# Development of Woody Ecological Performance Standards for Created/Restored Forested Wetlands
## Final Report

Submitted to:

PIEDMONT WETLANDS RESEARCH PROGRAM

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August 2018

## Executive Summary

Previous studies suggested that existing ecological performance standards (EPS), which are used to evaluate compensatory mitigation sites (CMS), may not be suitable criteria for assessing the replacement of woody structure and/or other functions in forested wetland systems (sensu Hudson et al. 2016). Development of woody vegetation, including shrub and tree biomass, is an important component of assessing CMS. While EPS vary across U.S. Army Corps of Engineers (USACE) districts, a majority reference the soil, vegetation, and hydrology indicators from the 1987 USACE Wetlands Delineation Manual and subsequent on-line editions and regional supplements.

In Virginia, vegetation EPS are divided between herbaceous and woody vegetation. Virginia woody vegetation EPS require that more than 50% of all dominant woody plants are FAC or wetter and have a stem density of 495-990 stems/ha (200-400 stems/acre) until canopy cover is 30% or greater (USACE Norfolk District and VADEQ 2004). In practice the woody stem density is often required to be greater than 990 stems/ha (400 stems/acre) (M. Rolband 2016, Personal Communication). Virginia has currently implemented a woody growth EPS for mitigation banks in particular (VADEQ 2010a) requiring that until canopy coverage exceeds 30% woody vegetation must have an average increase in height of 10% by the 5th and 10th year following construction. An alternative goal requires tree height to average 1.5 m (5 ft) in the 5th monitoring year and 3.05 m (10 ft) in the 10th monitoring year (VADEQ 2010a). Monitoring and compliance reports are required in order to ensure that EPS are being fulfilled for CMS.

Existing woody EPS, however, are not direct measurements of wetland functions or services (Hudson et al. 2016). Therefore, meeting the current site-specific EPS does not guarantee that wetland functions and services are being replaced. In our previous study we found no relationship between woody biomass [or carbon (C)] accumulation and canopy cover, height growth, and planted tree survival. However, there was a significant relationship between stem diameter at groundline (SAG) and total biomass and C (Hudson et al. 2016). The purpose of this study was to quantitatively determine how SAG develops in CMS and to recommend a minimum SAG EPS. This study focused on CMS in the Coastal Plain and Piedmont Regions of Virginia and measured both planted and volunteer woody species. Using data collected from 17 sites ranging in age from 2-22 years following construction, we provide recommendations for

establishing a SAG EPS as an alternative woody EPS. Finally, using regional wetland plant indicator status, we developed a SAG prevalence index (SAG-PI).

Woody stem density and SAG-PI did not follow any established trend through time. SAG, however, increased slowly from ages 2-6 and then increased rapidly from ages 8-14, and then began to level off (stabilize) from ages 16-22. Non-linear regression using a three-parameter logistic model confirmed this relationship between age and "reduced" SAG (age class average minus standard error) with a low residual standard error. Based on these results, a recommended conservative SAG EPS is provided below. The average SAG-PI for all sites was < 3. Therefore, the majority of woody vegetation at these sites was hydrophytic.

| **Age (Years)** | **Recommended SAG EPS ($m^2$/ha)** | **Recommended SAG EPS ($ft^2$/ac)** |
|---|---|---|
| 1 | 0.1 | 0.6 |
| 2 | 0.2 | 1.0 |
| 3 | 0.4 | 1.5 |
| 4 | 0.6 | 2.4 |
| 5 | 0.9 | 3.8 |
| 6 | 1.3 | 5.8 |
| 7 | 2.0 | 8.9 |
| 8 | 3.1 | 13.5 |
| 9 | 4.6 | 20.1 |
| 10 | 6.7 | 29.1 |
| 11 | 9.4 | 40.8 |
| 12 | 12.5 | 54.7 |
| 13 | 16.0 | 69.8 |
| 14 | 19.4 | 84.7 |
| 15 | 22.5 | 98.0 |
| 16 | 25.0 | 108.9 |
| 17 | 26.9 | 117.2 |
| 18 | 28.3 | 123.2 |
| 19 | 29.2 | 127.3 |
| 20 | 29.9 | 130.1 |
| 21 | 30.3 | 131.9 |
| 22 | 30.6 | 133.1 |

In conclusion, our original study (Hudson et al. 2016) showed that SAG was an appropriate measure that represents ecological functions beyond the established EPS for Virginia. The present study shows that SAG follows a predictable pattern across a variety of sites and can be used to track site development through time. We suggest that SAG should be used as

an alternative EPS to identify whether forested CMS are successfully returning specific ecological functions, such as biomass and C accumulation, to the landscape.

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## Introduction

The overall goal of compensatory wetland mitigation sites (CMS) is to return ecological functions and services to the landscape that are lost during permitted impacts (33 CFR PART 332). The current legislatively-mandated method for determining if a CMS is developing into the desired wetland type and is providing the expected ecological functions is through meeting project-specific ecological performance standards (EPS) (aka: success criteria, success standards, or release criteria) [33 CFR PART 332.5, United States Army Corps of Engineers (USACE) and United States Environmental Protection Agency (USEPA) 2008]. Performance standards for all CMS are required to be clear, objective, verifiable, based on the best available science, and able to be assessed in a practicable manner (33 CFR PART 332.5, USACE and USEPA 2008).

While EPS vary across USACE districts, the majority reference soil, vegetation, and hydrology criteria/indicators from the 1987 USACE Wetlands Delineation Manual (1987 Manual) (Environmental Laboratory 1987) and subsequent on-line editions and regional supplements (USACE 2010) (Breaux and Serefiddin 1999, Streever 1999, Matthews and Endress 2008, USACE 2008). Additional vegetation EPS may include survival of planted stock, specific density (or cover) of herbaceous or woody plants, and limitation of exotic and nuisance plants (Breaux and Serefiddin 1999, Streever 1999, Matthews and Endress 2008, USACE 2008).

### Ecological Performance Standards in Virginia

The USACE Norfolk District and the Virginia Department of Environmental Quality (VADEQ) (2004) provide recommended EPS for CMS developed in Virginia. However, these recommendations only serve as guidelines and may not be suitable for every CMS. EPS have been developed for soil, hydrologic, and vegetative ecosystem components and are designed to ensure that the CMS meets the wetland criteria specified in the 1987 Manual. EPS for soil require positive hydric soil indicators [National Technical Committee for Hydric Soils (NTCHS) indicators, as cited in USACE 2010] be demonstrated within 12 inches of the soil surface. Hydrology EPS requires satisfying the hydrology criteria in the 1987 Manual (USACE Norfolk District and VADEQ 2004).

Vegetation EPS are divided between herbaceous and woody vegetation. Common herbaceous vegetation EPS require greater than 50% of all the dominant herbaceous plant species are “FAC or wetter” (i.e., FAC, FACW, or OBL) and that areal coverage exceed a minimum of 50% in emergent wetland areas after one growing season. A similar EPS for woody vegetation requires that more than 50% of all dominant woody plants should be FAC or wetter. Additionally, a woody stem density of 495-990 stems/ha (200-400 stems/acre) until canopy cover exceeds 30% (USACE Norfolk District and VADEQ 2004) is often required. However, in practice most CMS in Virginia are required to have greater than 990 stems/ha (400 stems/acre) (M. Rolband 2016, Personal Communication). Since woody vegetation is often planted in CMS, specific survival rates may also be required. The particular percentage survival required varies by project; however, planted woody vegetation can be required to exceed 80% survival (M. Rolband 2016, Personal Communication). In addition to these three woody vegetation EPS, Virginia has currently implemented a woody height growth EPS for mitigation banks in particular (VADEQ 2010a); however, few projects have implemented this performance standard (M. Rolband, personal communication). The EPS requires that until the canopy coverage exceeds 30%, average height of all woody stems (including planted and colonizing trees) in each cell, field, or block, must have an average increase in height of 10% by the 5th and 10th year following construction. An alternative goal requires the average tree height is 1.5 m (5 ft) in the 5th monitoring year and 3.05 m (10 ft) in the 10th monitoring year (VADEQ 2010a).

In order to ensure that EPS are being fulfilled for CMS, monitoring and compliance reports are required. Additionally, undesirable (invasive, non-native, etc.) plant or animal species are often required to be removed. Using reference wetlands to assess CMS development may also be used if approved by the agencies involved. The current monitoring period in Virginia for CMS is to conduct six years' worth of monitoring over a 10-year period (i.e., monitoring typically occurs in years 1, 2, 3, 5, 7, and 10 following construction of the site) (USACE Norfolk District and VADEQ 2004).

### Challenges Associated with Ecological Performance Standards

Several studies have suggested that commonly used EPS may be measurements of woody structure (Wilson and Mitsch 1996, Breaux and Serefiddin 1999, Matthews and Endress 2008) and may not be direct measurements of wetland functions or services (Mitsch and Wilson 1996, Streever 1999, National Research Council (NRC) 2001, Hudson et. al. 2016). Additionally, many EPS may not be adequate indicators of wetland functions or services (Kentula 2000, Cole 2002a). Therefore, meeting site-specific EPS does not guarantee that wetland functions and services are being replaced (Matthews and Endress 2008).

Results from Hudson (2016) and Hudson et al. (2016) showed that the existing woody EPS used in Virginia were not directly and/or statistically related to woody biomass and C accumulation, both important ecosystem functions. Stem area at groundline (SAG) of woody vegetation, however, did have a significant relationship with woody biomass accumulation and other morphological variables and was proposed as an alternative EPS measurement. But due to the experimental design of the 7-year study (lack of measurements for naturally colonizing trees) an appropriate amount of SAG could not be recommended as an EPS. The purpose of this study was to quantitatively determine the development of planted and volunteer woody species SAG in Coastal Plain and Piedmont Virginia CMS. We also present quantitative recommendations (minimum SAG values) for using SAG as an alternative woody EPS.

## Methods

To determine how SAG of woody vegetation develops through time in created/restored forested CMS, 19 CMS in Virginia were investigated between June 2016 and February 2017 (Table 1). These sites ranged in age from 2 to 22 years following construction (at the time of sampling) and were operated by Wetland Studies and Solutions, Inc., the Virginia Department of Transportation, and The Nature Conservancy. All 19 sites were designed and constructed to compensate for forested wetland loss; however, some sites further classified target wetland types (e.g., mixed hardwood, bald cypress/black gum complex, bottomland hardwood subtype). The most common target wetland type was palustrine forested (PFO) wetland.

**Table 1. Site identification and description of location, size, and number of plots sampled.**

| Site* | Province | County/City | Restoration Size [ha (acres)] | Number of Plots |
|---|---|---|---|---|
| 2A | Coastal Plain | Gloucester and King & Queen | 0.55 (1.37) | 5 |
| 4A | Coastal Plain | Accomack | 5.83 (14.4) | 26 |
| 4B | Coastal Plain | Hampton | 17.77 (43.9) | 22 |
| 4C | Piedmont | Loudoun | 0.7 (1.74) | 6 |
| 4F** | Piedmont | Loudoun | 0.78 (1.93) | 23 |
| 5A | Piedmont | Loudoun | 0.81 (2) | 4 |
| 6A | Coastal Plain | New Kent | 0.62 (1.52) | 4 |
| 6B | Coastal Plain | Virginia Beach | 6.39 (15.8) | 33 |
| 8A | Coastal Plain | Mathews | 5.06 (12.5) | 9 |
| 8B | Piedmont | Loudoun | 4.76 (11.77) | 7 |
| 9A | Piedmont | Loudoun | 2.74 (6.76) | 8 |
| 10A | Piedmont | Loudoun | 3.69 (9.12) | 6 |
| 10B | Coastal Plain | Sussex | 9.31 (23) | 12 |
| 12A | Piedmont | Prince William | 13.28 (32.81) | 7 |
| 14A | Piedmont | Prince William | 11.12 (27.47) | 6 |
| 16A | Piedmont | Prince William | 8.47 (20.92) | 5 |
| 18A | Piedmont | Prince William | 5.54 (13.69) | 14 |
| 20A | Piedmont | Prince William | 1.44 (3.55) | 9 |
| 22A | Piedmont | Fairfax | 1.32 (3.25) | 5 |

* Numbering represents site age (post-construction) in 2016
** Site did not meet prescribed performance standards in 2015 and, therefore, has been excluded from further calculations.

The most recent mitigation monitoring reports were obtained in order to determine site histories. Of the sites investigated, 18 out of 19 satisfied their prescribed EPS during their most recent monitoring. Site 4F failed to meet prescribed EPS (low woody stem density) in 2015 but was used in our study to observe how woody development could be delayed (Note: Additional planting has been scheduled by the contractor for site 4F to increase stem density).

Sites ranged in size from 0.55 ha (1.37 ac) to 17.77 ha (43.90 ac). All sites were located in Virginia, with 12 of the sites in the piedmont province and 7 in the coastal plain (including 1 site on the Eastern Shore) (Figure 1). Site 5A required a corrective action plan to be implemented in 2012. From the regulatory and ecological perspective, this impact and corrective action reset this site to pre-restoration conditions. Site 4B, as a result of dry conditions, also had a corrective action plan implemented that included re-grading to remove higher elevation areas, amending the soils and replanting woody vegetation. Similar to site 5A, this corrective action reset the site to pre-restoration conditions.

Previous land uses included row crop agricultural fields, horse and cattle grazing fields, open fields, soil borrow pits, open water (pond), sand mining operation, and uplands. Construction techniques were based on prior land use and landscape position and included removal of dams, installation of water control structures, plugging of ditches, filling of ditches, installation of instream structures, soil grading (lowering elevation), soil amendments, soil disking, subsoil compaction, and berm construction. Woody vegetation was initially planted at all sites using a variety of species, stocktypes, and planting densities. Additional woody vegetation was planted at 10 sites after the first growing season to increase stem densities.

Invasive species control (herbicide application and/or manual removal) was implemented at all sites to control one or more of the following species: *Phragmites australis, Lespedeza cuneata, Lonicera japonica, Lythrum salicaria, Arthraxon hispidus, Rosa multiflora, Elaeagnus umbellata, Phalaris arundinacea, Pyrus calleryana, Ligustrum sinense, Hedera helix, Rumex cripsus, Schedonorus arundinaceus, Xanthium strumarium,* and *Typha* spp.

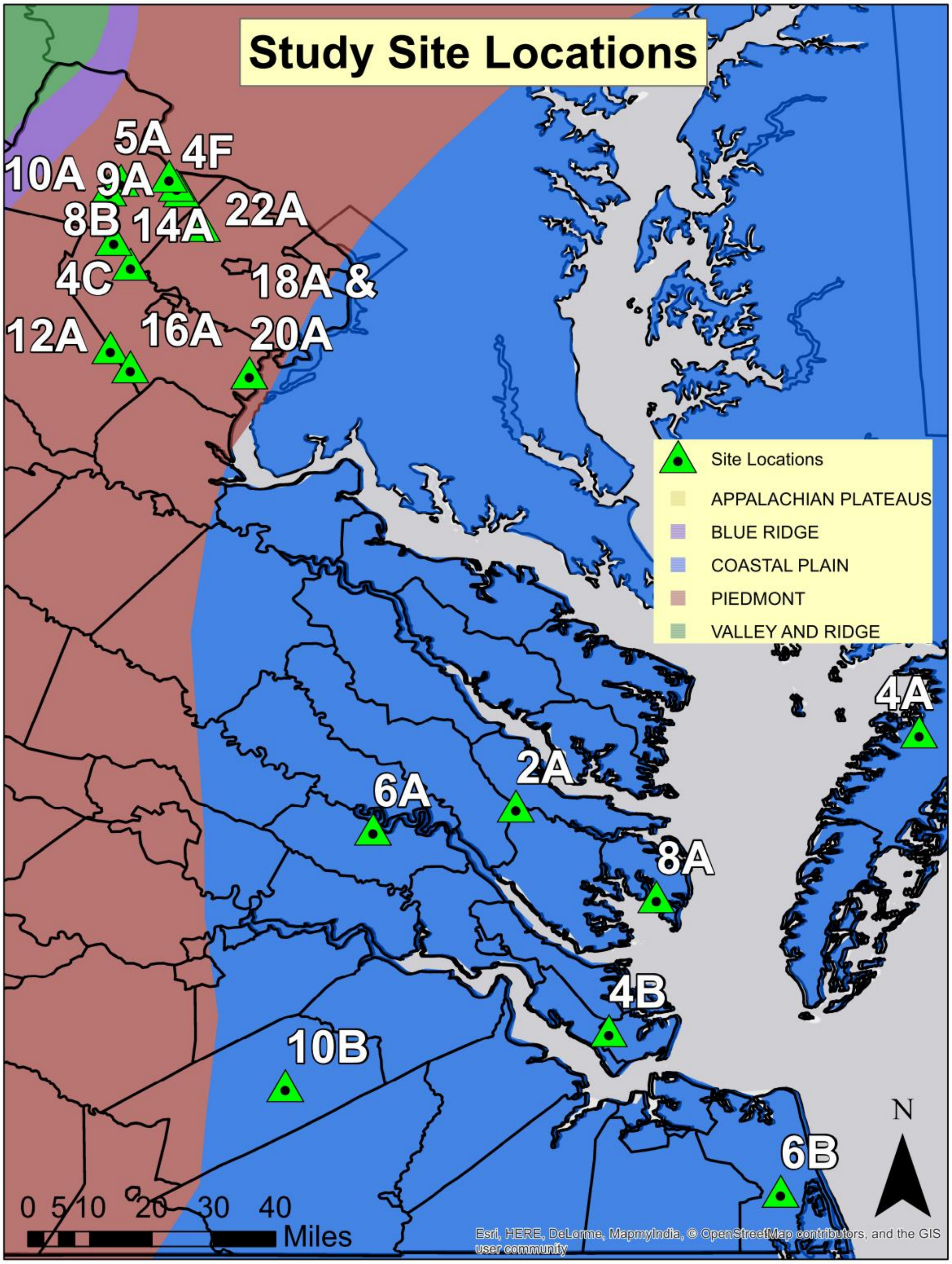

**Figure 1. All study sites were located within the Commonwealth of Virginia. Site identification numbers represent site age.**

## Data Collection

Data collection methods followed Hudson (2016) and Hudson et al. (2016). The number and locations of plots at each site corresponded with those established for compliance monitoring purposes following USACE Norfolk District and VADEQ (2004) guidelines. Plots were located in sections of each site designated as PFO or PFO/PSS. Stem diameter at groundline was measured on all woody vegetation (trees, shrubs, subshrubs) present within a 4.6 m (15ft) radius circular plot [0.0066 ha (0.0163 ac)]. All sampled woody vegetation was identified to species and the United Stated Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) PLANTS Database was used to determine species nomenclature, nativity, and growth habit (USDA NRCS 2016). Additionally, Atlantic and Gulf Coastal Plain wetland indicator status was determined for each species (Lichvar 2016). If significant buttressing or stem malformation occurred, stem diameter was measured directly above, where stem taper became constant. If multiple stems originated from belowground, the five largest stems were measured.

## Data Analysis

Stem area at groundline (SAG) was calculated for each sampled individual (or each stem for multi-stemmed individuals) and was summed for each plot. An equivalent stem diameter was calculated for multi-stemmed individuals by converting the summed SAG to an equivalent stem diameter. This has the effect of converting a multi-stemmed individual to a single stemmed individual of equivalent diameter. All stems were measured to the nearest 0.01m in diameter and rounded to 0.1m for final presentation. The relative frequency of equivalent stem diameter occurrence was determined for each age class (size class distribution). Finally, stem density was also calculated for each plot.

A weighted average based on wetland indicator status and SAG was determined for each plot. This method is derived from the prevalence index used to determine if hydrophytic vegetation is present during wetland delineations. The following equation was used to calculate the SAG prevalence index (SAG-PI) for each plot, which was then averaged to determine a single SAG-PI for each site.

$$SAG{\sim}PI = \sum_{i=0}^{n} y_i \, u_i$$

Where $y_i$ is the relative SAG for species i, and $u_i$ are the indicator status values (OBL=1, FACW=2, FAC=3, FACU=4, UPL=5) for species i.

In order to detect sites that may not be following similar trajectories, pairwise t-tests among sites of same ages using all three parameters (SAG, density, and SAG-PI) were used. Variance was estimated separately for each group, the Welch modification to degrees of freedom was used and Holm's p-value adjustment was used to control the family-wise error rate.

The following generalized nonlinear least-squares model was used to investigate how SAG develops through time. Notation for this three-parameter logistic model follows Pinherio and Bates (2000).

$$SAG = \phi_1 / \{1 + \exp\left[-\frac{t - \phi_2}{\phi_3}\right]\}$$

Where $\phi_1$ represents asymptotic SAG (where SAG levels off), t represents time, $\phi_2$ represents the time at which SAG reaches half of its asymptotic height, and $\phi_3$ represents the time between SAG reaching half and ~3/4 its asymptote. This model was based on a subset of the original 19 sites. Site 4F was not included because it failed to meet the prescribed EPS in the most recent monitoring effort. Site 8A was removed from this analysis because of the significantly greater SAG (p=0.002), stem density (P<0.001), and SAG-PI (p<0.001) when compared to site 8B (Table 3). The remaining 17 sites were divided into age classes based on their age since construction. Average SAG and standard errors were calculated for each age class. To recommend a conservative SAG EPS, the standard error of each age class was subtracted from the average SAG (this data will be referred to as “reduced SAG”). The previously described model was fit to the resulting data. All data preparation and analyses were performed in R version 3.3.3 (R Core Team 2017) and alpha values were set at 0.05. A protocol for implementing this EPS is presented in Appendix A.

## Results

In total, 12,720 stems were measured from 10,114 individuals (1,266 individuals had multiple stems) across 19 created/restored forested wetlands (Table 2). Fifty-eight species were identified from 24 plant families. All but 6 species were native to Virginia: There was a total of 62 individuals introduced species. Of the 58 species, 30 had growth habit classifications as trees, 17 as shrub/trees, 8 as shrubs, and 1 shrub/subshrub/tree classification.

SAG ranged in size from 0.1 cm (0.04 in) to 53 cm (20.9 in) across all trees sampled. Across all sites and ages the plot-level SAG ranged from 0.01 $m^2$/ha (0.04 $ft^2$/acre) to 74.85 $m^2$/ha (326.05 $ft^2$/acre). Site 8A had the greatest average SAG (Table 3) and had significantly greater SAG, stem density, and SAG-PI when compared to site 8B. *Pinus taeda* (loblolly pine) was the most commonly encountered species. Therefore, site 8A was not included when developing the model describing SAG development through time.

Site 2A had extremely high stem density in a single plot, which increased the average stem density and variation for this site (Table 3). The median stem density for Site 2A (7157 stems/ha, 2896 stems/acre) may be more representative of this site and other 2-year old sites. The average SAG-PI for all sites was below 3 and did not vary greatly among sites (except 8A being slightly higher due to the high density of *P. taeda*).

Finally, since sites were located in two different geographic provinces (but had similar hydrology and vegetation) we ran a Student t-test (2-tail, uneven variance) on the raw SAG data to determine if the data from the two provinces could be combined. The results showed that there was no significant difference in the SAG data of the two provinces (P=0.4101) and, therefore, we combined the two data sets into one for further analysis.

**Table 2. Numbers of individuals found for each species across all sites. Growth habit, native status and wetland indicator status were determined using the USDA NRCS PLANTS Database (2016).**

| Family | Species | Growth Habit | Native Status | Wetland Indicator Status | Count |
|---|---|---|---|---|---|
| Aceraceae | *Acer rubrum* | Tree | Native | FAC | 2240 |
| Salicaceae | *Salix nigra* | Tree | Native | OBL | 1276 |
| Myricaceae | *Morella cerifera* | Shrub/Subshrub/Tree | Native | FAC | 909 |
| Hamamelidaceae | *Liquidambar styraciflua* | Tree | Native | FAC | 809 |
| Pinaceae | *Pinus taeda* | Tree | Native | FAC | 773 |
| Oleaceae | *Fraxinus pennsylvanica* | Tree | Native | FACW | 694 |
| Cornaceae | *Cornus amomum* | Shrub | Native | FACW | 549 |
| Cupressaceae | *Taxodium distichum* | Tree | Native | OBL | 403 |
| Fagaceae | *Quercus bicolor* | Tree | Native | FACW | 383 |
| Rubiaceae | *Cephalanthus occidentalis* | Shrub/Tree | Native | OBL | 364 |
| Asteraceae | *Baccharis halimifolia* | Shrub/Tree | Native | FAC | 302 |
| Fagaceae | *Quercus palustris* | Tree | Native | FACW | 296 |
| Platanaceae | *Platanus occidentalis* | Tree | Native | FACW | 235 |
| Ulmaceae | *Ulmus americana* | Tree | Native | FAC | 182 |
| Fagaceae | *Quercus phellos* | Tree | Native | FACW | 89 |
| Betulaceae | *Betula nigra* | Tree | Native | FACW | 86 |
| Aquifoliaceae | *Ilex verticillata* | Shrub/Tree | Native | FACW | 82 |
| Aceraceae | *Acer negundo* | Tree | Native | FAC | 56 |
| Caprifoliaceae | *Viburnum dentatum* | Shrub/Tree | Native | FAC | 42 |
| Salicaceae | *Salix purpurea* | Shrub/Tree | Introduced | FACW | 39 |
| Cupressaceae | *Juniperus virginiana* | Tree | Native | FACU | 33 |
| Aquifoliaceae | *Ilex opaca* | Shrub/Tree | Native | FAC | 28 |
| Ebenaceae | *Diospyros virginiana* | Tree | Native | FAC | 28 |
| Fagaceae | *Quercus michauxii* | Tree | Native | FACW | 26 |
| Betulaceae | *Alnus serrulata* | Shrub/Tree | Native | FACW | 23 |
| Salicaceae | *Populus deltoides* | Tree | Native | FAC | 20 |
| Cornaceae | *Nyssa sylvatica* | Tree | Native | FAC | 17 |
| Rosaceae | *Aronia arbutifolia* | Shrub | Native | FACW | 12 |
| Rosaceae | *Pyrus calleryana* | Tree | Introduced | NA | 11 |
| Fagaceae | *Quercus lyrata* | Tree | Native | OBL | 11 |
| Fagaceae | *Quercus rubra* | Tree | Native | FACU | 10 |
| Ericaceae | *Gaylussacia sp.* | | | NA | 9 |
| Caprifoliaceae | *Viburnum nudum* | Shrub/Tree | Native | FACW | 8 |
| Magnoliaceae | *Magnolia virginiana* | Shrub/Tree | Native | FACW | 7 |
| Magnoliaceae | *Liriodendron tulipifera* | Tree | Native | FACU | 6 |
| Salicaceae | *Salix fragilis* | Tree | Introduced | FAC | 6 |
| Rosaceae | *Amelanchier arborea* | Shrub/Tree | Native | FACU | 5 |
| Betulaceae | *Carpinus caroliniana* | Shrub/Tree | Native | FAC | 4 |
| Caprifoliaceae | *Sambucus nigra subsp. canadensis* | Shrub/Tree | Native | NA | 4 |
| Fagaceae | *Quercus nigra* | Tree | Native | FAC | 4 |
| Caprifoliaceae | *Lonicera maackii* | Shrub | Introduced | NA | 3 |
| Fagaceae | *Quercus falcata* | Tree | Native | FACU | 3 |
| Ulmaceae | *Ulmus alata* | Tree | Native | FACU | 3 |
| Clethraceae | *Clethra alnifolia* | Shrub | Native | FACW | 2 |
| Ericaceae | *Vaccinium formosum* | Shrub | Native | FAC | 2 |
| Annonaceae | *Asimina triloba* | Shrub/Tree | Native | FAC | 2 |
| Oleaceae | *Ligustrum sinense* | Shrub/Tree | Introduced | FAC | 2 |
| Lauraceae | *Lindera benzoin* | Shrub/Tree | Native | FACW | 2 |
| Caprifoliaceae | *Viburnum prunifolium* | Shrub/Tree | Native | FACU | 2 |
| Fagaceae | *Quercus sp.* | Tree | | NA | 2 |
| Salicaceae | *Salix caroliniana* | Tree | Native | OBL | 2 |
| Rosaceae | *Aronia melanocarpa* | Shrub | Native | FAC | 1 |
| Elaeagnaceae | *Elaeagnus umbellata* | Shrub | Introduced | NA | 1 |
| Ericaceae | *Vaccinium corymbosum* | Shrub | Native | FACW | 1 |
| Rosaceae | *Crataegus viridis* | Shrub/Tree | Native | FACW | 1 |
| Cornaceae | *Nyssa aquatica* | Tree | Native | OBL | 1 |
| Fagaceae | *Quercus alba* | Tree | Native | FACU | 1 |
| Salicaceae | *Salix sp.* | | | NA | 1 |
| | *Unknown* | | | NA | 1 |

**Table 3. Site specific average SAG, stem density, and SAG-PI (with associated standard errors).**

| Site* | Province | SAG ($m^2$/ha) | Density (stems/ha) | SAG-PI |
|---|---|---|---|---|
| 2A | Coastal Plain | 0.5 (0.1) | 13035 (10550) | 1.79 (0.4) |
| 4A | Coastal Plain | 2.1 (0.4) | 2776 (377) | 1.6 (0.51) |
| 4B | Coastal Plain | 0.3 (0) | 2734 (513) | 1.64 (0.53) |
| 4C | Piedmont | 0.5 (0.2) | 914 (162) | 1.84 (0.27) |
| 4F** | Piedmont | 0.2 (0) | 1152 (136) | 1.95 (0.43) |
| 5A | Piedmont | 0.9 (0.7) | 1104 (200) | 1.94 (0.13) |
| 6A | Coastal Plain | 6 (2.9) | 11459 (7289) | 2.43 (0.41) |
| 6B | Coastal Plain | 1.6 (0.4) | 9598 (1913) | 1.97 (0.89) |
| 8A*** | Coastal Plain | 46.3 (6.9) | 14517 (1364) | 2.89 (0.21) |
| 8B | Piedmont | 11.2 (6.3) | 2219 (619) | 1.42 (0.49) |
| 9A | Piedmont | 6.4 (1.7) | 4359 (467) | 1.41 (0.22) |
| 10A | Piedmont | 17.8 (3.1) | 10025 (2775) | 1.76 (0.46) |
| 10B | Coastal Plain | 8.5 (1.8) | 10304 (2970) | 1.89 (0.74) |
| 12A | Piedmont | 13.8 (4.1) | 2893 (682) | 1.46 (0.18) |
| 14A | Piedmont | 26.8 (7.6) | 9695 (5060) | 1.7 (0.15) |
| 16A | Piedmont | 32 (5.7) | 11055 (3635) | 1.53 (0.21) |
| 18A | Piedmont | 35.1 (5.2) | 10757 (2480) | 1.66 (0.09) |
| 20A | Piedmont | 32.7 (5) | 4636 (602) | 1.9 (0.12) |
| 22A | Piedmont | 39.4 (8.5) | 4142 (2071) | 1.88 (0.35) |

*Site number represents age
**Site 4F failed to meet existing EPS in 2015
***Site 8A had significantly greater SAG, density, and SAG-PI than site 8B

**Table 4. Average SAG, stem density and SAG-PI for each age class followed by standard error. Site 4F and 8A not included.**

| Age (Years) | Sites | Plots | SAG ($m^2$/ha) | Density (stems/ha) | SAG-PI |
|---|---|---|---|---|---|
| 2 | 1 | 5 | 0.5 (0.1) | 13035 (10550) | 1.79 (0.18) |
| 4 | 3 | 54 | 1.2 (0.2) | 2552 (285) | 1.64 (0.07) |
| 5 | 1 | 4 | 0.9 (0.7) | 1104 (200) | 1.94 (0.07) |
| 6 | 2 | 37 | 2.1 (0.5) | 9799 (1841) | 2.02 (0.14) |
| 8 | 1 | 7 | 11.2 (6.3) | 2219 (619) | 1.42 (0.19) |
| 9 | 1 | 8 | 6.4 (1.7) | 4359 (467) | 1.41 (0.08) |
| 10 | 2 | 18 | 11.6 (1.9) | 10211 (2136) | 1.85 (0.15) |
| 12 | 1 | 7 | 13.8 (4.1) | 2893 (682) | 1.46 (0.18) |
| 14 | 1 | 6 | 26.8 (7.6) | 9695 (5060) | 1.7 (0.15) |
| 16 | 1 | 5 | 32 (5.7) | 11055 (3635) | 1.53 (0.21) |
| 18 | 1 | 14 | 35.1 (5.2) | 10757 (2480) | 1.66 (0.09) |
| 20 | 1 | 9 | 32.7 (5) | 4636 (602) | 1.9 (0.12) |
| 22 | 1 | 5 | 39.4 (8.5) | 4142 (2071) | 1.88 (0.35) |

Sites were combined into age classes so that stem density, SAG-PI, and SAG development could be analyzed across a chronosequence. Stem density and SAG-PI do not show any established trend through time (Table 4). In comparison, SAG increased slowly from ages 2-6 and then increased rapidly from ages 8-14, and then began to level off (stabilize) from ages 16-22 (Figure 3). The variance associated with SAG also increased through time.

The three-parameter logistic model provided an adequate representation of the relationship between age and reduced SAG based on the low standard error of the regression (1.68) (Figure 2). The results of the model are presented below and were used to provide a conservative SAG EPS recommendation (Table 5). When the sites were compared to the model, all sites except 4F exceeded the minimum recommended SAG EPS. This was not surprising since, as we noted earlier, site 4F did not meet existing EPS in 2015 and had been purposely excluded from the model construction.

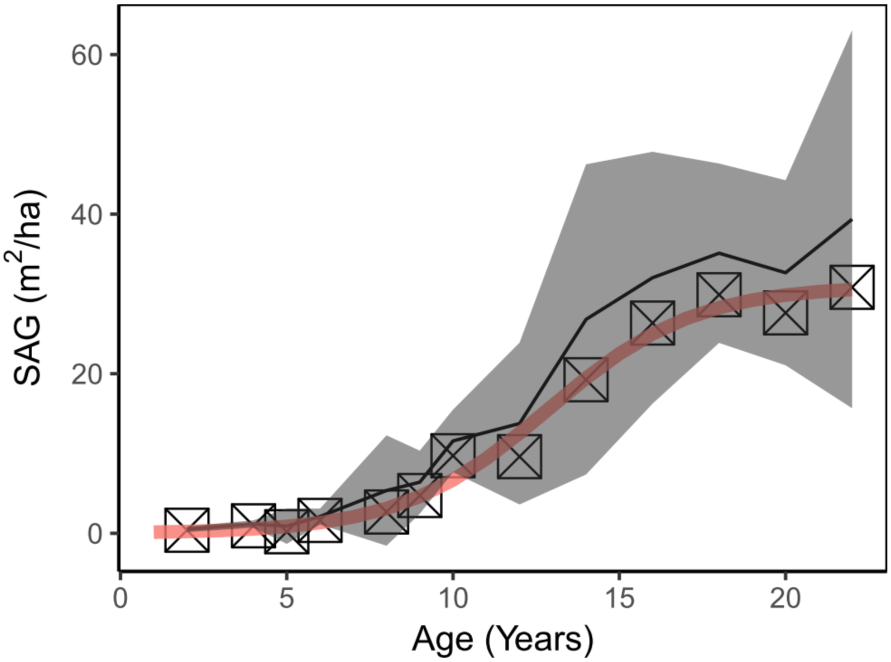

**Figure 2. Average SAG for sampled sites is shown by the black solid line. Grey ribbon represents 95% confidence intervals around the means. Solid red line represents results from the non-linear logistic model fit to the reduced SAG data (represented by squares**

**with X) ($\phi_1$=31.04, $\phi_2$=12.86, $\phi_3$=2.21, residual standard error=1.68). The red line also represents the recommended SAG, by year, as determined by the model.**

**Table 5. Recommended SAG EPS based on reduced SAG logistic model.**

| Age (Years) | Recommended SAG EPS ($m^2$/ha) | Recommended SAG EPS ($ft^2$/ac) |
|---|---|---|
| 1 | 0.1 | 0.6 |
| 2 | 0.2 | 1.0 |
| 3 | 0.4 | 1.5 |
| 4 | 0.6 | 2.4 |
| 5 | 0.9 | 3.8 |
| 6 | 1.3 | 5.8 |
| 7 | 2.0 | 8.9 |
| 8 | 3.1 | 13.5 |
| 9 | 4.6 | 20.1 |
| 10 | 6.7 | 29.1 |
| 11 | 9.4 | 40.8 |
| 12 | 12.5 | 54.7 |
| 13 | 16.0 | 69.8 |
| 14 | 19.4 | 84.7 |
| 15 | 22.5 | 98.0 |
| 16 | 25.0 | 108.9 |
| 17 | 26.9 | 117.2 |
| 18 | 28.3 | 123.2 |
| 19 | 29.2 | 127.3 |
| 20 | 29.9 | 130.1 |
| 21 | 30.3 | 131.9 |
| 22 | 30.6 | 133.1 |

Age specific relative frequency of equivalent stem diameter revealed that small diameter woody vegetation decreased through time while the occurrence of larger stem diameters increased (Figure 3). However, older age classes still had a large proportion of small diameter stems (<2 cm) which may represent natural colonization.

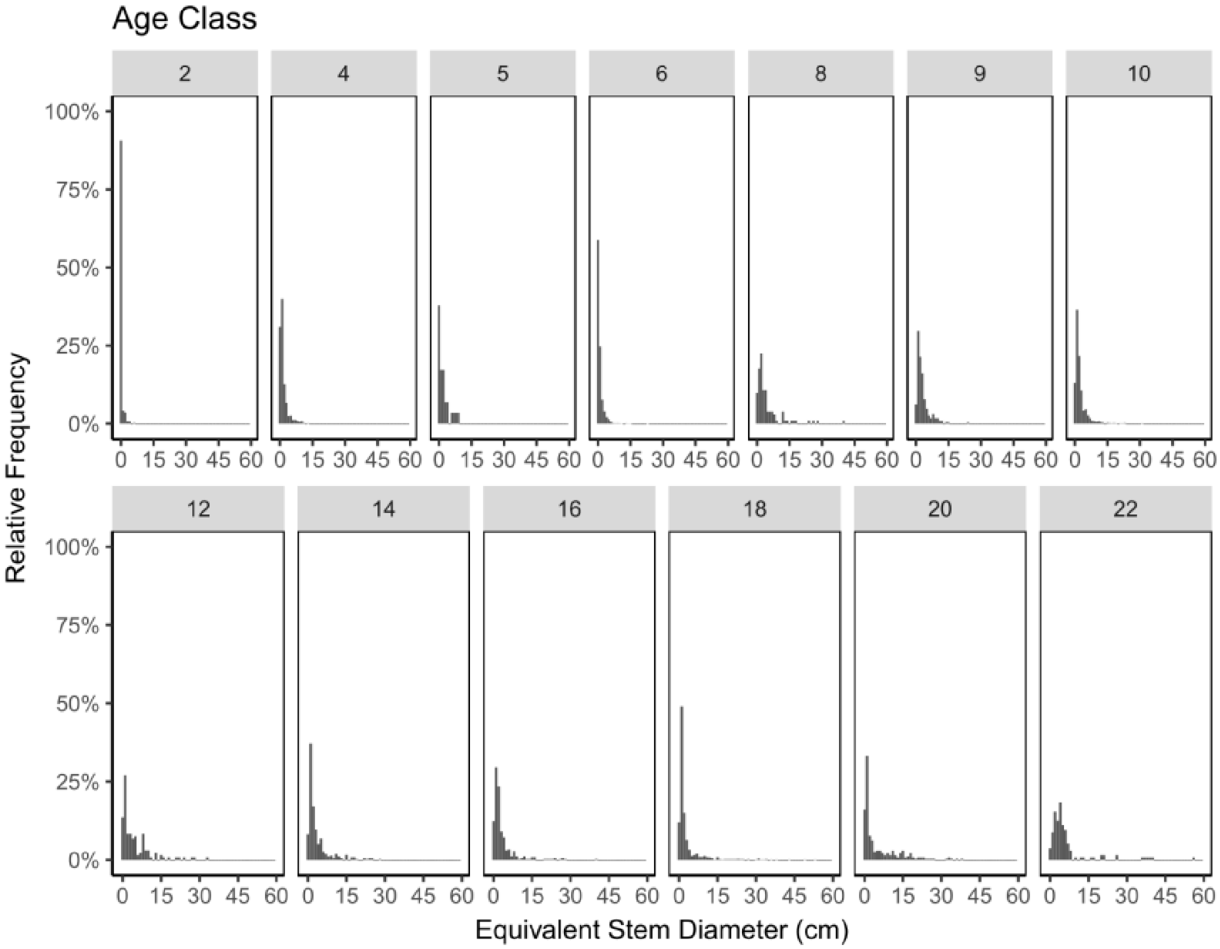

**Figure 3. Relative frequency of equivalent stem diameters (multiple SAG summed and converted back to stem diameter) for each age class. Bins represent 1 cm (0.39 in) stem diameters.**

## Discussion

There was high variation in stem density both within sites and age classes and stem density did not appear to follow a defined pattern through time. This reinforces the notion that stem density is not homogeneous within individual sites possibly due to high rates of natural colonization near forest edges (Johnson 1988, Myster and Pickett. 1992, Clark et al. 1999, Gardescu and Marks 2004, Hudson 2010). Additionally, this may suggest that natural colonization rates and natural mortality rates fluctuate through time, as the variation generally increased through time. This suggests that static stem density requirements may not be appropriate and that stem density over longer time periods may follow a predictable pattern (Berkowitz 2013). All of the sites (except 4C) had an average stem density that greatly exceeded 990 stems/ha (400 stems/acre) possibly due to the inclusion of all woody vegetation regardless of size.

SAG-PI did not vary from year to year. This is most likely due to site specific conditions, as weighted averages are heavily based on herbaceous vegetation, SAG-PI would reflect patterns in short term (seasonal) site hydrology in created wetlands (Atkinson et al. 1993). As well, while the use of SAG-PI as an EPS may be useful in determining the present hydrophytic status, PI may be falsely skewed due to the presence of planted trees with OBL or FACW status. Therefore, since SAG-PI did not show annual variation, and the problem of planting wetland woody plants play in skewing the data, we do not recommend using SAG-PI as an indicator of ecological functioning.

Using data from 17 CMS that were geographically distributed, had different starting conditions and used a variety of restoration/creation techniques, the change in SAG through time followed a three-parameter logistic model with low residual standard error. This suggests that

SAG development may follow a predictable pattern and may be suitable as an EPS. There are very few studies that investigate stem area or diameter of woody vegetation at groundline (or at the root collar or 30 cm above the ground) in natural or created/restored wetlands. In a study of old-field succession in bottomland hardwoods, Battaglia et al (2002) measured diameter of woody vegetation 30 cm above the ground. These authors found that the total area was 0.71 $m^2$/ha after 16 years. Additionally, these authors found that stem area increased with elevation for most species. The basal area reported by these authors may be lower than the present study due to differences in species composition, landscape position, and hydrology. Several studies have investigated the effects of flooding, herbaceous vegetation control, nursery source on root collar diameter in small, short term experiments (Angelov et al. 1996, Gardiner et al. 2007).

The SAG observed in this study is not similar to studies that investigate woody vegetation basal area [measured at 1.4 m (4.6 ft) above ground level, referred to as diameter at breast height (dbh)]. This is due to the stem taper and the inclusion of trees of any height in this study. For example, in an investigation of created wetlands, Charles (2013) found that 11-year-old sites had a basal area averaging 1.05 $m^2$/ha (4.57 $ft^2$/ac). In an 11-year-old restored headwater forested wetland on phosphate-mined land in Florida, Clewell (1999) found that total basal area was 8.31 $m^2$/ha (36.2 $ft^2$/ac) for trees that had stem diameters greater than 10 cm (3.9 in) at dbh. Again, the exclusion of small trees makes the comparisons to these studies difficult, but may explain why the measurements in the current study are larger.

The frequency distribution of stem diameter sizes provides additional information beyond site average SAG. The distribution provides information concerning how the size of trees make up site average SAG. In this study the distribution of small diameter trees decreased through time, while large diameter trees increased through time. This pattern suggests that trees are colonizing and growing in size. Additionally, older sites that still have small trees within the distribution suggest that natural colonization is continuing to occur, which is a positive aspect of site development. Deviations from these patterns may suggest problems with recruitment and development.

Several authors have attempted to develop EPS that are more closely linked with ecosystem functions and services (Atkinson et al. 1993, Bedford 1996, Brinson 1996, Breaux and Serefiddin 1999, Environmental Law Institute 2004, Faber-Langendoen et al. 2006; 2008, DeBerry and Perry 2015). Results from this study provide conservative SAG EPS recommendations from age 1 through 22 (Table 5) that may be appropriate for CMS in the piedmont and coastal plain of Virginia. A SAG-PI of ≤ 3may be an additional measure that can ensures that woody vegetation is hydrophytic, however we do not recommend using SAG-PI as an EPS.

Tracking SAG through time provides an indication of woody biomass development, an important ecological function. Changes in ecological variables through time have been referred to as site trajectories by a number of authors (Zedler 1999, Kentula et al. 1992, Matthews et al. 2009, Matthews 2015). These trajectories can conform to a wide number of simple mathematical functions, but often are more complex (Matthews 2015). Deviations from trajectories can indicate problems with site development that warrant further investigation and possible intervention. For example, site 4F had an average SAG of 0.19 $m^2$/ha (0.83 $ft^2$/ac) which is lower than the 0.6 $m^2$/ha (2.4 $ft^2$/ac) recommended EPS at 4 years. This suggests that this site is not on the trajectory towards 6.7 $m^2$/ha (29.1 $ft^2$/ac) at 10 years and that corrective actions are needed. In comparison, site 8A had an average SAG of 46.27 $m^2$/ha (201.55 $ft^2$/ac) and an average stem density of 14,517 stems/ha (5,875 stems/ac). This site far exceeds the 3.1 $m^2$/ha (13.5 $ft^2$/ac) recommended 8-year SAG EPS and suggests that this site is following a different trajectory. The high density of *Pinus taeda* suggests that this site is developing into a different wetland type than the remaining sites.

The SAG EPS proposed here has the potential to replace, or supplement, existing EPS in Virginia including planted tree survival, stem density, height growth, and/or canopy cover. SAG would simplify monitoring reporting while providing valuable information about site development. Since the trajectories of existing EPS are unknown, uncertain, morphologically specific (e.g. height growth or crown diameter) and/or highly variable (e.g. stem density), they cannot provide as robust or calculable a trajectory as does SAG. Additionally, deviations from the proposed SAG developmental trajectory provide similar information as that developed from the deviations from existing EPS. For example, high SAG directly following planting that decreased the next year would indicate poor survival and low natural colonization. If SAG increased slowly and the distribution of stem diameters remained positively skewed (more small stems) this would indicate that the woody vegetation is not growing and canopy closure is not occurring since stem diameter at groundline is correlated with canopy cover (Hudson 2016).

Few examples could be found of existing stem area EPS. Breaux and Serefiddin (1999) report that 5 CMS between 1988 and 1995 required basal area of trees to be measured in 110 projects they reviewed. The Indian Creek wetland mitigation bank in Georgia was the only CMS located that had an EPS that required an increase in the root collar diameter each year (Environmental Law Institute 2002). However, basal area has been recommended previously as an appropriate EPS in bottomland hardwood restorations (Allen et al. 2004).

There remain additional applications of the SAG EPS to explore. For example, SAG could be described by species or by groups of woody vegetation (e.g. shrubs and trees, early successional and late successional), further describing site development. In conclusion, SAG represents an additional woody EPS that is directly related to the development of ecological functioning in created/restored CMS. Inclusion of this woody EPS in future and existing CMS will lead to enhanced understanding of how these sites are developing and will provide evidence for their success in returning ecological functions to the landscape.

## Acknowledgements

We would like to thank our funding sources, Wetland Studies and Solutions, Inc., Peterson Family Foundation, Resource Protection Group, Inc. for providing the financial resources to make this project possible. We would like to thank The Nature Conservancy in Virginia (Kathryn Rubis & Karen Johnson), Virginia Department of Transportation (Leo Snead & Robert Condrey) and Wetland Studies and Solutions, Inc. (Mike Rolband & Jennifer Van Houten), for providing access to compensation sites. We would like to thank Hunter Gosda, Melissa Letosky, Katharine Mott, Jamie Larkin, Neil Gutherman, Robbie Clark, Pin-Han Kuo, Stephen Bendele, Jourdan Peratsakis, Autumn Tilghman, and Alyssa Robinson for their hard work in the field. Finally we would like to thank Drs. Robert Atkinson (Christopher Newport University) and Doug DeBerry (College of William & Mary) for their guidance and input on this project and report.

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## Appendix A. Sampling Protocol and Supporting Literature Review

See two included documents referenced below.

DeBerry, D.A. 2018. Vegetation Sampling on Compensatory Mitigation Sites: Literature Review.

DeBerry, D.A. 2018. Recommendations for 2017 MBI Template Revisions: Vegetation Sampling Protocol.