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Assessment of Bryophyte Communities Along the Waccamaw River, SC

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ASSESSMENT OF BRYOPHYTE COMMUNITIES ALONG THE WACCAMAW RIVER, SC

By

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Abstract

The focus of this study was to determine the bryophyte communities present along the Waccamaw River, South Carolina and determine if there are any environmental constraints affecting bryophyte diversity. Another aspect of this study was to determine if bryophyte communities are bioindicators for dissolved inorganic nutrients in the Waccamaw River.

A total of 1050 bryophyte specimens were collected over the course of the study. Twelve genera were identified and consisted of thirteen moss species and one liverwort species. The bryophyte species were collected at seven sites along the Waccamw River in a nested sampling design which assessed the bryophytes growing on trees, knees, and benthic zone (river bottom). The specimens were then taken to the lab and washed of any debris and epiphytes. Afterwards they were sorted by species based on leaf morphology. Then they were weighed for an initial wet weight and placed in a drying oven for 48 to 72 hours at 77° C. Then they were weighed again to get a dry weight which was used to determine the biomass of the species.

Water samples were collected at the seven sites to determine the variability of the water chemistry along the Waccamaw River. These samples were sent to the Agricultural Service Laboratory at Clemson University and were tested for the following variables: calculated dissolved salts, calculated sodium absorption ratio, calcium, carbonate, chloride, copper, bicarbonate, boron, electrical conductivity, iron, nitrate nitrogen, magnesium, manganese, phosphorus, potassium, sodium, total dissolved solids, zinc. A YSI 85 instrument was used to determine the salinity, temperature, dissolved oxygen, conductivity, and oxygen concentration in the field.

Bryophytes can store nutrients in their tissues at a higher rate than those found in their surrounding environment. Therefore, samples of two commonly found bryophytes (*Fontinalis*

sullivantii and *Calypogeia muelleriana*) were sent to the Agricultural Service Laboratory at Clemson University and analyzed for the following variables: phosphorus, potassium, total nitrogen, calcium, magnesium, zinc, copper, manganese, iron, sulfur, and sodium. These samples were not replicated and used to determine the variability of the nutrients in the bryophytes species along the Waccamaw River.

Bryophytes were found on trees in 33 plots, on knees in 33 subplots, and on benthic substrate in 23 quadrats. Benthic samples yielded the highest biomass per m^2 of river bottom while the biomass of bryophytes growing on trees yielded the lowest biomass (g/m^2). Total bryophyte biomass was highest at the Conway site and lowest at the Sandy Island. *Fontinalis sullivantii* and *Calypogeia muelleriana* yielded the highest biomass and the common species according to presence/absence data were *Brachythecium acuminatum*, *Calypogeia muelleriana*, *Fontinalis sullivantii* and *Fissidens fontanus.* The water physicochemical parameters and elemental composition of plant tissue samples showed little variability among sites, however, total dissolved solids and total bryophyte biomass were significantly correlated.

The bryophyte communities were not correlated with any environmental variables and therefore are not bioindicators of ecosystem health for the Waccamaw River, SC. However, they do provide valuable information about the ecological integrity of the Waccamaw River and potentially other blackwater river systems.

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Introduction

Bryophytes play important roles in many systems supporting biodiversity, nutrient biogeochemical cycling, water retention, and plant colonization (Hornberg, 1998; Okland, 2008; Lang, 2011; Sun, 2012). Bryophytes, in swamp forests of Sweden, accounted for the greatest number of plant species and played an important role in recovery following disturbance (Hornberg, 1998; Okland, 2008; Gundale, 2011). Wolf (1993) and Sun (2012) both concluded that bryophyte richness increased along an altitudinal gradient and significantly contributed to the overall plant biodiversity of the region. Bryophytes, along with contributing to biodiversity, are also important players in nutrient cycling in many ecosystems.

Several studies documented the importance of bryophytes in nutrient cycling. Since bryophytes cover the substrate, they easily capture and accumulate detritus, fix carbon from atmospheric pools, compete with vascular plants for inorganic nutrients, and influence soil microclimate (Turstsky, 2003; Lindo, 2010). Bryophytes are the dominant plant group in boreal and temperate forests where they contribute significantly to net primary production and the global carbon cycle (Hornberg, 1998; DeLucia, 2003; Turstsky, 2003; Lindo, 2010). Bryophytes also play an important role in forest succession since they are typically one of the first colonizers thereby supporting other flora and fauna (Smith, 1982).

The role of bryophytes in the establishment and persistence of plant communities is well documented (Fenton and Bergeron 2006; Tardif et al. 2013; Lammrani et al. 2014), mosses also play a significant ecological role supporting a range animals from invertebrates to large migratory mammals. For example, bryophytes provide shelter from the environment and also help to camouflage invertebrates from predators (Smith, 1982). Englund (1991) reported that the density of invertebrates in bryophytes was two orders of magnitude greater than on bare substrates while showing a negative correlation between bryophyte community disturbance and invertebrate abundance.

Bryophytes often compete for space within the given environment and intermediate levels of disturbance may support their diversity (Grime, 1979; Muotka, 1995; Grime 1998; Zechmeister, 2000; Diaz, 2007; Kershaw 2013). Ecosystems such as streams, swamps, and riparian wetlands which experience frequent disturbances from the movement of water, flooding and drainage events allow for high levels of biodiversity among the bryophyte communities. However, when the levels of disturbance are too high, bryophytes cannot effectively colonize which leads to decreased biodiversity (Grime, 1979; Muotka, 1995; Zechmeister, 2000).

Fluctuating water levels can affect species richness in riparian forests and wetlands. One study (Battaglia, 2005) concluded that there was a strong link between hydrology and vegetation patterns within Carolina Bays and other wetland studies found similar results .These studies also indicated that wetland plant communities are strongly linked to hydrology (Luken, 2000; Battaglia, 2005). Bryophytes, like plants, are susceptible to environmental changes and can therefore indicate changes in the environment such as fluctuations in water level, nutrients, and salinity.

Bryophytes can be used to assess and monitor water quality because they are particularly sensitive to chemical pollutants (Carbiener et al., 1990; Siebert et al., 1996; Arroniz-Crespo et al., 2008; Ceschin et al. 2012). Their sensitivity to nutrients and pollutants makes them ideal bioindicators (Fernandez et al., 2006; Davies, 2007). Bryophyte assemblages are currently being used in Europe and Canada as bioindicators for heavy metals and other contaminants (Vanderporrten, 1999). As nonvascular plants, aquatic bryophytes are reported to be particularly sensitive to anthropogenic disturbances including climate change, pollution, including eutrophication, and salinity since they absorb nutrients and water directly through their cell walls maintaining a very intimate relationship with the surrounding environment (Lopez and Carballeira 1989; Vanderpoorten et al., 1999; Bates, 2002; Raven et al., 2005; Arroniz-Crespo et al 2008). The effects of disturbance on bryophytes can then be used to assess the health of the entire ecosystem.

It is impossible to underestimate the importance of riverine hydrologic features and associated riparian forests and swamps (Costanza et al. 1998). For example, using the values provided by Costanza et al. (1998) and applying it to SC rivers, riparian zones and adjacent wetlands provides nearly five billion dollars a year in ecosystem services (Godwin unpublished) and these aquatic resources serve as important nurseries and food for many, including humans (Conner, 1981) while facing increasing human pressures and continued degradation . However, these important ecosystems are threatened by anthropogenic disturbances such as the building of canals, logging, point and non-point pollution and altered flow of water (Conner, 1981). Conservationists, therefore, are interested in using bioassessment to ensure the long-term health of these valuable ecosystems (Vazquez, 2003). Environmental and hydrological indices are necessary for bioassessments to be effective. Previous environmental and hydrological indicators include the historic depth of the water table, the upper elevation of adventitious roots, the angular change of cypress trees and the lower limit of epiphytic bryophytes (Carr, 2006).

Accurate assessment of ecological integrity is a prerequisite for understanding how human impacts modify hydrologic features (Keddy et al. 1993; Rader 2001; Karr and Yoder 2004). One way to assess ecological integrity is through the analysis of the species composition, diversity, and the functional organization of the resident community (i.e., bioassessment; Karr and Chu 1999). Plants are ideal to study biological integrity as they are pervasive and often interact with a range of organisms and environmental conditions (Ott, 1978; Rosenberg et al. 1986; Hutchens et al. 2004). There is substantial justification to potentially view bryophytes as biotic indicators of environmental degradation or change.

The focus of my study was to determine which bryophyte species are present in the swamp forest along the Waccamaw River, SC and if any abiotic factors influence bryophyte distribution in space and time. A secondary objective was to assess whether bryophyte communities found along the Waccamaw River SC could be used as bioindicators for dissolved inorganic nutrients. For the purpose of my study the term "bioindicator" is defined following Siebert (1996) as: an organism which provides information on the quality of its environment.

My research allows the following questions to be answered about the bryophyte communities along the Waccamaw River, SC:

- What are the bryophyte communities along the Waccamaw River, SC?
- What environmental constraints affect the distribution of the bryophyte species along the Waccamaw River, SC?
- Are bryophytes bioindicators for dissolved inorganic nutrients in the Waccamaw River, SC?

Materials and Methods

Study area

The Waccamaw River is a black water river that flows entirely within the Atlantic Coastal Plain beginning in southeastern North Carolina and flows southwest into South Carolina (Goodman, 2013). The river drains 2,875 square km and travels about 241 km from its headwaters through South Carolina to the Atlantic Ocean (Goodman, 2013). In the upper reaches, the Waccamaw River is 11 m wide near Lake Waccamaw, the river's width increases in the study site (upper and middle part of the river) to 27 and 58 m, and up to 1,219 m wide as it approaches the Atlantic Ocean (USACE, 2009; Goodman, 2013).

Throughout my study area the Waccamaw River is a slow moving black water river system surrounded by a mosaic of wetland communities ranging from herbaceous emergent to forested deepwater (Cowardin, 1979; USFW, 2013). The Waccamaw River is a low gradient river with low pH, hardness and specific conductance (Hupp, 2000). The river receives discharge from local precipitation and since the Waccamaw River is a black water river, it is narrower, has a less developed floodplain and reduced sediment load compared to alluvial rivers (Wharton, 1982). The river gets its characteristic coloring from the tannins that leach from the surrounding high organic bottomland hardwood forested ecosystem or the riparian wetlands (Hupp, 2000). The bottomland hardwood forested ecosystems are characteristic of southeastern rivers, feature high levels of biodiversity and are important for maintaining water quality.

The Waccamaw River is an impaired waterbody, according to the EPA guidelines, due to low dissolved oxygen levels (S.C. DHEC, 2007) (Figures 2 and 3) and also faces other environmental threats such as high mercury levels, increased urbanization, salinity, nutrients and turbidity. Anthropogenic disturbances such as logging and draining have diminished water retention, aquifer recharge and degraded contiguous and adjacent wetlands (Goodman, 2013). The restoration of wetlands is critical since they provide many important functions such as immobilization of nutrients, erosion and sediment control, flood attenuation, and outdoor recreation (Tiner, 2002; Millennium Ecosystem Assessment, 2005). The Waccamaw River bryophyte communities present along and in the river could potentially serve as a bioindicator for these anthropogenic disturbances.

Assessing Bryophyte Communities of the Waccamaw River

Seven sites were selected within the study area between June 2, 2012 and October 20, 2012 located along the river at intervals of 3 to 12 km allowing me to capture a presumed the floristic and salinity gradient across the study area (Figure 1). My sites were located on the river at the intersection of the swamp forest and surface water. The Waccamaw River is tidally influenced and therefore sampling occurred at low tide because the bryophyte communities are exposed. The sites were selected to accurately represent the shoreline of the Waccamaw River. Sites were dominated by bald cypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*), water ash (*Fraxinus caroliniana*) and tree knees and were accessed by a small canoe.

I used a nested sampling design to quantify vegetation within my sites; trees, cypress knees, and benthic zone (river bottom). I did this by establishing five 10 m by 5 m plots where all of the bryophytes on the trees that fell completely within the plot were collected. The bryophytes that were removed marked the high tide mark at each site and were found from the bottom of the tree to approximately 0-0.3 m. The bryophytes that were recovered from a particular tree were placed in a bag, the tree species was identified and the diameter at breast height was recorded. These plots were then equally divided with the bryophytes growing on the knees that were located entirely in the 5x5m subplot were removed and placed into a bag that was labeled with the date and subplot location. The bryophytes growing on the river bottom were sampled by randomly establishing four ¼ m^2 quadrats within each subplot were collected and placed into a bag that was labeled with the date and removed for subsequent analysis.

Determining Bryophyte Species Biomass

Bryophytes were taken to the lab where they were sorted into different species based on leaf morphology. After the bryophytes were sorted, they were washed of any debris or epiphytes. Then they were weighed for an initial wet weight and placed in a drying oven for 48 to 72 hours at 77° C. Then they were weighed again to get a dry weight which was used to determine the biomass of the species.

Identification of Bryophyte Species

The specimens were identified using microscopic leaf and cell morphology characteristics. All bryophyte specimens were identified to species. The scientific names for the moss species were determined using Crum and Anderson (1981) and the liverworts were identified according to Hicks (1992).

Stand Basal Area

Stand basal area was determined at six of the seven sites along the Waccamaw River (Lee, Pitch, Bucksport, Peach, Wacca, and Sandy). Stand basal area was calculated by measuring the diameter at breast height of all the trees located entirely within the plot. We did not vary the height at which diameter at breast height was measured for buttressed tree trunks; therefore our measurements may be slightly larger than other studies since they included the swell that naturally occurs in buttressed trees. The diameter at breast height was then converted to stand basal area.

Water and Plant Tissue Analysis

Water samples were collected on October 20, 2012 at each site in order to determine if the bryophyte communities were responding to nutrients in the surface water of the Waccamaw River. We also collected water samples at two additional sites (Bull Creek and Jackson Bluff) since they are areas of known poor water quality due to the mixing of the Waccamaw River with the Pee Dee River at these sites. Water samples were collected to determine the variability of the water chemistry of the Waccamaw River. These samples were sent to the Agricultural Service Laboratory at Clemson University and were tested for the following variables: calculated dissolved salts, calculated sodium absorption ratio, calcium, carbonate, chloride, copper, bicarbonate, boron, electrical conductivity, iron, nitrate nitrogen, magnesium, manganese, total phosphorus, potassium, sodium, total dissolved salts, zinc. A YSI 85 instrument was used to determine the salinity, temperature, dissolved oxygen, and conductivity, in the field. All of these measurements were taken when the bryophyte specimens were collected.

Bryophytes can store nutrients in their cells at higher levels than those found in the environment, therefore two bryophyte species (*Fontinalis sullivantii* and *Calypogeia muelleriana*) that were commonly found in the Waccamaw River were also sent to the Agricultural Service Laboratory at Clemson University on May 9, 2013. Plant samples were not replicated and were used to determine if their was any variability in the nutrient content in the plant tissues. The plant tissues of these two species were analyzed for the following variables: phosphorus, potassium, total nitrogen, calcium, magnesium, zinc, copper, manganese, iron, sulfur, and sodium content.

Statistical analysis

I examined the data using several different techniques including one way analysis of variance (i.e., ANOVA), simple linear regression and Pearson correlation analysis, once parametric statistical assumptions were met. If data failed assumptions (e.g., normal distribution), non parametric equivalents (e.g., Kruskal Walis by ranks) were used. For all analyses, I utilized a 95% confidence interval (i.e., $p \leq 0.05$) in SPSS, vol. 20 (2012). I report all p values for individual interpretation.

Results

Stand Basal Area

Stand basal area was highest at Lee landing and averaged 175 m^2/ha (Fig. 4). Stand basal area was lowest at Peach Landing and averaged 60 m^2/ha. After Peach landing the stand basal area increased to 104 m^2/ha at the Wacca Wachee site and 140 m^2/ha at the Sandy Island site. These results indicated a reverse bell curve for the stand basal area within the study area.

Bryophyte Richness

A total of 1050 bryophyte specimens were collected from the seven sites, 36 plots, 36 subplots, and 181 quadrats. 12 moss genera with 13 moss species and one liverwort were identified (Table 1). The number of species in each plot remained consistent throughout the Waccamaw River, SC (Figure 5). The Sandy Island site showed a slight decrease in the number of species per plot with the number of species decreasing from approximately five to seven at the six other sites to one to five at the Sandy Island site. The species richness at each site was between 4 and 7.4 with the highest value at the Wacca Wachee site and the lowest value at the Sandy Island site (Figure 6). The other sites had similar levels of species richness per site averaging around 6.

Among the thirteen bryophyte species found in the Waccamaw River, *Calypogeia muelleriana* and *Fontinalis sullivantii* were the dominant species and yielded the highest biomass at all seven sites along the Waccamaw River, SC (Figure 7). The most common species, according to the presence/absence data were *Brachythecium acuminatum*, *Calypogeia muelleriana*, *Fontinalis sullivantii* and *Fissidens fontanus* (Table 2). The biomass and species richness of bryophyte species decreased at the Sandy Island site.

Bryophyte Biomass

Bryophytes were found on trees in 33 plots, on knees in 33 subplots, and on benthic substrate in 23 quadrats. Benthic samples yielded the highest biomass per m^2 of river bottom while the biomass of bryophytes growing on trees yielded the lowest biomass (g/m^2) (Figure 8). The total biomass was highest at the Conway site and averaged 36 g/m^2 (Figure 9). The total biomass was lowest at the Sandy Island site and averaged 4 g/m^2. Generally, higher biomass was observed in the middle sites along the sampled stretch of the Waccamaw River.

Benthic and tree sampling yielded the highest biomass at the Conway site with the benthic samples averaging 26 g/m^2 and the tree sampling averaging 3 g/m^2. Benthic samples had the lowest biomass at the Wacca site and averaged less than 1 g/m^2. Bryophyte biomass on trees was lowest at the Lee Landing site and the Sandy Island site. Biomass from knees was highest at the Peach landing site was lowest at the Sandy Island site.

Water and Plant Tissue Analysis

The water quality parameters showed little change over the sample period (Tables 3 and 4). Total dissolved solids was measured at seven sites along the Waccamaw River and then compared with the total bryophyte biomass (Figure 10), and I report a significant linear relationship between the total dissolved solids and total bryophyte biomass ($R^2 = 0.6197$, $p = 0.0356$).

The analysis of *Fontinalis sullivantii* and *Calypogeia muelleriana* tissues showed little variation in elemental composition along the Waccamaw River (Tables 5 and 6). Nitrogen in *Calypogeia muellereiana* tissues was somewhat higher at the Wacca Wachee and Sandy Island sites and lower at the Bucksport site. Phosphorous levels were consistent at the seven sites. Calcium content of *Calypogeia muelleriana* tissues was generally higher at the Lee Landing site and somewhat lower at the Wacca site. The nutrients in *Fontinalis sullivantii* tissues were similar to those of *Calypogeia muelleriana*.

Discussion

Bryophytes can be useful bioindicators of ecosystem health because they are sessile, lack roots, have a wide geographic distribution and can accumulate a high volume of contaminants and nutrients (Vazquez, 2006). During this study, fourteen bryophytes were identified from the shoreline and additional species might be found further in the riparian wetlands (Carol, 2003). The results of the present study also indicated that there was a shift in bryophyte community. The shift was most likely due to the salt intrusion that occurs in the estuary of the Waccamaw River, SC. The salt water intrusion and high salinity levels toward the bottom of the river caused the vegetation to switch from a forested ecosystem to a marsh plant dominated system.

Swamps are highly productive ecosystems and contain high levels of nutrients due to periodic flooding and the lack of a boundary between the land and the water. However, swamps also experience rapid rate of decomposition because the organic matter from falling leaves and other sources is quickly consumed by microorganisms, invertebrates, fish, other organisms, or is flushed out of the system by high waters (Conner, 1976). Bryophytes may be acting as a vernal dam in these wetland systems thereby capturing many of the nutrients that would otherwise be lost (Muller, 1978; Frangi, 1992; Tessier, 2003). The bryophyte communities present in the Waccamaw River may be preventing the leaching of crucial nutrients from the Waccamaw River and North Inlet. Further research however needs to be conducted on the full potential of the bryophyte community to act as a vernal dam.

Another important trend observed in my study was the relationship between total dissolved solids and total bryophyte biomass (Figure 10). Total dissolved solids is the measure of inorganic salts, organic matter, and other dissolved materials in the water (Scannell, 2007). Total dissolved solids can be found in all water bodies and their concentration is dependent upon the geology of the water body, atmospheric precipitation and the evaporation-precipitation balance

(Scannell, 2007). Changes to the total dissolved concentration and composition can lead to toxicity, switches in the biotic community, limit biodiversity, and cause chronic effects at various life stages for developing organisms (Scannell, 2007). Both the total dissolved solids and the bryophyte biomass were highest in the middle stations of the examined stretch of the Wacamaw River. Both parameters were somewhat lower at the Bucksport site, which could be due to the merging of the Pee Dee River and the Waccamaw River. Historically, the Pee Dee has more agricultural activity and therefore higher concentrations of herbicides and fertilizers. The merging of these two rivers while lowering the biomass at the Bucksport site may also be responsible for the abrupt changes in bryophyte community structure that was recorded at that site (Table 3).

Bryophytes are an important component of many ecosystems and provide valuable habitat other organisms such as invertebrates and fish (Frangi, 1992; Lang, 2011; Virtanen, 2009; Chantanaorrapint, 2011; Baldwin, 2011). Some studies indicate that structure of the bryophyte assemblages changes in response to habitat conditions and water chemistry (Scarlett, 2005; Baldwin, 2011; Lang, 2011), which may also change along a habitat gradient (Wolf, 1993; Scarlett, 2005; Lang, 2011). The results of this study indicated that a gradient exists in the Waccamaw River, SC since the number of species at the site level is highest at the Bucksport site (Figures 3 and 6) and the presence/absence data (Table 2) showed the appearance of additional bryophyte species and a decrease in the biomass of dominant species (*Brachythecium acuminatum*, *Calypogeia muelleriana*, *Fontinalis sullivantii*). The change in assemblage structure observed in this study is most likely due to the merging of the Waccamaw River, SC with the Pee Dee River, SC and also the switch from a bottomland hardwood forest system to marsh system. The decline in the biomass of some species is likely due to the increasing salt water intrusions from North Inlet into the Waccamaw River, SC.

Since the Waccamaw River, SC is tidally influenced, the bryophyte communities experience regular disturbance events which may affect the number of taxa present. The Lee Landing site experiences the smallest tidal fluctuation and the Sandy Island Site experiences the largest tidal fluctuation due to its proximity to the Atlantic Ocean. However, the Bucksport Site had the greatest number of bryophyte taxa present (Figure 4). It is possible that salinity and water chemistry at the Sandy Island site are limiting the bryophyte diversity since there are no saltwater bryophyte species. However, several species including *Fontinalis sullivantii* can tolerate periods of flooding and high salinity water (5-15 ppt) (Bates, 1974, Bates 1975, Carol, 2003). The aquatic bryophyte community in the Waccamaw River has clearly developed a strategy for handling the frequent periods of flooding.

The Waccmaw River is a tidally influenced black water river system that lies entirely within the Coastal Plain. The Waccamaw River is considered an impaired waterbody and faces several anthropogenic threats such as pollution from point and non-point sources, land conversion, high mercury levels and issues with storm water runoff. This study was the first of its kind and identified fourteen bryophytes which make up the bryophyte assemblages in the Waccamaw River. This study also assessed the potential of the bryophyte assemblage to be used as a bioindicator for the Waccamaw River in keeping with new management practices. This study found that the total bryophyte biomass was strongly correlated with total dissolved solids. This correlation suggests that the total dissolved solids may be affecting the distribution of the bryophyte community however further research is needed in order to make definitive conclusions. The bryophyte assemblages in the Waccamaw River may not be a bioindicator for nutrient levels but they do provide the baseline for the ecological integrity of blackwater rivers.

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Table 1. List of moss species collected on the Waccamaw River, SC. Names follow Crum and Anderson (1981) and Hicks (1992).

Moss Species
Amblystegium serpens
Anomodon attenuatus
Brachelyma subulatum
Brachythecium acuminatum
Calypogeia muelleriana (liverwort)
Fissidens fontanus
Fissidens taxifolius
Fontinalis sullivantii
Hypnum lindbergii
Lepidopilum polytrichoides
Mnium cuspidatum
Plagiothecium latebricola
Thuidium minutum

Table 2. Presence and absence data for bryophyte species occurring at seven sites along the Waccamaw River, SC. The sites are listed from north to south.

	Lee						Conway					Pitch					Peach					Bucksport					Wacca					Sandy				
	1	2	3	4	5	6	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Species																																				
Amblystegium serpens																p													p							
Anomodon attenuatus		p		p	p	p	p	p		p	p	p	p	p	p			p		p	p	p	p	p			p		p	p	p					
Brachelyma subulatum							p		p	p		p	p					p	p	p		p	p	p	p	p	p	p	p	p	p	p	p		p	
Brachythecium acuminatum	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p		p	p		p	p		p			
Calypogeia muelleriana	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	
Fissidens fontanus	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p			p		p	p	p	p	p	p	p	p	p	p	p
Fissidens taxifolius																						p	p	p								p				
Fontinalis sullivantii	p	p	p	p	p	p		p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	
Hypnum lindbergii										p													p							p						
Lepidopilum polytrichoides												p													p											
Mnium cuspidatum																							p							p	p				p	
Plagiothecium latebricola																p											p									
Thuidium minutum	p	p		p	p	p	p		p			p	p	p			p	p		p	p	p	p					p	p		p			p		

Table 3. Water quality variables from samples collected on October 20, 2012. All variables are in mg/L except for EC (mmhos/cm), pH, and HCO_3 (meq/L).

Site	P	K	Ca	Mg	Zn	Mn	Fe	S	B	Na	TDS	EC	pH	HCO3
Lee	0	2.7	11.3	1.8	0	0.02	1.52	4	0.03	6	64	0.1	6.2	0.2
Conway	0	3	13.2	1.9	0	0.01	1.56	3	0.04	7	70	0.11	6.4	0.4
Pitch	0.1	3	11.7	1.7	0	0.02	1.6	4	0.03	7	77	0.12	6.3	0.2
Bucksport	0	3.2	10.8	1.8	0	0.02	1.48	3	0.03	7	70	0.11	6.2	0.2
Bull Creek	0.1	3.9	7.9	2.7	0	0.01	0.82	4	0.04	12	64	0.1	6.9	0.5
Jackson Bluff	0.1	3	11.5	1.8	0	0.02	1.62	3	0.03	7	58	0.09	6.1	0.3
Peach Tree	0.1	3.2	10.8	1.8	0.01	0.02	1.51	3	0.03	7	70	0.11	6.2	0.2
Wacca	0.1	3.9	9.2	2.6	0	0.01	0.89	3	0.04	11	64	0.1	6.7	0.5
Sandy Island	0.1	4.2	8.9	2.9	0.02	0.01	0.76	4	0.04	12	58	0.09	6.8	0.5

Table 4. Correlations between total bryophyte biomass and water quality variables. The first row is the r value and the second row is the p value

	B	Ca	Cl	EC	Fe	HCO3	K	Mg	Mn	Na	P	Ph	S	TDS	Zn
Biomass	-0.117	0.8337	-0.3387	0.7972	0.6951	-0.3016	-0.52	-0.6161	0.117	-0.5498	-0.1478	-0.4342	-0.308	0.7887	-0.3121
	0.8027	0.0198	0.4574	0.0318	0.083	0.511	0.2316	0.1407	0.8027	0.2011	0.7518	0.3303	0.5016	0.035	0.4956

Table 5. Elemental composition of *Fontinalis sullivantii* plant tissues. Specimens were taken from sites along the Waccamaw River, SC on May 9, 2013. N, P, K, Ca, Mg, and S are reported as percent of the dry sample. The other parameters are in ppm.

Sites	N	P	K	Ca	Mg	S	Zn	Cu	Mn	Fe	Na	B	Al
Lee	3.04	0.33	0.34	1.05	0.12	0.24	51	13	4324	10795	822	34	4312
Conway	2.91	0.35	0.48	0.74	0.12	0.21	56	12	3976	6044	328	22	3438
Pitch	3.03	0.42	0.43	0.73	0.11	0.21	53	15	2216	6288	359	26	3046
Peach	3.18	0.39	0.4	0.8	0.12	0.24	55	15	2756	10780	563	29	3399
Bucksport	3.22	0.46	0.49	0.8	0.17	0.23	52	15	3330	7131	735	27	3640
Wacca	3.18	0.46	0.23	0.66	0.21	0.25	78	18	4292	6937	1145	34	3756
Sandy	2.96	0.4	0.21	0.7	0.2	0.23	67	13	3570	6469	956	35	3311

Table 6. Elemental composition of *Calypogeia muelleriana* plant tissues. Specimens were taken from sites along the Waccamaw River, SC on May 9, 2013. N, P, K, Ca, Mg, and S are reported as percent of the dry sample. The other parameters are in ppm

Sites	N	P	K	Ca	Mg	S	Zn	Cu	Mn	Fe	Na	B	Al
Lee	3.03	0.42	0.43	0.73	0.11	0.21	53	15	2216	6288	359	26	3046
Conway	3.17	0.26	0.48	0.69	0.13	0.24	69	15	3181	11015	996	16	6316
Pitch	3.12	0.24	0.19	0.78	0.14	0.25	70	18	3620	13328	1126	16	4919
Peach	3.26	0.24	0.54	0.56	0.13	0.23	57	11	2630	11359	645	15	6031
Bucksport	2.66	0.18	0.11	0.62	0.15	0.19	73	21	2978	7819	1243	14	4538
Wacca	3.5	0.27	0.32	0.52	0.23	0.22	81	18	3156	7681	1407	14	6309
Sandy	3.49	0.27	0.5	0.58	0.23	0.23	99	29	4408	8411	1621	14	7110

Table 7. A comparison of bryophyte biomass results from different studies to this study. The results of this study fall within the values found in the literature.

Literature	Study Location	Bryophyte Biomass (g/m^2)
Chantanaorrapint, 2011	Tropical rainforest in Southern Thailand	1.15-199
Sillett, 1995	Cloud Forest Reserve, Costa Rica	72.6-88.1
Beramini, 2001	Montane wetlands in north-eastern Switzerland	1-330
Frangi, 1992	Luquillo Experimental Forest, Puerto Rico	0-600
Sun, 2013	Gongga Mountain, China	0-375
Pande, 1989	NW Himalaya	21.1-877
Hastings, 1989	Alaska	228-447
Raczka, 2014	Waccamaw River, SC	4-36

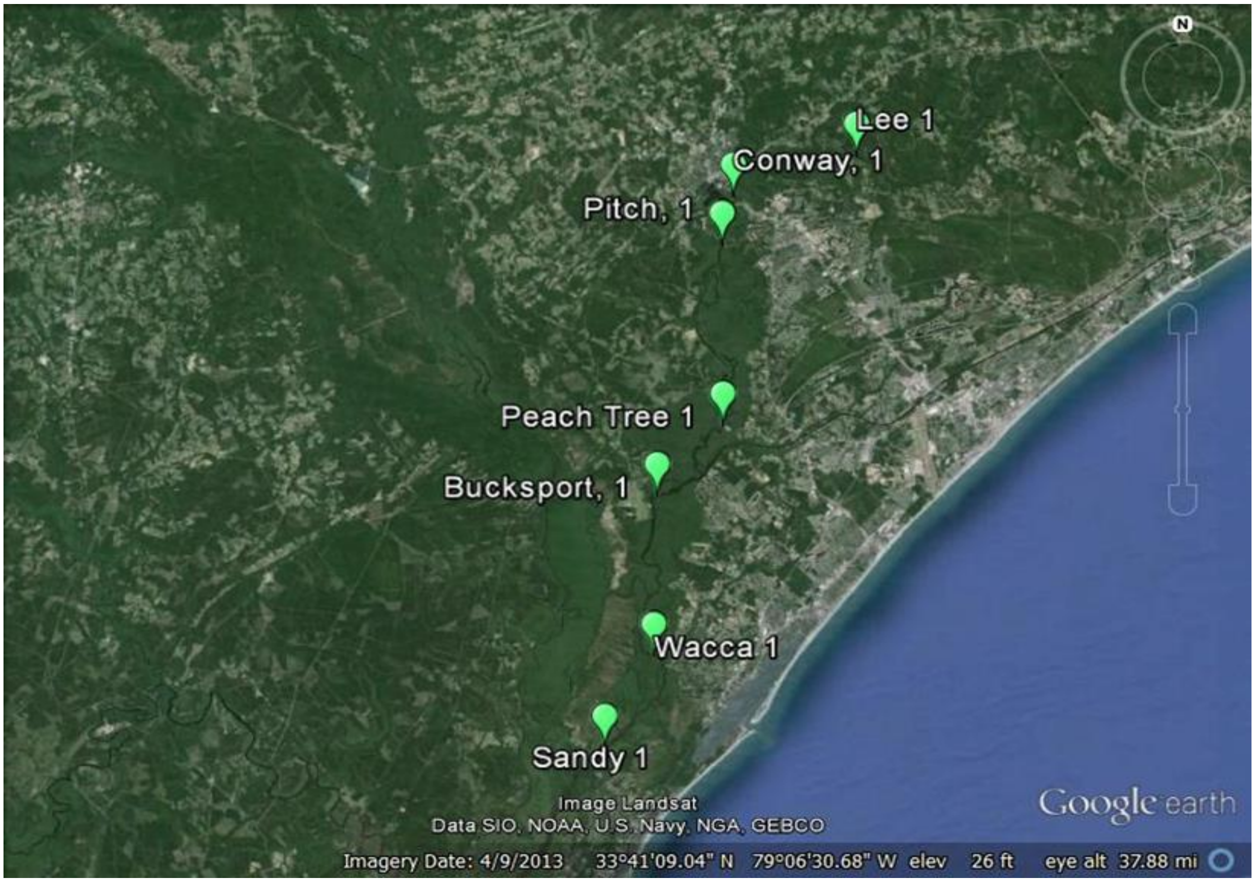

Figure 1. Aerial view of my seven study sites used to assess bryophyte diversity, biomass, water quality analysis and plant tissue analysis along the Waccamaw River, SC

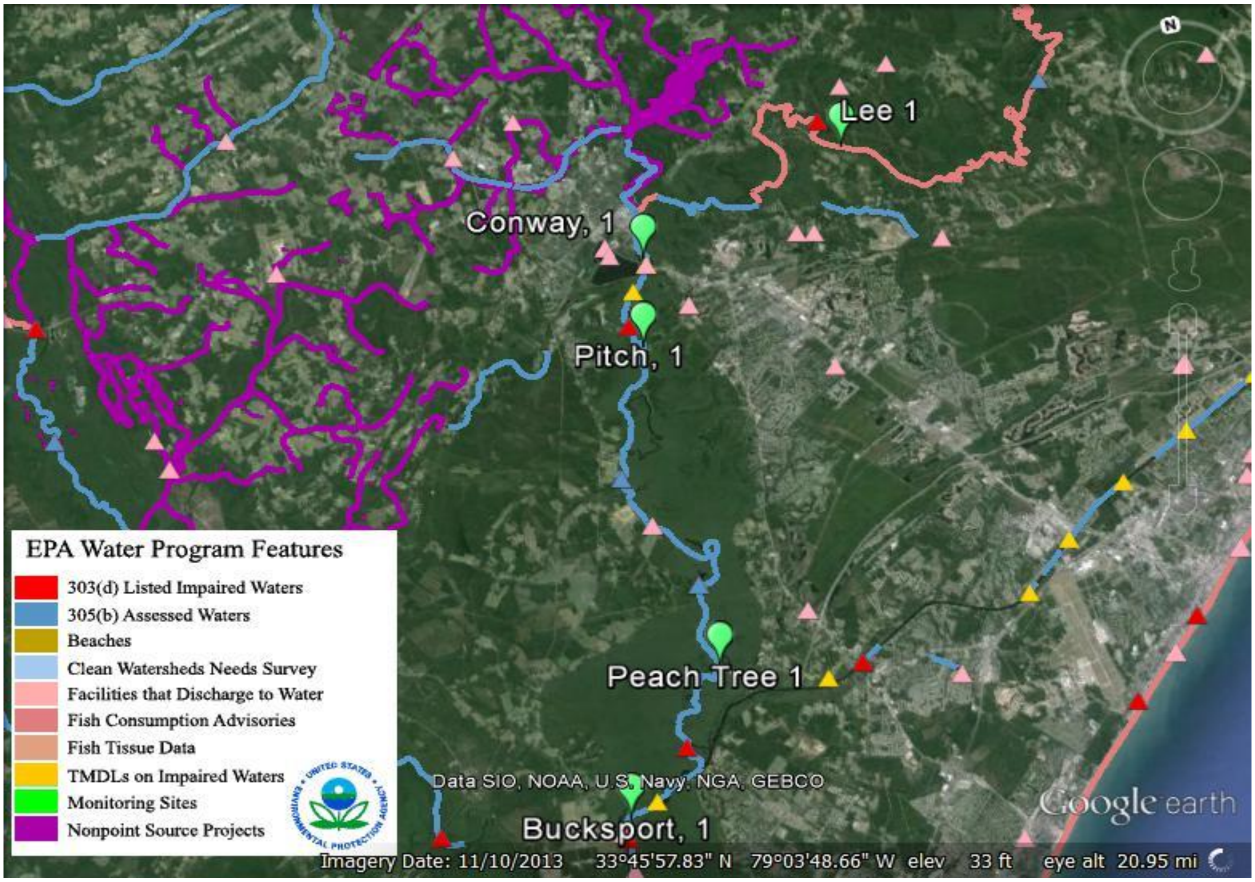

Figure 2. Aerial view of the upper portion of the study area with EPA data overlaid. The red triangles are EPA303 (d) listed impaired water bodies, the blue lines are EPA 305 (b) assessed waters, the yellow triangles indicate Total Maximum Daily Loads (TMDL) on impaired waters, pink triangles are facilities that discharge to water, pink lines are fish consumption advisories, and purple lines are non point source projects.

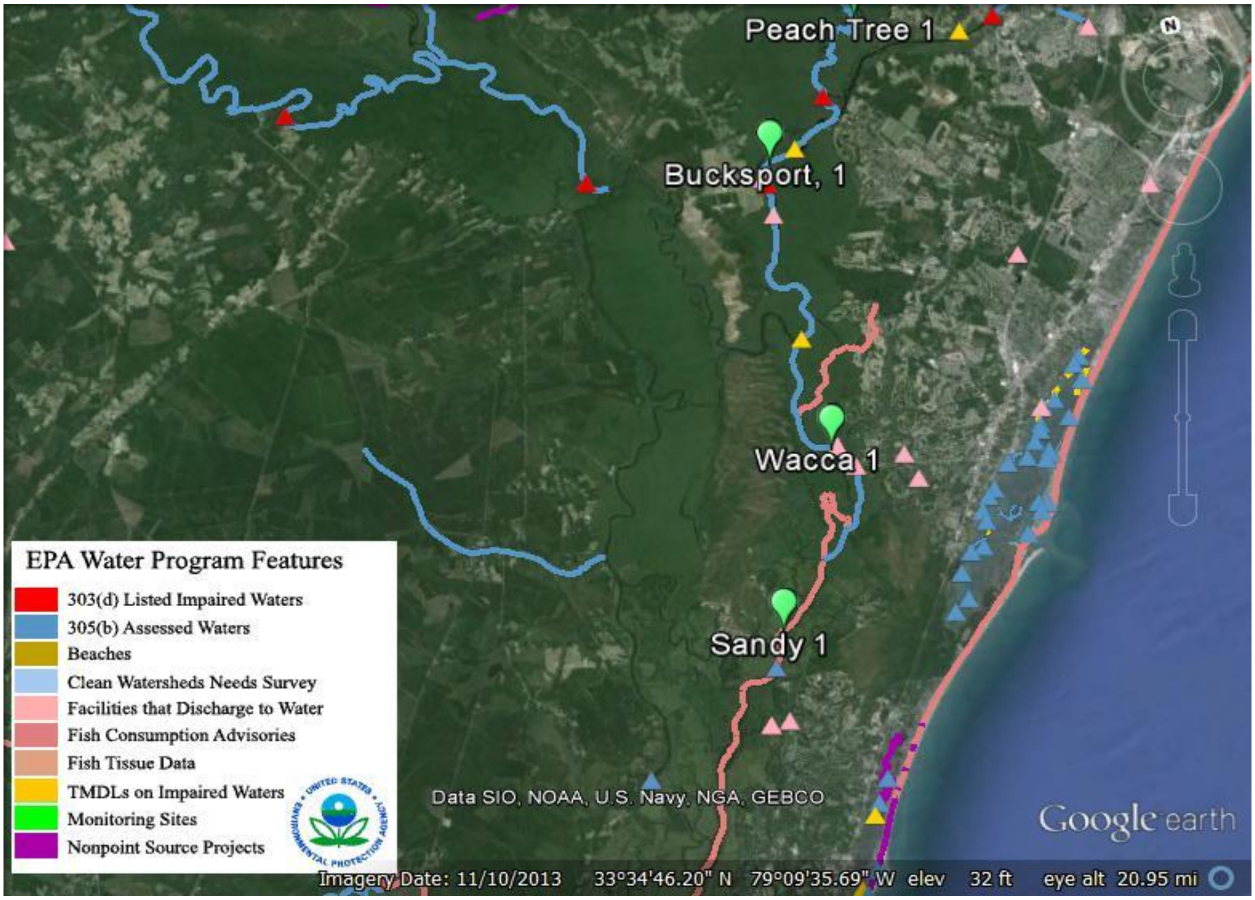

Figure 3. Aerial view of the lower portion of the study area with EPA data overlaid. The red triangles are EPA303 (d) listed impaired water bodies, the blue lines are EPA 305 (b) assessed waters, the yellow triangles indicate Total Maximum Daily Loads (TMDL) on impaired waters, pink triangles are facilities that discharge to water, pink lines are fish consumption advisories, and purple lines are non point source projects

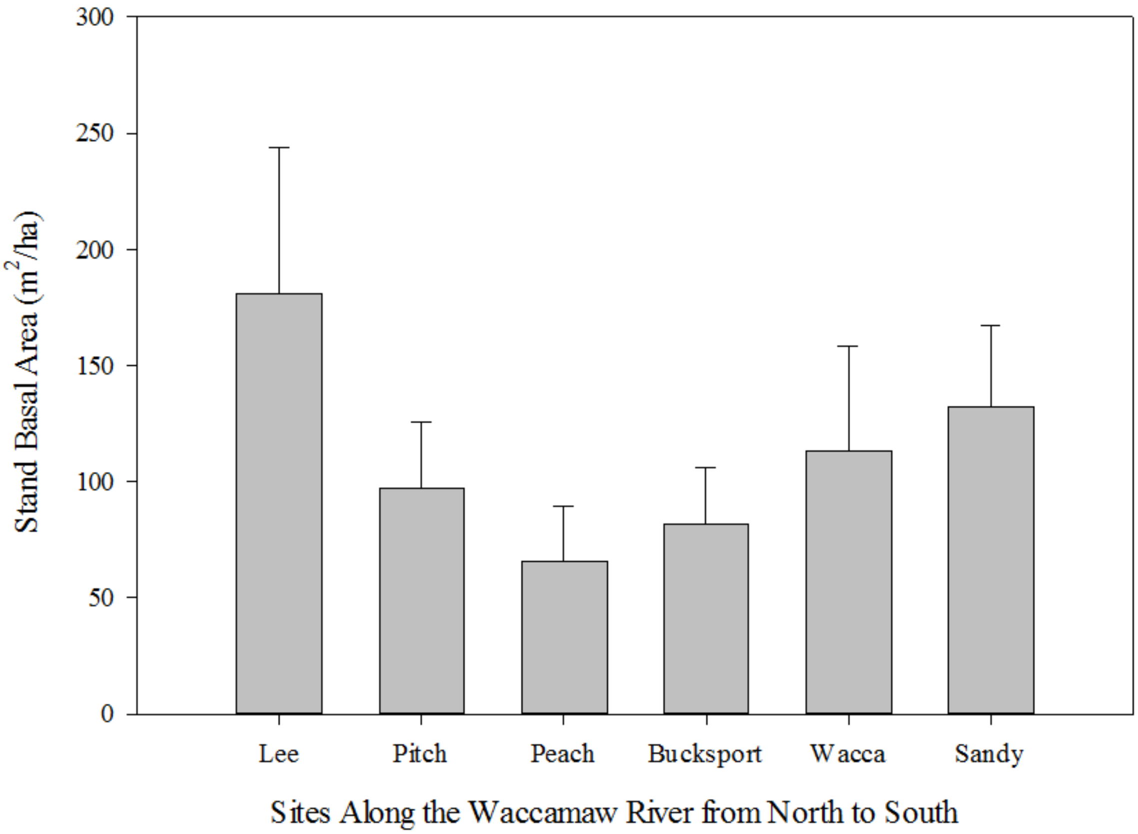

Figure 4. Variation in Stand Basal Area at six sites sampled at the intersection of forested wetland and surface water along the Waccamaw River, SC. Results were analyzed using one-way ANOVA ($p=0.0001$). Means ±1 SE are shown, $n=5$ ($n=6$ for Lee Landing site).

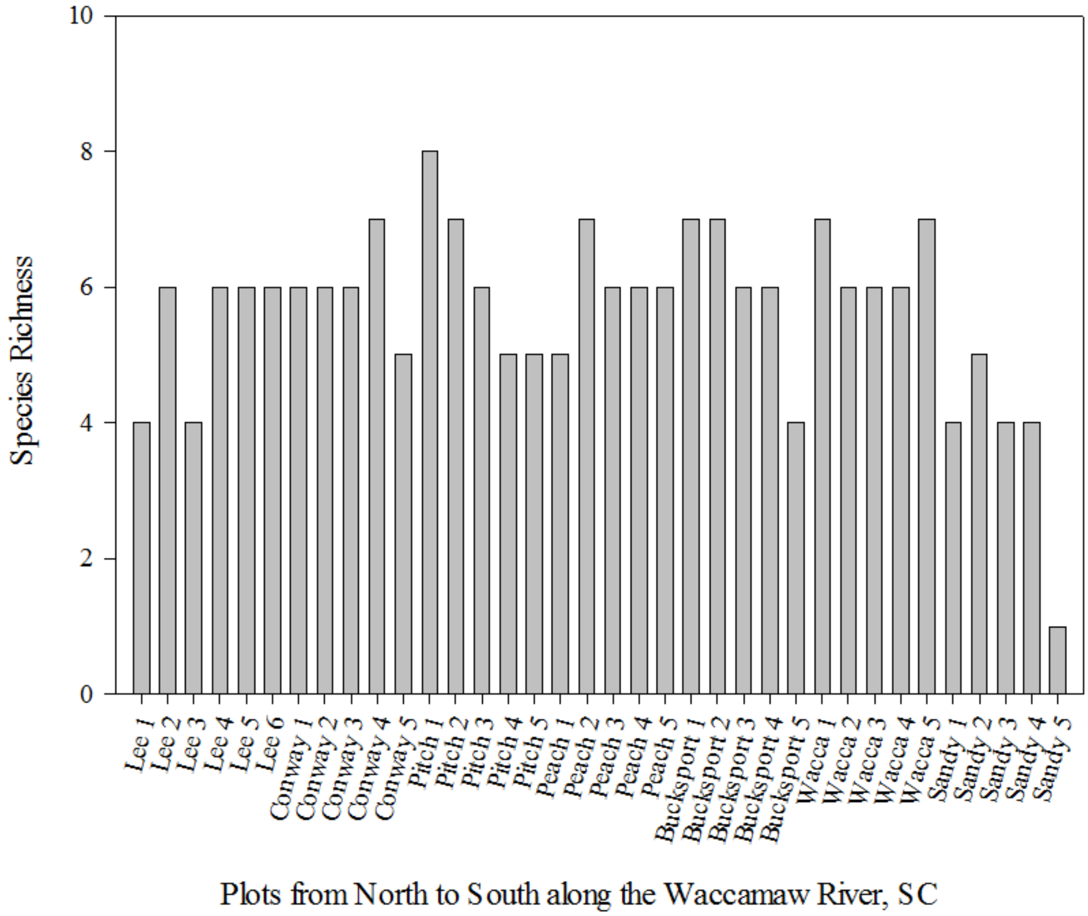

Figure 5. Species richness at the plot level at seven sites along the Waccamaw River, SC.

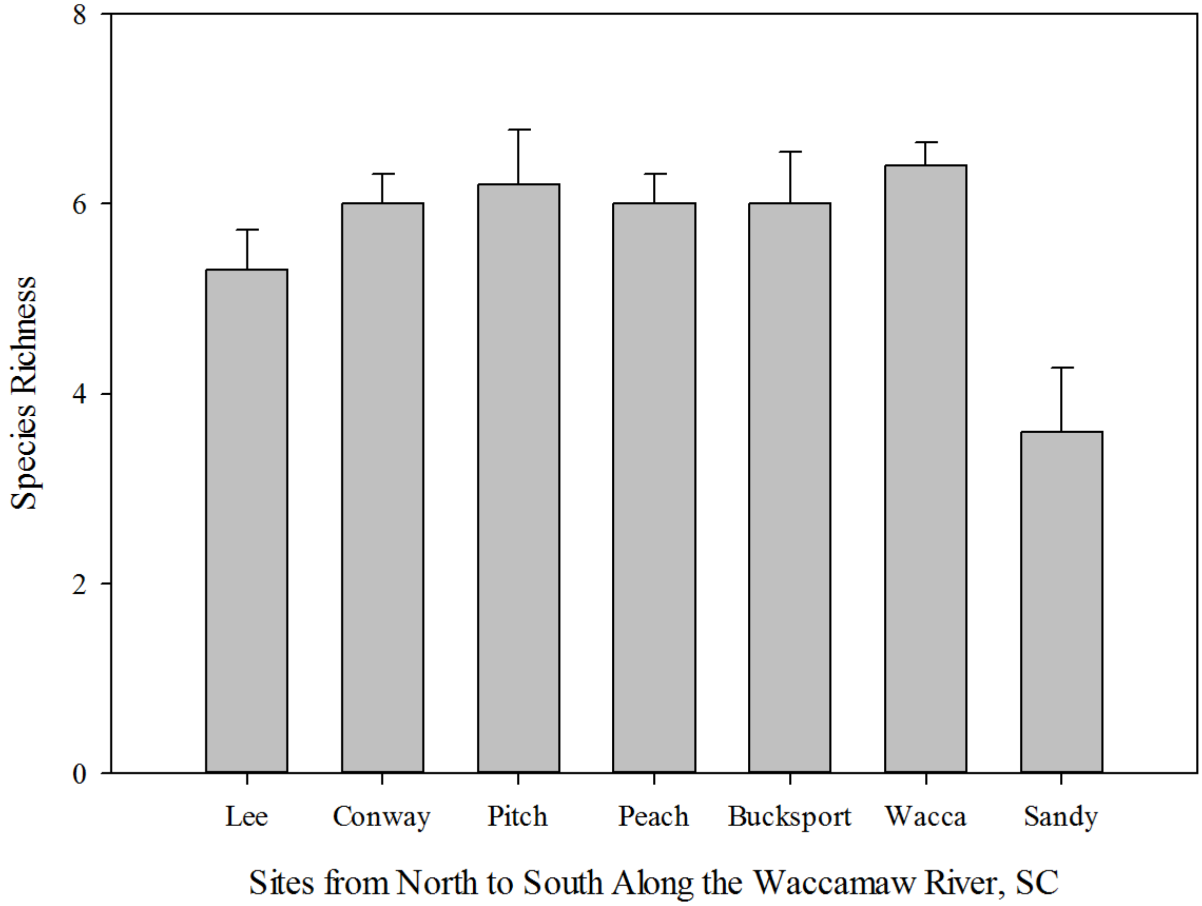

Figure 6. Species richness at each site along the Waccamaw River, SC. Results were analyzed using one-way ANOVA ($p=0.004$). Means ±1 SE are shown, $n=5$ ($n=6$ for Lee Landing site).

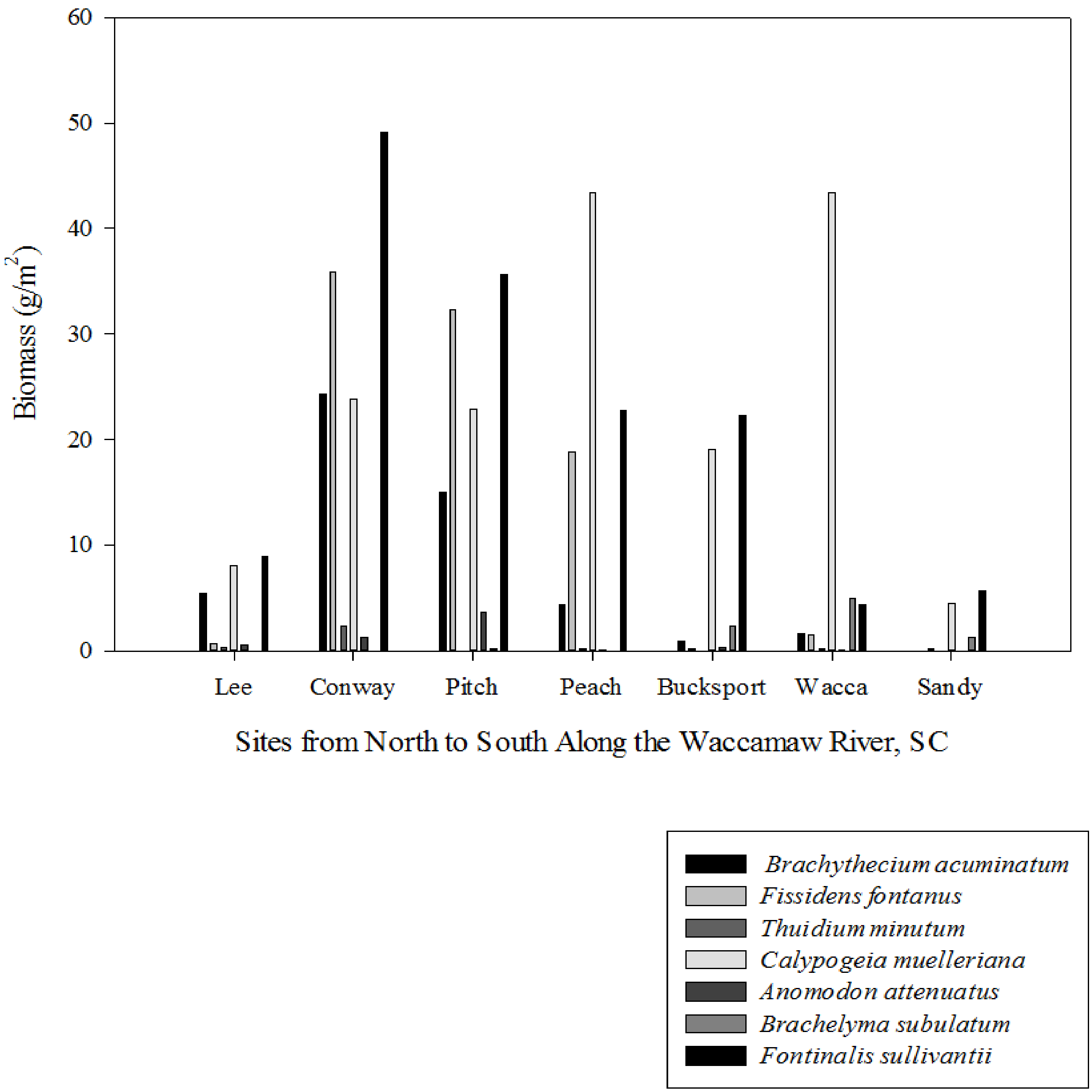

Figure 7. Changes in the species biomass at seven sites along the Waccamaw River, SC. The two dominate species in the aquatic bryophyte community were *Calypogeia muelleriana* and *Fontinalis sullivantii.*

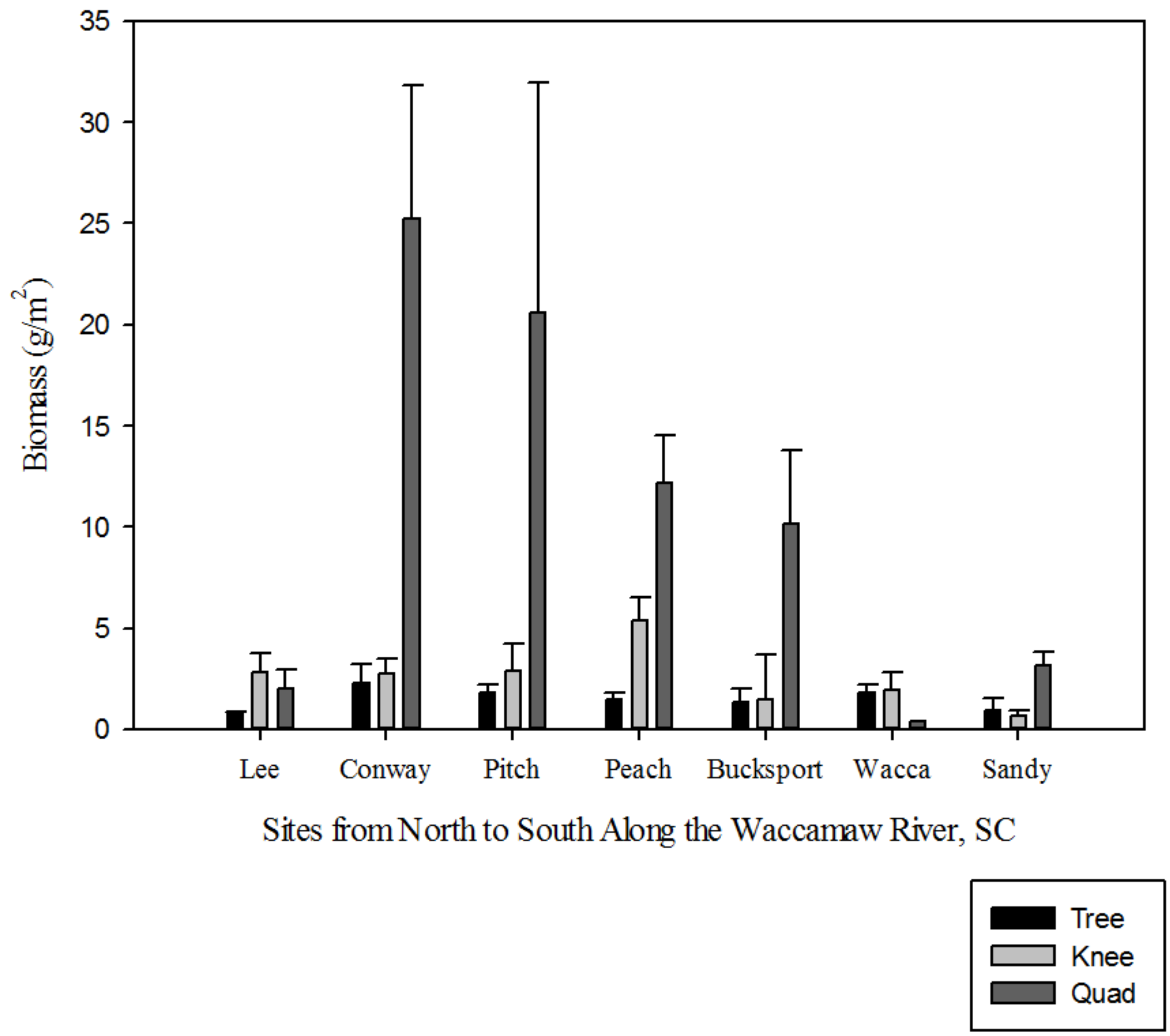

Figure 8. Bryophyte biomass that was found on trees, knees, and in benthic samples at seven sites along the Waccamaw River, SC. The results were analyzed using Kruskal-Wallis non-parametric one-way ANOVA by ranks to analyze the affect that site had on bryophyte biomass associated with trees (p=0.425, f=0.988), knees (p=0.217, f=1.487), and benthic samples (p=0.013, f=3.305) Means ±1 SE are shown, n=5 (n=6 for Lee Landing site).

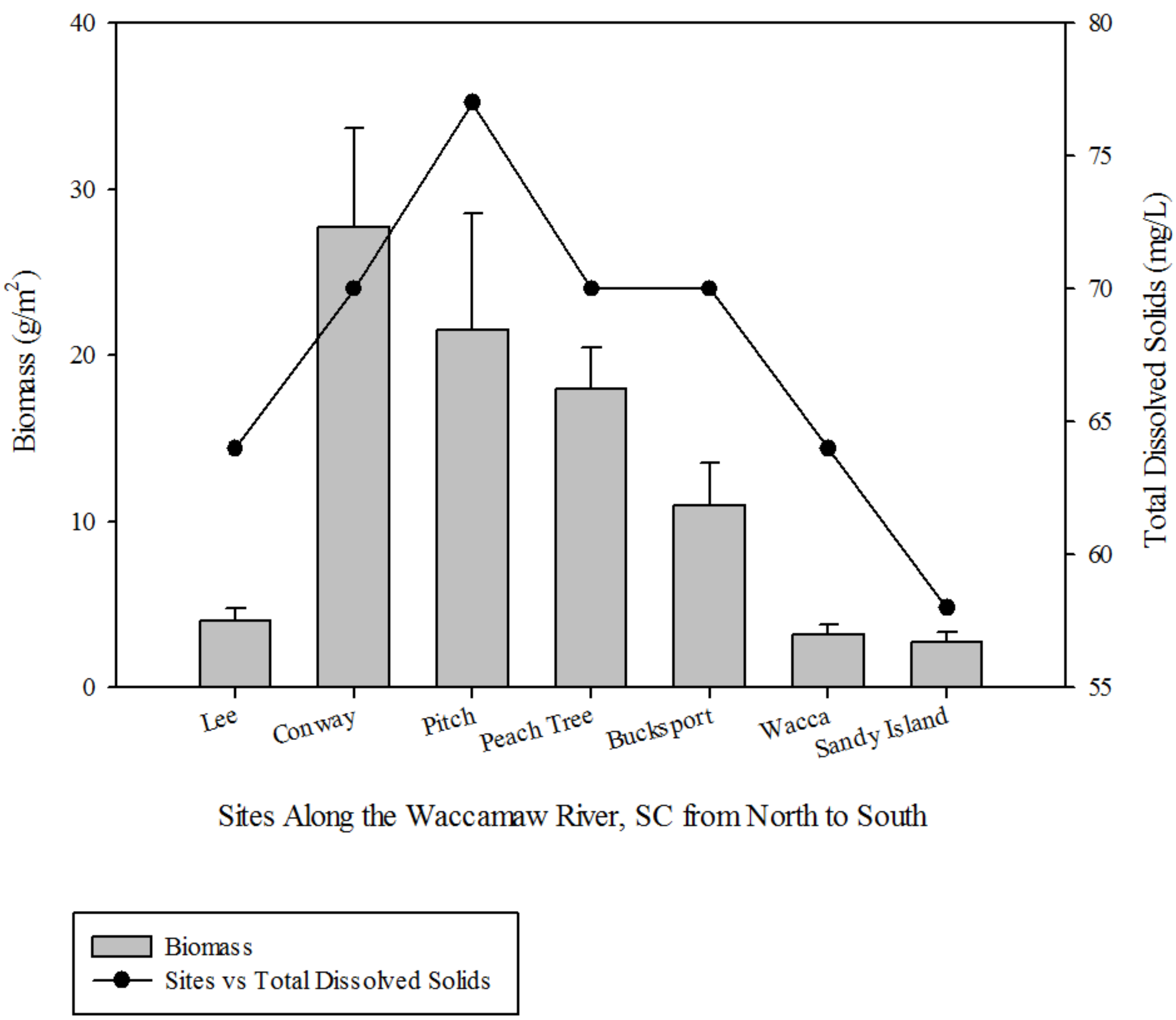

Figure 9. Bryophyte biomass and total dissolved solids found at seven sites along the Waccamaw River, SC. The results were analyzed using Kruskal-Wallis non-parametric one-way ANOVA by ranks (p=0.0013). Means ±1 SE are shown, n=5 (n=6 for Lee Landing site).

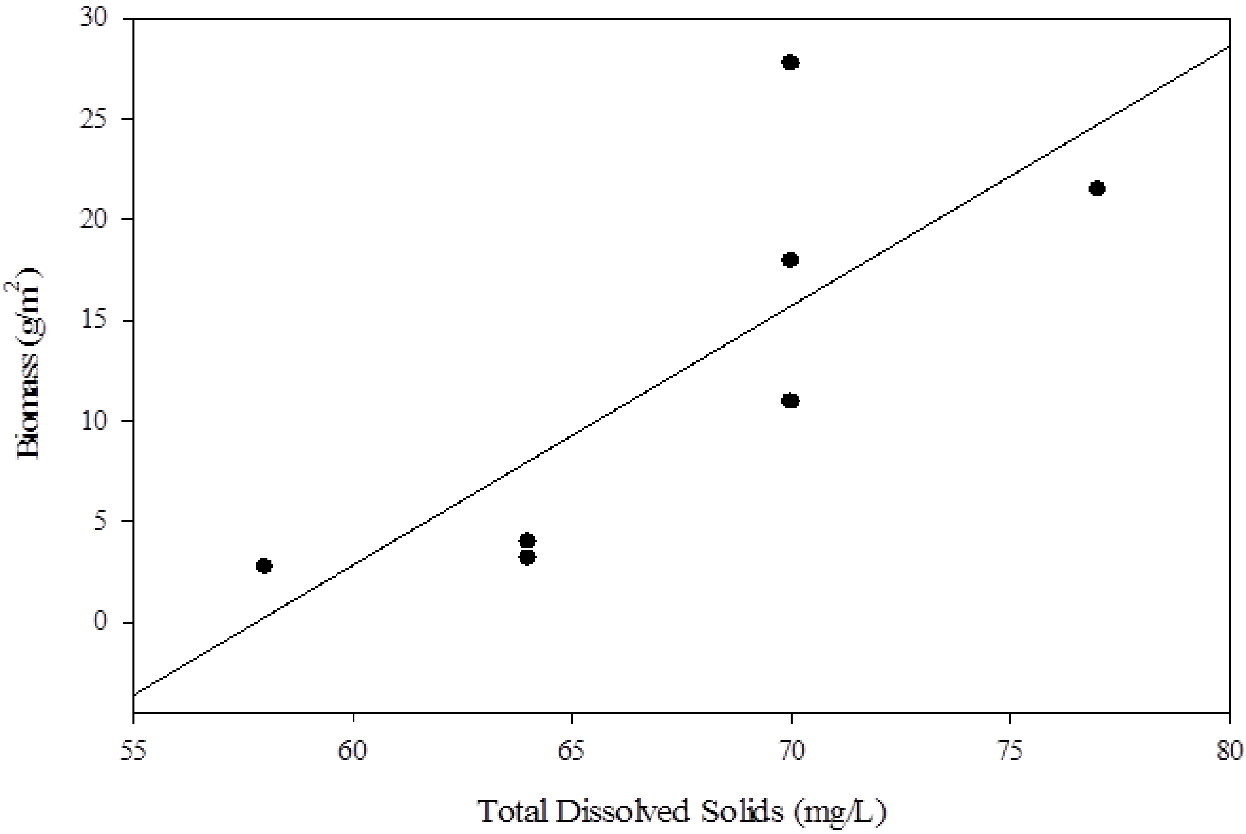

Figure 10. Linear regression of total bryophyte biomass versus total dissolved solids ($r=0.7872$, $r^2=0.6197$, $p=0.0356$).