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QUANTIFYING ABOVEGROUND BIOMASS AND ITS RATE OF CHANGE IN GREAT DISMAL SWAMP, VIRGINIA, USA

Jamie A Duberstein[1], Todd J Hawbaker[2], Gary K. Speiran[3], Zhilang Zhu[4], Nicole Cormier[5] and Frederic C Wurster[6]

[1] Baruch Institute of Coastal Ecology and Forest Science, Clemson University, Georgetown, SC, USA
[2] U.S. Geological Survey, Geosciences and Environmental Change Science Center, Denver, CO, USA
[3] U.S. Geological Survey, Virginia Water Science Center, Richmond, VA, USA
[4] U.S. Geological Survey, National Center, Reston, VA, USA
[5] U.S. Geological Survey, Wetland and Aquatic Research Center, Lafayette, LA, USA
[6] U.S. Fish and Wildlife Service, Great Dismal Swamp National Wildlife Refuge, Suffolk, VA, USA

**Corresponding email: JamieDuberstein@gmail.com*

SUMMARY

To better understand differences in carbon budgets among peatland forest types, we surveyed trees, saplings, and shrubs at three replicate field plots across three different forest types (n = 9 field plots) in the Great Dismal Swamp, a 450 km^2 forested peatland in Virginia and North Carolina, USA. Our goal was to estimate standing carbon stocks via biomass calculations, and measure growth rates of co-dominant trees. Forest types included healthy, mature Atlantic white cedar (*Chamaecyparis thyoides*); healthy, mature tall pond pine (*Pinus serotina*) pocosin; and a mix of red maple (*Acer rubrum*) and blackgum (*Nyssa sylvatica*), which are associated with degraded conditions and not desired by managers of this ecosystem. Total carbon stocks were greatest in the Atlantic white cedar forest type (14.1 kg C m^{-2}) compared to red maple/blackgum (8.1 kg C m^{-2}) and tall pine pocosin (13.1 kg C m^{-2}). The Atlantic white cedar forest type also had the greatest tree growth rates (8.6 cm^2 tree^{-1}) compared to red maple/blackgum (7.3 cm^2 tree^{-1}) and tall pine pocosin (3.8 cm^2 tree^{-1}). Our results indicate that Atlantic white cedar may have potential to play a role in restoration efforts to meet the management goal of protecting and expanding this native forest ecosystem, while also providing an added benefit of sequestering and storing carbon to help offset greenhouse gas emissions from fossil fuel combustion.

***Keywords**: Chamaecyparis thyoides, Pocosin, carbon sequestration, tree growth, dendrometer*

INTRODUCTION

In global efforts to ameliorate the impacts of greenhouse gases, it has become increasingly important to quantify changes in standing stocks of aboveground woody biomass and associated carbon sequestration rates. Peatlands are especially important ecosystems with regard to global carbon dynamics because they accumulate large above and belowground carbon stocks over time (Mitsch and Gosselink, 2000).

In 2014, a multifaceted study (the Great Dismal Swamp Carbon Project) was initiated by the U.S. Fish and Wildlife Service and the U.S. Geological Survey to quantify different components of the carbon budget and inform the development of management plans for the swamp. In the current study, we estimated the standing carbon stocks and changes in aboveground biomass in three dominant forest types (Cedar, Maple, and Pocosin) of interest to refuge managers planning long-term strategies to restore and/or manage tree communities. We used surveys of trees and shrubs to develop biomass estimates that yielded relative amounts of in situ aboveground carbon storage within the forest types studied (Jenkins *et al.,* 2003; Woodall *et al.,* 2011). We are also monitoring (sub-) surface water levels and growth rates of co-dominant trees. Relating tree growth to water levels may facilitate the management goal of determining the impact that water levels have on aboveground biomass.

The Great Dismal Swamp (GDS) is a large forested peatland that once covered more than 600,000 ha (Shaler, 1890). Since colonial times, the swamp was owned by numerous forest products companies and others. A network of canals and adjacent levees (spoil piles) were constructed to drain the swamp to facilitate harvesting timber and agriculture (Shaler, 1890), though most canals were constructed between 1954 and 1968 (USGS, 1954, 1968). A portion of the original GDS was preserved as the Great Dismal Swamp National Wildlife Refuge (North Carolina and Virginia, USA) and Dismal Swamp State Park (North Carolina, USA) in 1974 (Figure 1). These preserves now comprise the current GDS, and are managed to protect and restore the ecological integrity of the area, enhance wildlife observation, and maintain sound working relationships with adjoining, neighboring, and other key stakeholders (USFWS, 2006). The primary challenge facing GDS is to manage water levels in canals using an extensive network of adjustable-height dams to reduce the hydrologic changes the canals have created and mitigate the impacts on ecosystems in the GDS.

The pre-development forest communities that existed in GDS included extensive tracts of the cypress-gum forest type, composed largely of bald cypress [*Taxodium distichum* (L.) Rich.] and water tupelo (*Nyssa aquatic* L.) (Shaler,1890; Kearney,1901). Additional forest types included: maple-gum (hereafter, "Maple"), dominated by red maple (*Acer rubrum* L.) and blackgum (*Nyssa sylvatica* Marshall); tall pine pocosin (hereafter, "Pocosin"), dominated by pond pine (*Pinus serotina* Michx.); and peatland Atlantic white cedar (hereafter "Cedar"), composed largely of Atlantic white cedar [*Chamaecyparis thyoides* (L.) B.S.P.]. The canal and levee system caused hydrologic changes within GDS, which had an impact on tree regeneration following timber extraction. Because of the combined impacts of timber harvest, associated wetland draining, and wildfires, relatively few tracts of the Cedar forest type currently exist in GDS. And while Cedar and cypress-gum were originally the dominant forest types with the Maple forest type as a minor constituent, the Maple forest type now covers more than 60 percent of the swamp (Carter, 1976; USFWS, 2006). A current management goal is to increase the coverage of the Cedar forest type and decrease the dominance of the red maple.

METHODS

Three replicate 20 x 25 m (500 m^2) field plots were established in representative stands of each of the three forest types of interest (Cedar, Maple, Pocosin) for a total of nine total field plots (Figure 1). Two of the cedar plots were located in close proximity (40 m) to each other because few mature stands of the Cedar forest type exist in the swamp today. Smaller subplots were established within each 500 m^2 plot for purposes of quantifying saplings and shrubs (Figure 2). All trees, defined as ≥12.7 cm diameter at breast height (DBH, taken at 1.4 m from ground level), within the 500 m^2 plots were identified to species with the exception of ash which was identified to the genus level (*i.e., Fraxinus* spp.). Trees were measured for DBH and height, and estimated for cull (nearest 1%) if the individual tree was missing major branches or had areas of obvious decay; snags (*i.e.,* dead trees) were also inventoried, but assigned a decay class so that biomass reduction factors could later be applied (Domke *et al.,* 2011). Saplings (2.5 ≤ DBH (cm) ≤ 12.7) within nested 100 m^2 subplots (Figure 2) were identified to species and measured for DBH; sapling snags were also inventoried and assigned a decay class. Shrubs (DBH < 2.5 cm) within 5.5 m^2 subsections (Figure 2) were identified and measured for diameter at the root collar (DRC); dead shrubs were not inventoried.

Ten co-dominant trees in each field plot were selected for growth measurements. These trees spanned the 12 to 60 cm DBH range of the dominant trees in each field plot, though DBHs were not necessarily uniform between field plots. When adequate trees were not available inside the field plots, trees immediately adjacent to field plots were selected for growth measures. During the winter of 2014, a section of the bark of selected trees was smoothed with a mini file and equipped with dendrometer bands that were immediately scribed with a reference line adjacent to the band collar (Bormann and Kozlowski 1962; Keeland and Sharitz 1993). Atlantic white cedar and pond pine trees were selected to represent the Cedar and Pocosin forest types, respectively, while trees banded in the Maple forest type were half red maple and half blackgum (*i.e.,* five of each per field plot). Growth measurements, measured as increase in circumference (mm) of the main tree bole, began in March 2015, and continued every three months through 2015 (*i.e.,* quarterly) with the exception of one field plot (Pocosin 2) that could not be accessed for the December 2015 measurement.

Aboveground biomass was computed for all non-vine woody plants measured in the field plots (Figure 2) and scaled to represent biomass as kilograms of carbon per square meter (kg C m^{-2}). Biomass of trees and saplings were calculated using the component ratio method, which utilizes species-specific algorithms to sum individual components (*e.g.,* bole, bark, stump, branches, foliage) based on DBH, height, percent cull, and decay class for snags (Jenkins *et al.,* 2003; Woodall *et al.,* 2011). Tree-level biomass error from these equations can be as high as 20 to 35%, but the errors are assumed to be random and cancel out when aggregated at the plot-level (Jenkins *et al.*, 2003). Biomass of shrubs was calculated as the sum of individual stem and foliage components using DRC measurements and parameters for hardwoods (Day and Monk, 1974). We assumed that biomass was 50 percent carbon (Woodall *et al.,* 2011).

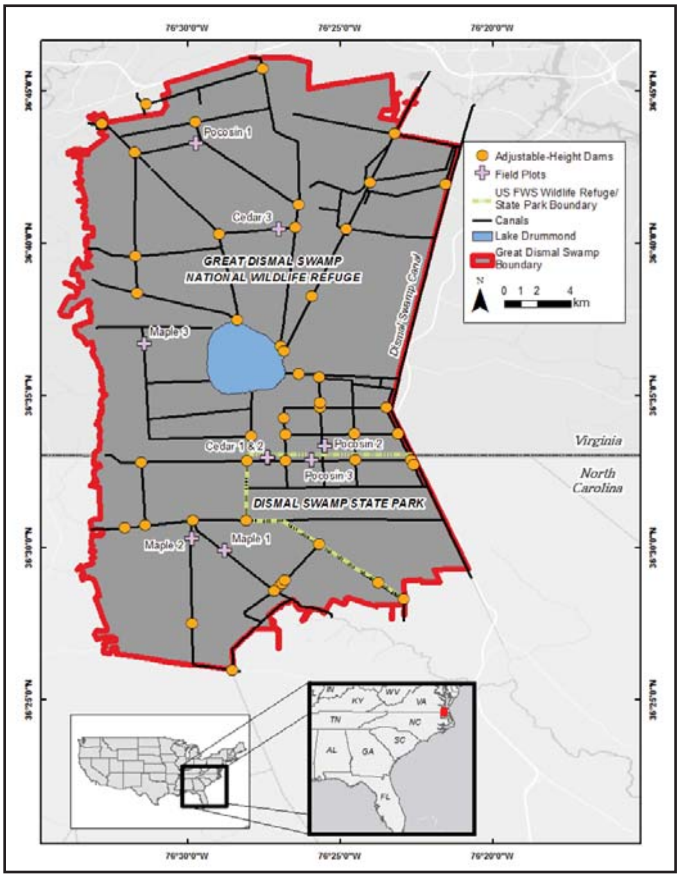

Figure 1: Map of Great Dismal Swamp, including locations of water control structures, ditches, and field plots.

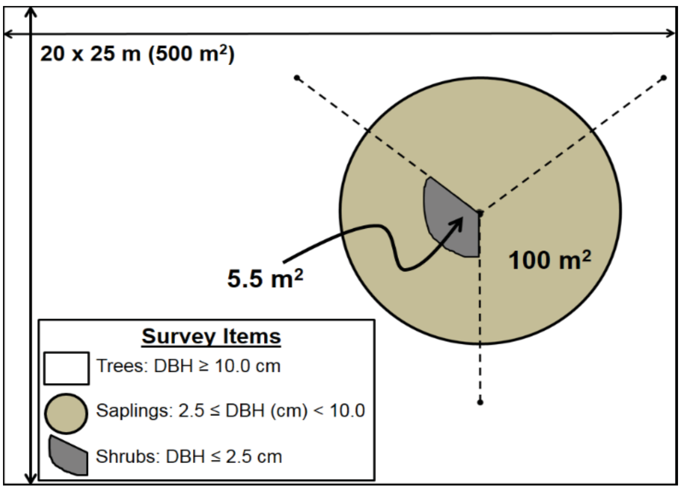

Figure 2: Layout of the nested field plots from which non-vine woody plants were surveyed. DBH, diameter at breast height.

Tree growth was calculated for individual trees outfitted with dendrometer bands. Quarterly measurements of dendrometer band expansion were used to calculate the new individual tree DBH and basal area, which was used to calculate the amount of basal area growth (increment) relative to either the previous measurement (*i.e.*, quarterly) or initial DBH (for annual growth computations). Basal area increments were averaged across trees within each field plot, and across trees within the same forest type, on a quarterly and annual basis; values reported are average basal area increment per tree (cm^2 $tree^{-1}$) for the specified time period. Dendrometer measurements (mm) were not used in calculations of basal area increment until after the first positive dendrometer measurement had been previously obtained. This protocol protected against underestimates of quarterly growth, as the first positive dendrometer measurement may have been smaller due to dendrometer band settling. Because of this calculation protocol there were no qualified measurements to calculate first quarter growth (December – March). Some dendrometer bands were damaged by wildlife, in which cases the trees were re-banded and subject to the same calculation protocol.

RESULTS

The mature Cedar forest type had the largest total amount of total biomass (14.1 kg C m^{-2}) compared to the other forest types. The Pocosin forest type had a moderate amount of total biomass (13.1 kg C m^{-2}), and the degraded Maple forest type had the least (8.1 kg C m^{-2}). Even though there was some overlap in the distribution of total biomass values, they were significantly different (2-tailed t-test p-values were 0.04 for Cedar vs. Maple and < 0.01 for Pocosin vs. Maple). The distribution of aboveground non-vine woody biomass was similar for the Cedar and Maple forest types, with trees as the major constituent, averaging roughly 94% of total biomass for both forest types (Table 1). Shrubs were the smallest constituent to total biomass for the Cedar and Maple forest types, averaging 4% or less. However, while total biomass in the Pocosin forest type was also dominated by trees (94.3% on average), shrubs (5.5%) were a larger constituent than saplings (<1%).

Average basal area increment of trees (Table 2) in the Cedar forest type was greatest of all forest types for all calendar quarters and the duration of the 2015 growing season (8.6 cm^2 $tree^{-1}$). Trees in the Maple forest type had an average basal area increment that was similar (7.3 cm^2 $tree^{-1}$) to the Cedar trees, while the pond pine trees in the Pocosin forest type averaged much less (3.8 cm^2 $tree^{-1}$). There was substantial overlap in the range of basal area increments, and the differences between the Cedar and Maple, and Pocosin and Maple forest types were not significant (2-tailed t-test p-values > 0.05).

Table 1. Carbon storage (kg C ha^{-1}) of trees, saplings, and shrubs in three replicate Great Dismal Swamp field plots of three forest types (Cedar, Maple, Pocosin), and averaged within forest type (□). Surveys of trees (DBH ≥ 12.7 cm) utilized 500 m^2 areas, saplings (2.5 ≤ DBH (cm) ≤ 12.7) 100 m^2 areas, and shrubs (DBH < 2.5 cm) 5.5 m^2 areas (see also Figure 2). DBH, diameter at breast height.

Field Plot	Shrubs	%	Saplings	%	Trees	%	Total
Cedar 1	0.4	2.3%	0.1	0.4%	15.1	97.3%	15.5
Cedar 2	0.2	1.5%	0.5	5.1%	9.6	93.5%	10.3
Cedar 3	1.4	8.4%	0.1	0.8%	15.2	90.8%	16.7
x̄:	**0.6**	**4.0%**	**0.2**	**2.1%**	**13.3**	**93.9%**	**14.1**
Maple 1	0.1	0.7%	0.4	5.0%	7.4	94.3%	7.8
Maple 2	0.1	1.8%	0.4	5.6%	6.9	92.6%	7.4
Maple 3	0.1	1.5%	0.3	3.2%	8.5	95.3%	8.9
x̄:	**0.1**	**1.3%**	**0.4**	**4.6%**	**7.6**	**94.1%**	**8.1**
Pocosin 1	0.4	2.8%	0.0	0.1%	13.2	97.1%	13.6
Pocosin 2	0.9	7.3%	0.0	0.3%	11.3	92.4%	12.2
Pocosin 3	0.9	6.3%	0.0	0.2%	12.6	93.5%	13.4
x̄:	**0.7**	**5.5%**	**0.0**	**0.2%**	**12.4**	**94.3%**	**13.1**

Table 2. Year 2015 basal area increase (BAI: cm^2 $tree^{-1}$) of trees in the Great Dismal Swamp, VA and NC, USA. BAIs are averaged over trees in replicate field plots (*e.g.*, Cedar 1), and within forest type (□). Numbers of individual trees (n) vary due to dendrometer settling time and occasional wildlife interference.

	Mar - Jun		Jun - Sep		Sep - Dec		2015 Growing Season	
Field Plot	BAI	(n)	BAI	(n)	BAI	(n)	BAI	(n)
Cedar 1	6.3	(8)	3.2	(8)	1.0	(10)	11.5	(8)
Cedar 2	1.9	(2)	1.4	(7)	0.8	(10)	5.8	(7)
Cedar 3	4.7	(7)	3.0	(10)	1.1	(10)	8.2	(8)
x̄ (total n):	**5.1**	**(17)**	**2.4**	**(25)**	**1.0**	**(30)**	**8.6**	**(23)**
Maple 1	3.0	(4)	2.1	(10)	0.9	(10)	6.1	(6)
Maple 2	6.8	(6)	3.2	(10)	0.4	(10)	9.9	(10)
Maple 3	2.5	(7)	1.6	(10)	0.4	(11)	5.5	(10)
x̄ (total n):	**4.1**	**(17)**	**2.3**	**(30)**	**0.6**	**(31)**	**7.3**	**(26)**
Pocosin 1	1.0	(1)	0.9	(10)	0.6	(10)	4.0	(8)
Pocosin 2	N/A[a]	(0)	2.6	(4)	N/A[b]	0	N/A[b]	(0)
Pocosin 3	1.4	(1)	2.4	(6)	1.0	(8)	3.7	(9)
x̄ (total n):	**1.2**	**(2)**	**1.7**	**(20)**	**0.8**	**(18)**	**3.8**	**(17)**

[a]: No dendrometer bands in this field plot had previously measured positive growth.
[b]: Pocosin 2 field plot could not be accessed in December 2015.

DISCUSSION

The Cedar and Pocosin field plots were in healthy, mature stands of large DBH trees with few individuals that qualified as saplings (2.5 ≤ DBH (cm) ≤ 12.7). The notable exception was Cedar 2 that contained several large (>10 cm DBH) saplings, though this field plot was still considered "healthy and mature." The Cedar and Pocosin forest types also averaged a higher percentage of total biomass as shrubs compared to saplings, while the inverse was true of the Maple forest type (Table 1). The fact that Maple field plots had more biomass in saplings than shrubs may be due to their degraded nature that resulted from the altered hydrology; many trees appear to have been established prior to loss of nearly 1 m of peat. The relatively large contribution to total biomass by shrubs in the Pocosin forest type is due to the abundance of *Clethra alnifolia* (L.). Cedar 1 and Cedar 2 also had numerous *C. alnifolia*, but the survey of Cedar 3 (shrubs contributing 8.4% to total biomass) did not include *C. alnifolia* but rather numerous *Ilex coriacea* [(Pursh) Chapm.] and *Lyonia lucida* [(Lam.) K. Koch]. This may be attributed to the fact that Cedar 3 was in a presumably wetter part of the refuge (Figure 1); hydrologic monitoring may confirm this supposition. Shrubs in Maple field plots were dominated by *C. alnifolia*, but densities were lower.

Tree growth in the Pocosin field plots was markedly lower than those in Cedar and Maple field plots, especially for the March-June growing period (Table 2). Indeed, the low number of dendrometer readings used in computations for Pocosin field plots was more a product of slow growth that led to extended time for dendrometer band settling (n = 22 trees), as opposed to damage by wildlife (n = 9 trees). Further monitoring in 2016 will clarify these trends and future work will relate the differences in biomass among the forests types to their unique hydrologic regimes.

CONCLUSION

Aboveground biomass was significantly greater in the Cedar forest type as compared to Pocosin forest type and the less desirable Maple forest type. Tree growth rates were also greatest in the Cedar forest type, but not significantly greater than the Pocosin and Maple forest types. Our findings to date confirm previous results from Dabel and Day (1977) and indicate that Atlantic white cedar restoration will help meet the management goal of protecting and expanding this periled forest type while concurrently protecting large carbon stocks and enhancing carbon sequestration to help offset greenhouse gas emissions from fossil fuel combustion.

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