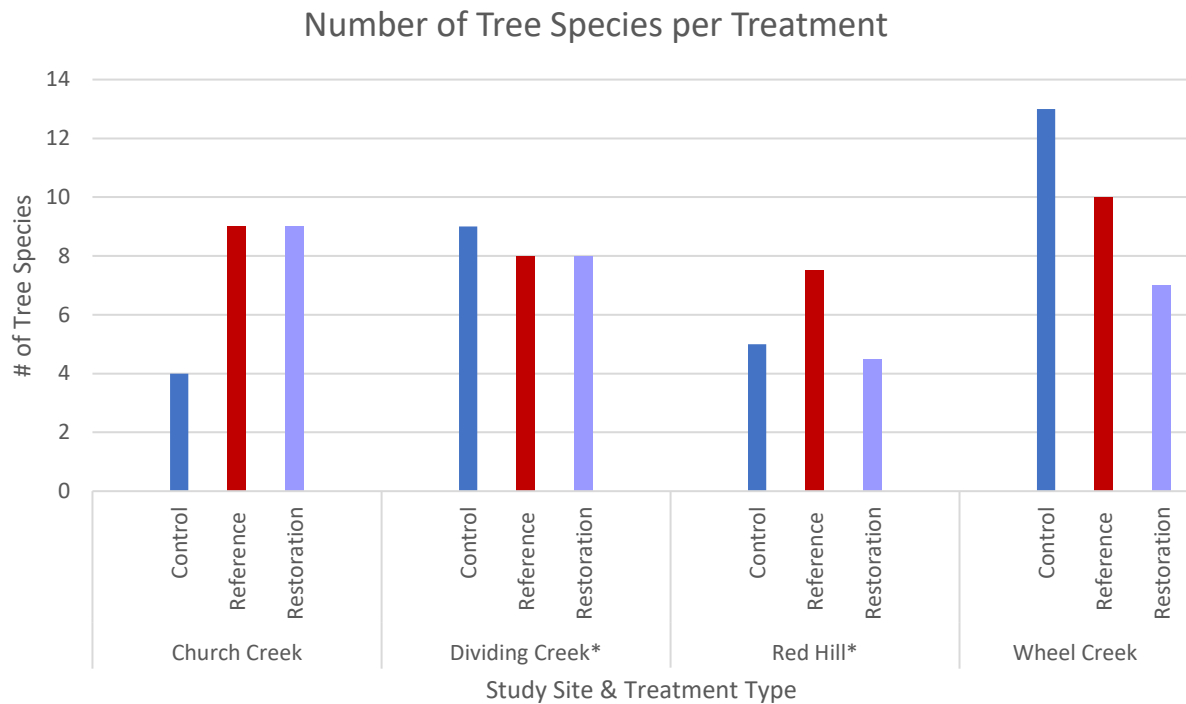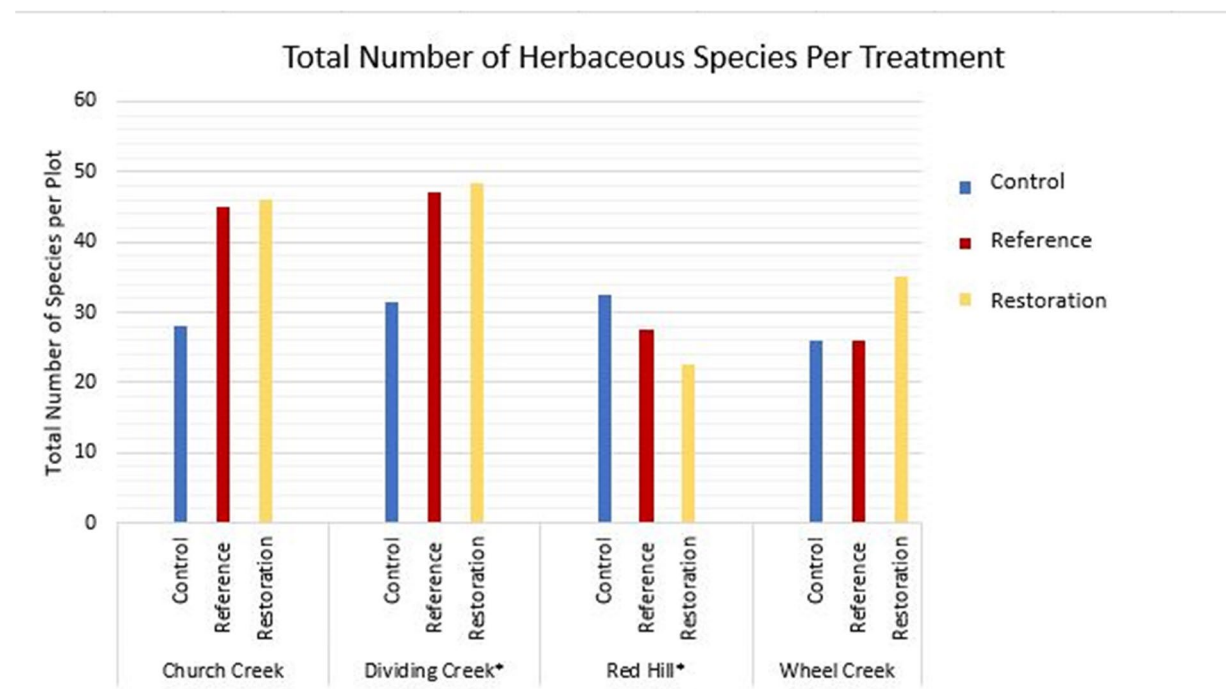

Figure 10. *Graph Herbaceous Species Per Treatment*
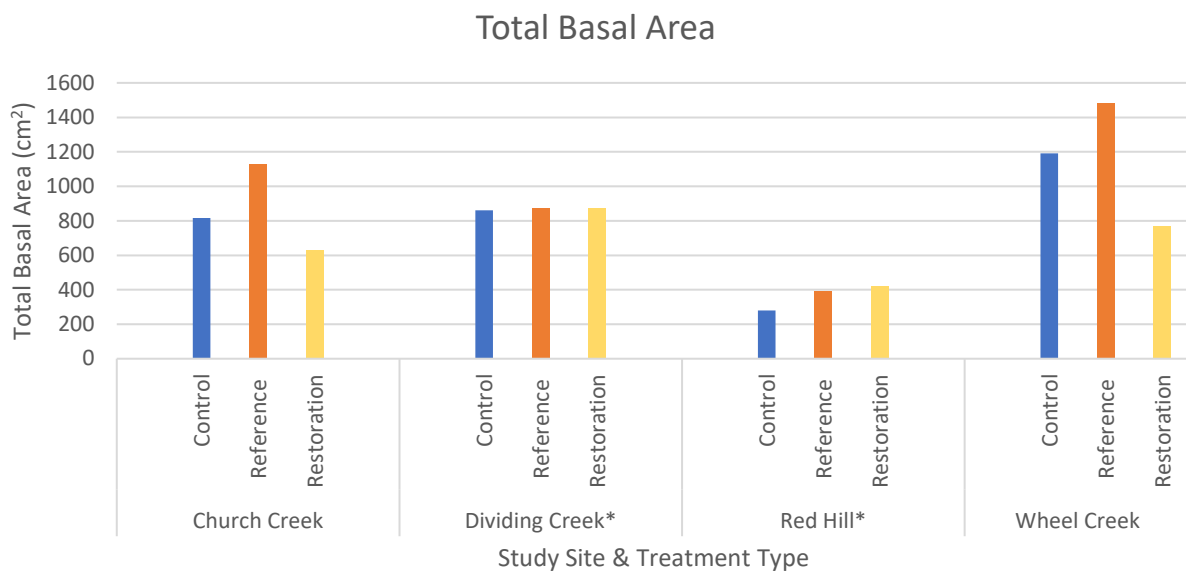**These sites were sampled in 2017 and 2018, so an average of the two years was used*

Plant functional groups were analyzed using an *ANOVA* to examine the difference between treatments. A Pearson Correlation Analysis and linear regression were also performed. This functional group analysis showed that restoration treatments 1) had higher species and functional richness than reference and control treatments, although the difference was not statistically significant, and 2) were similar to reference treatments in terms of a) higher C4 cover (similar to control treatments, though likely driven by the presence of Japanese Stiltgrass), and b) woody cover was higher than at reference treatments but similar to control treatments (See Data Appendix).

Soil samples collected at study sites were sent to the Penn State *Agricultural Analytical Services Laboratory* for nutrient analysis. Soils were tested for their percent Nitrogen, Carbon, and Phosphorus; Carbon to Nitrogen ratio (C:N ratio) was calculated as well. The results from soil analysis can be found in Table 7.

On average, Church Creek had the highest C:N ratio among all study sites, followed closely by Dividing Creek. Expressing these ratios relative to N=1, the Church Creek average ratio was 16.7 and Dividing Creek was slightly lower at 16.1. Red Hill Branch had the lowest C:N ratio, on average, with a ratio relative to N=1 of 11.7. These ratios indicate that soil respiration is N-limited, with a resulting buildup of organic carbon from roots and burial of vegetation detritus. This is expected and normal in forested areas.

Table 7. Summary of Soil Data Analysis					
Study Site	**Treatment**	**%N**	**%C**	**%P**	**C:N**
Church Creek	Control	0.160	2.51	0.062	15.8
	Reference	0.193	3.48	0.067	15.6
	Restoration	0.153	2.88	0.062	18.6
Dividing Creek*	Control	0.138	2.24	0.024	16.0
	Reference	0.145	2.40	0.034	16.7
	Restoration	0.158	2.43	0.039	15.5
Red Hill Branch*	Control	0.333	4.06	0.081	12.1
	Reference	0.208	2.34	0.062	11.1
	Restoration	0.210	2.50	0.079	11.9
Wheel Creek	Control	0.330	4.36	0.034	13.1
	Reference	0.227	2.92	0.041	12.7
	Restoration	0.267	3.33	0.042	12.5

*These sites were sampled in 2017 and 2018, so an average of the two years was used for this table

When evaluating soil nutrient content on its own, there are no correlations between nutrient content and treatment types – restoration, reference and control – rather, the variation is between study sites. However, when paired with other results such as plant functional groups and woody species cover, some modest relations were observed:

- **P Stocks –** correlated with higher C4/invasive species cover (Japanese Stiltgrass)
- **C:N –** declined as C4 cover increases
- **C:N –** increased as woody cover increases

The full set of Pearson Correlations is shown Figure 11, with selected regressions in Figures 12 and 13. Note that in Figure 11, there are only two correlations with magnitude above 0.6 – C:N ratio vs. C4 Cover, and C:N ratio vs. woody cover. Scattergrams with regression lines for these two cases are shown in Figures 12 and 13. These are very weak statistical results, with r^2 values (% variance explained) less than 0.5. As noted above, it is not unexpected to find higher C:N ratios in forested areas; the wide scatter shown in the graphs suggest that local conditions and site history are of greater importance than the amount of vegetation.

Pearson Correlation Matrix

	C4_COVER	C3_COVER	FORB_COVER	LEGUME_COVER	WOODY_COVER	N_MGG	C_MGG	P_MGG	CNRATIO
C4_COVER	1.000								
C3_COVER	-0.359	1.000							
FORB_COVER	-0.085	0.457	1.000						
LEGUME_COVER	-0.276	-0.032	0.251	1.000					
WOODY_COVER	-0.604	0.254	-0.031	0.154	1.000				
N_MGG	0.283	-0.372	-0.195	-0.051	-0.171	1.000			
C_MGG	-0.087	-0.218	-0.032	0.210	0.049	0.879	1.000		
P_MGG	**0.476**	-0.132	-0.018	0.186	-0.335	0.430	0.318	1.000	
CNRATIO	**-0.684**	0.265	0.031	0.224	**0.622**	-0.577	-0.207	-0.484	1.000

Figure 11. *Pearson Correlation Matrix*

Dependent Variable	P_MGG
N	18
p-value	**0.002**
Squared Multiple R	0.468
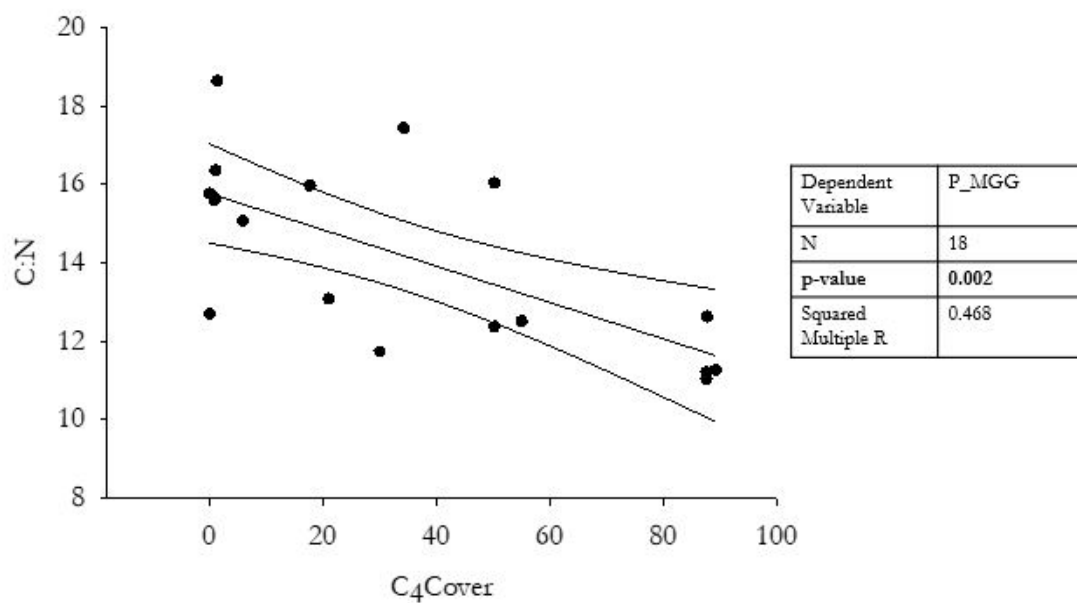
Figure 12. *C4 Cover and C:N Ratio*

Dependent Variable	P_MGG
N	18
p-value	**0.006**
Squared Multiple R	0.386
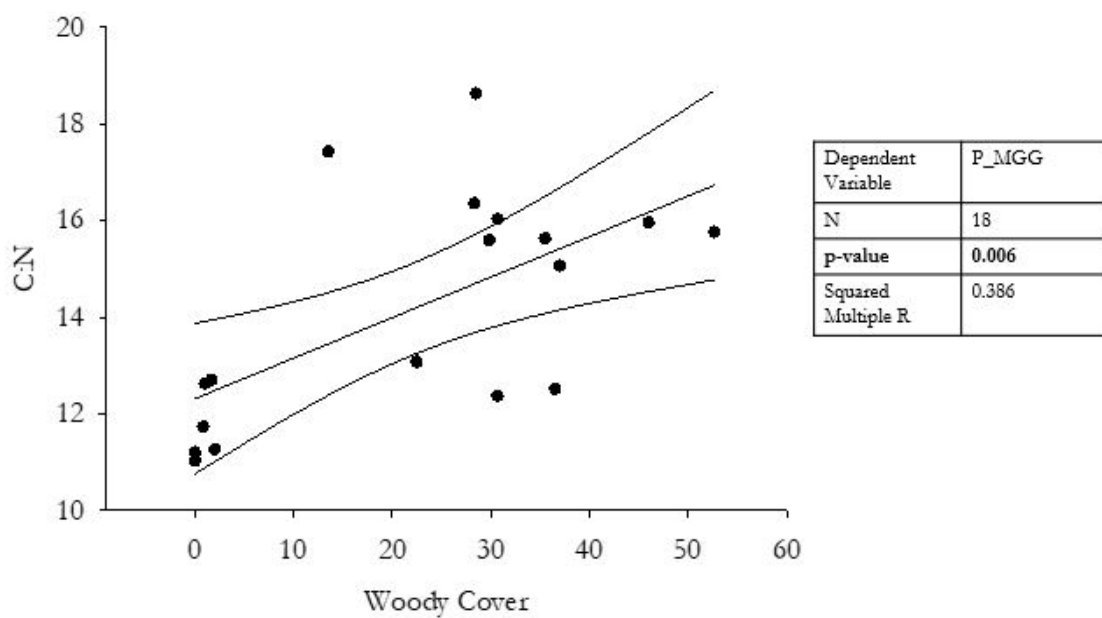
Figure 13. *Woody Cover and C:N Ratio*

VII. Conclusions

In the *Introduction*, it was noted that the purpose of the study was to measure response of forest species to reestablishment of a flooding regime, and to detect potential resulting changes in the local ecological community. The focus was on four specific questions, which we answer below in light of results discussed above.

Question 1 - What are observed impacts of stream restoration on biological communities currently found on the floodplain?

There were no detectable patterns in species diversity or tree basal area. At two of four restoration treatments, there were fewer species than either control and reference treatments (Figure 4), but restoration treatments matched reference treatments in species counts for the other two sites. In terms of tree species diversity, preliminary analysis of average species counts, by treatment type, show no effect of restoration vs. either control or reference. This mixed pattern is also seen in overall basal area (Table 5 and Figure 9), with restoration treatments as good or higher than the other two treatments in two of the study sites and measurably lower in the other two.

Question 2 - Does the reconnection of floodplain to a stream alter the functional composition and diversity of plant communities?

There was no clear evidence that reconnection of a stream's floodplain alters functional composition and diversity in plant communities. A plant functional group analysis showed that restoration treatments 1) had higher species richness and functional richness than reference treatments (the difference was not statistically significant), and 2) were similar to reference treatments in terms of a) higher C4 cover and b) higher woody cover than at reference treatments but similar to control treatments. It appeared that much variation, in the results, is likely due to geographical differences or different stream restoration approaches at study site locations. Future research should consider using stream reaches within the same watershed that underwent the same, or at least similar, stream restorations to limit influence of these confounding factors.

Question 3 - Do invasive species increase or decrease after the floodplain is hydrologically reconnected to the stream?

In terms of woody vegetation, there was only one invasive species found at all study sites, Chinese Wisteria, and that was in a reference treatment. All other tree species found in study plots were native to Maryland. However, the top five herbaceous species found at all treatments were all non-native, invasive species in Maryland. The dominant herbaceous species across all study sites was the invasive Japanese Stiltgrass (*Microstegium vimineum*) which was found at 22 of 27 study plots in 2018. Given the slightly higher occurrence of Japanese Stiltgrass at restoration treatments, it is possible that floodplain reconnection increases the presence of invasive species cover. However, there are too many confounding factors to draw this conclusion with any confidence; similar outcomes could result from any ground disturbance in Maryland.

Question 4 - Are soil nutrients stocks in the floodplain altered in response to reconnection to the stream? Or to changes in plant functional composition?

When evaluating soil nutrient content by itself, there are no correlations between nutrient content and the three treatments. Rather, variation is between study sites. There were very weak correlations between the cover amount of some species and the C:N ratio. However, these explained less than 50% of variance, and followed the natural C-enhancement pattern expected in forested areas. The wide scatter shown in the regression graphs (Figures 12 and 13) suggest that local conditions and site history are more important than the amount of vegetation in determining C:N ratio.

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APPENDIX A

Woody Vegetation Counts

Summary Table

Species	Church Creek			Dividing Creek			Red Hill Branch			Wheel Creek			Sum
	CON[1]	REF[2]	RES[3]	CON	REF	RES	CON	REF	RES	CON	REF	RES	
Acer negundo	3		1					1	2				7
Acer rubrum	24	17	7	11	10	8	1	2	0.5	16		23	119.5
Acer saccharinum			1										1
Alnus serrulata		1			2								3
Betula nigra								2					2
Carpinus caroliniana		1		3	13	4					23		44
Carya tomentosa										8	5		13
Cornus florida										2			2
Euonymus atropurpureus										1			1
Fagus grandifolia			1	1	1	3				18	12	1	37
Fraxinus americana											3		3
Fraxinus pennsylvanica		1					6			6		7	20
Hamamelis virginiana											16		16
Ilex glabra				3.5		2							5.5
Ilex opaca		1	3	1.5		2							7.5
Juglans nigra	1						1	7	11.5				20.5
Juniperus virginiana										1			1
Kalmia latifolia						1							1

1 CON = Control
2 REF = Referrence
3 RES = Restoration

Species	Church Creek			Dividing Creek			Red Hill Branch			Wheel Creek			Sum
	CON	REF	RES	CON	REF	RES	CON	REF	RES	CON	REF	RES	
Lindera benzoin				0.5									0.5
Liquidambar styraciflua		1	5	9	6.5	15							36.5
Liriodendron tulipifera			3	2	2	2				4	14	5	32
Malus coronaria								1					1
Nyssa sylvatica		2	1	3		1				3	1		11
Platanus occidentalis	1	3			2					1	2		9
Prunus serotina				0.5			1		1.5	4		2	9
Quercus alba			1							2			3
Quercus palustris								3					3
Quercus rubra										1	7	1	9
Quercus velutina											4		4
Robinia pseudoacacia												2	2
Salix nigra		10					2		1				13
Wisteria sinensis					4								4
# Unique Species	4	9	9	10	8	9	5	6	5	13	10	7	
Total Woody Individuals	29	37	23	35	40.5	38	11	16	16.5	67	87	41	

APPENDIX B

Woody Vegetation Basal Area

(cm^2)

Summary Table

Species	Church Creek CON[1]	Church Creek REF[2]	Church Creek RES[3]	Dividing Creek CON	Dividing Creek REF	Dividing Creek RES	Red Hill Branch CON	Red Hill Branch REF	Red Hill Branch RES	Wheel Creek CON	Wheel Creek REF	Wheel Creek RES	Sum
Acer negundo	49		29					11	60				149
Acer rubrum	720	572	268	366	251	356	63	24	32	280		278	3210
Acer saccharinum			65										65
Alnus serrulata		5			12								18
Betula nigra								33					33
Carpinus caroliniana		21		36	196	41					186		480
Carya tomentosa										216	108		324
Cornus florida										14			14
Euonymus atropurpureus										7			7
Fagus grandifolia			7	11	8	35				170	128	19	378
Fraxinus americana											20		20
Fraxinus pennsylvanica		23					144			116		185	468
Hamamelis virginiana											117		117
Ilex glabra				43		19							62
Ilex opaca		10	27	24		20							81
Juglans nigra	26						34	200	259				519
Juniperus virginiana										6			6
Kalmia latifolia						6							6

1 CON = Control
2 REF = Referrence
3 RES = Restoration

Species	Church Creek			Dividing Creek			Red Hill Branch			Wheel Creek			Sum
	CON	REF	RES	CON	REF	RES	CON	REF	RES	CON	REF	RES	
Lindera benzoin				4									4
Liquidambar styraciflua		24	104	151	192	267							738
Liriodendron tulipifera			62	149	82	107				175	684	102	1361
Malus coronaria								14					14
Nyssa sylvatica		37	7	68		22				31	7		172
Platanus occidentalis	43	60			115					35	66		319
Prunus serotina				8			14		36	37		40	135
Quercus alba			61							25			86
Quercus palustris								106					106
Quercus rubra										79	109	54	242
Quercus velutina											59		59
Robinia pseudoacacia												90	90
Salix nigra		377					25		31				433
Wisteria sinensis					18								18
# Unique Species	4	9	9	10	8	9	5	6	5	13	10	7	
Total Basal Area (cm²)	838	1129	630	860	874	873	280	388	418	1191	1484	768	

APPENDIX C

Herbaceous Vegetation Counts

Summary Table

Species	Church Creek			Dividing Creek			Red Hill Branch			Wheel Creek		
	CON[1]	REF[2]	RES[3]	CON	REF	RES	CON	REF	RES	CON	REF	RES
3-Leaved, Serrated Edge				0.5								
4-Leaved, w/Seed Balls										1		
Little Hitchhikers												1
5-Leaved, Sticker											1	
Acer negundo	1											1
Acer rubrum	2	2	1		1			0.5		1		1
Acer saccharinum			1									
Ageratina altissima						0.5						
Ailanthus altissima			1									
Albizia julibrissin					0.5	0.5						
Alliaria petiolata								1	0.5			1
Allium canadense	1	1				0.5		0.5				
Allium vineale		1							0.5			
Alnus serrulata		1				0.5						
Ampelopsis brevipedunculata	3	3	3		1							
Amphicarpaea bracteata				0.5	0.5	0.5	0.5	0.5	0.5		1	1
Andropogon virginicus			1									
Apios americana				0.5	1	0.5	0.5	1.5	1			

[1] CON = Control
[2] REF = Referrence
[3] RES = Restoration

Species	Church Creek			Dividing Creek			Red Hill Branch			Wheel Creek		
	CON	REF	RES	CON	REF	RES	CON	REF	RES	CON	REF	RES
Apocynum cannabinum								2	0.5			
Arisaema triphyllum				1	0.5	0.5						
Artemisia biennis					1							
Artemisia vulgaris											1	
Arthraxon hispidus							0.5	0.5				
Asclepias incarnata						0.5						
Aster pilosus		1	1									
Aster vimineus					2							
Berberis thunbergii										2	1	2
Bidens frondosa			3	1		1						
Boehmeria cylindrica			2	1.5	2		2	1.5				1
Botrychium oneidense					0.5	1		0.5				
Calystegia sepium								0.5	1.5			
Carex lurida						0.5						
Carex obtusa						1.5						
Carex sp.			1	0.5	1			0.5	0.5		2	
Carex stipata								0.5				
Carpinus caroliniana					0.5	1					2	
Carya cordiformis											1	
Carya tomentosa										1		
Catalpa speciosa						0.5						
Celastrus orbiculatus	3	1	2	0.5	1	1.5		0.5	0.5	3	2	3
Cercis canadensis		1										

Species	Church Creek			Dividing Creek			Red Hill Branch			Wheel Creek		
	CON	REF	RES	CON	REF	RES	CON	REF	RES	CON	REF	RES
Cinna arundinacea		1		0.5	1.5							
Cinna latifolia	1											
Clematis virginiana	1	2		1	1							
Clethra alnifolia				1		2.5						
Trifolium sp. (Clover)												1
Commelina communis					1	1						1
Conyza canadensis							0.5					
Cornus amomum	1		1					1	1			
Cynanchum laeve				0.5								
Cyperus erythrorhizos				0.5		1						
Cyperus strigosus			1			0.5						
Dichanthelium clandestinum		1			0.5		0.5		2			1
Diospyros virginiana							1.5					
Dryopteris intermedia				1	1	1						
Duchesnea indica	2	1										
Echinochloa crus-galli			1									
Elaeagnus umbellata							1					
Elymus hystrix									1			
Equisetum fluviatile	1											
Equisetum sylvaticum	1											
Euonymus atropurpureus										1		
Euonymus fortunei					1	1						1

Species	Church Creek			Dividing Creek			Red Hill Branch			Wheel Creek		
	CON	REF	RES	CON	REF	RES	CON	REF	RES	CON	REF	RES
Eupatorium altissimum						0.5						
Eupatorium serotinum		1	1									
Euthamia graminifolia		1					1					
Eutrochium fistulosum						1						
Eutrochium purpureum											1	
Fagus grandifolia											3	
Fallopia japonica	1											
Fragaria vesca								0.5				
Fraxinus pennsylvanica		2				0.5	0.5			1		2
Galium aparine		1							0.5			1
Geum canadense					0.5							
Glechoma hederacea		1					1					
Hackelia virginiana	1											
Hamamelis virginiana											1	
Hedera helix		1	1		1	1.5				2		1
Hibiscus syriacus			1									
Ilex glabra						1						
Ilex opaca		2			2	1						1
Ilex verticillata		1		1								0
Impatiens capensis		3	1	1.5	1.5		1					
Impatiens pallida							1	0.5				
Juncus effusus			1		0.5	2						
Lactuca canadensis			1						0.5			

Species	Church Creek			Dividing Creek			Red Hill Branch			Wheel Creek		
	CON	REF	RES	CON	REF	RES	CON	REF	RES	CON	REF	RES
Lactuca sp.									0.5			
Lactuca virosa						0.5						1
Lawn Grass (var. sp.)		1	1			0.5	1	0.5		1		
Leersia oryzoides				1		1.5						
Lespedeza cuneata			1									
Ligustrum vulgare	3	2		3	1.5	1				1		1
Lindera benzoin	3		1	3	3	2				2	1	3
Liquidambar styraciflua		2	1	0.5	1	2.5						
Liriodendron tulipifera	1	1	1			1						
Liriope sp.					0.5							
Lolium perenne								1				
Lonicera japonica	3	1	3	2.5	2.5	2.5	1	0.5		2	3	3
Ludwigia alternifolia			1									
Lycopodium clavatum						1						
Lycopus virginicus						2.5						
Magnolia virginiana						1						
Maianthemum racemosum					0.5							
Microstegium vimineum		1	2	2	3	2.5	3	3	3	2		3
Mikania scandens		1		1	1	2	1					
Mimulus ringens								0.5				
Mitchella repens					1	1		0.5		1		
Morus sp.												2
Moss	1										1	

Species	Church Creek			Dividing Creek			Red Hill Branch			Wheel Creek		
	CON	REF	RES	CON	REF	RES	CON	REF	RES	CON	REF	RES
Onoclea sensibilis	1		1	2.5	1	0.5	2	0.5			1	1
Osmorhiza longistylis		1	1									
Osmundastrum cinnamomeum			1									
Pachysandra terminalis					1							
Panicum capillare			1									
Parthenocissus quinquefolia	2	2	3	2	3	0.5	1.5	1.5		2	2	2
Perilla frutescens									1			
Persicaria perfoliata					1		1.5	1	2	1		
Persicaria virginiana					2			1.5	1			3
Phalaris arundinacea							2	0.5			1	
Phytolacca americana						0.5						
Pilea pumila		1			1		1		1			
Platanus occidentalis		1	1			0.5						1
Polygonum arifolium				2	1		1					
Polygonum hydropiper				0.5								
Polygonum lapathifolium							0.5					
Polygonum pensylvanicum		1	2	1	1.5	0.5	1.5	1.5	1.5			2
Polygonum sagittatum				0.5	1		3	0.5	1.5			
Polystichum acrostichoides											3	1
Potentilla simplex					0.5		1	1.5	0.5			
Prunella vulgaris			1									
Pueraria montana		1										

Species	Church Creek			Dividing Creek			Red Hill Branch			Wheel Creek		
	CON	REF	RES	CON	REF	RES	CON	REF	RES	CON	REF	RES
Pyrus calleryana		1				0.5				2		
Quercus phellos		1				0.5						
Quercus prinus						0.5						
Quercus rubra	1		1			0.5						
Ranunculus sp.					1.5							
Rhus copallinum		1										
Robinia pseudoacacia						0.5						
Rosa multiflora	2	3	1		1		1.5	2.5	2	2	1	3
Rubus flagellaris						1	0.5			1		1
Rubus idaeus		1	1									
Rubus phoenicolasius			1					1		1	1	2
Rubus sp.							1	1				
Rumex obtusifolius					1		0.5					
Sagittaria latifolia							1					
Salix fragilis						0.5						
Salix nigra	1	2	2				0.5					
Sambucus canadensis				1		1						
Schoenoplectus americanus								0.5				
Scirpus atrovirens				1		1						
Scirpus cyperinus								0.5				
Shamrock								0.5				
Sisyrinchium angustifolium	1											

Species	Church Creek			Dividing Creek			Red Hill Branch			Wheel Creek		
	CON	REF	RES	CON	REF	RES	CON	REF	RES	CON	REF	RES
Smilax glauca		2	1	2	2	2.5				3	2	2
Solanum dulcamara									1.5			
Solidago canadensis	1						1	1.5	1.5			
Solidago latissimifolia		2	2									
Solidago nemoralis							0.5					
Solidago-like									0.5	1		
Sorghastrum nutans								1	0.5			
Symplocarpus foetidus	2			1		0.5	1					
Taxodium distichum			1		0.5							
Teucrium canadense									1			
Thalictrum thalictroides					0.5							
Thelypteris noveboracensis				1	0.5	1.5	1			2	3	1
Toxicodendron radicans	2	3	1	1	1.5	0.5	1	0.5				1
Trillium sp.										1	3	
Typha latifolia						1			0.5			
Ulmus rubra										1		
Urtica dioica											1	
Vaccinium corymbosum				0.5		1		0.5				
Vaccinium sp.				0.5		0.5						
Verbena hastata							0.5					
Vernonia noveboracensis			1					0.5				
Viburnum dentatum	3	1	1		0.5	1.5					1	
Viburnum nudum					0.5							

Species	Church Creek			Dividing Creek			Red Hill Branch			Wheel Creek		
	CON	REF	RES	CON	REF	RES	CON	REF	RES	CON	REF	RES
Viola sp.		1		1	0.5						1	
Vitis aestivalis				0.5	1							
Vitis sp.				0.5		1			0.5	1		1
Wisteria sinensis					1							
Woodwardia virginica				0.5								
# Species per Treatment	28	45	46	41	56	65	39	41	30	26	26	36

Photo & Data Appendices

The Following Sets of Photographs & Data Are Contained in a Separate File, Which Is Available From the Chesapeake Bay Trust

Field Datasheet Template

Impervious Surface Area

Project Database

Project Photos

Tree Core Data

Within the Data Appendix File, There Is A
ReadMe Doc Which Explains The Purpose And Use Of
The Various Data In That Appendix