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Edaphic and Land Use Influences on Central Appalachian Fens

Sarah Deacon

Thesis submitted to the
Davis College of Agriculture, Natural Resources and Design
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science in
Forest Resources Management

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Division of Forestry and Natural Resources

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vegetation; wetland

Abstract

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Sarah Deacon

Local and landscape-scale factors influence peatland floristic assemblages. Our goal in this paper was to assess the interactions between wetland vegetation communities, edaphic factors, and surrounding land cover in central Appalachian peatlands. Specifically we quantified plant community dynamics in relation to edaphic factors and land cover and identified species level responses to human altered landscapes. Cluster analysis on vegetation data identified 3 vegetation groups; an emergent floristic assemblage, a shrub dominated group, and a group with mixed shrub and emergent vegetation. We found that wetlands with emergent vegetation cover were more often associated with natural land cover, higher pH and lower $\text{NH}_4\text{-N}$. Shrub dominated floristic assemblages were associated with higher anthropogenically altered landscapes, higher pH and higher $\text{NH}_4\text{-N}$. The mixed floristic assemblage was associated with lower pH and lower mining in the surrounding watershed. Recursive partitioning results indicated edaphic factors were more influential than land cover for our three vegetation groups. The only landscape-scale factor that was used as a classifier was mining. Nutrient and pH-alkalinity gradients and to a lesser extent surrounding land cover influenced floristic assemblage. We found that vegetation did reflect changes in the landscape; however, species level response proved to be an ineffective technique for detecting the subtle changes in rural landscapes. Wetland vegetation at the community level can be an effective indicator of watershed degradation even in areas with less pronounced anthropogenic disturbance.

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INTRODUCTION TO CENTRAL APPALACHIAN PEATLANDS AND LANDSCAPE

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INTRODUCTION AND JUSTIFICATION

Peatlands are freshwater wetlands primarily found in the cool environments of the northern United States and Canada. These wetlands are generally peat accumulating, acidic, anoxic and nutrient-poor (Wheeler and Proctor 2004). In the central Appalachians peatlands are primarily classified as poor fens that support bog flora (Muzika et al. 1996; Walbridge 1994; Rheinhardt et al. 1999; Moorhead et al. 2000). Plant communities contain species with different adaptations, habitat tolerances, and life-history strategies. In peatlands plants are adapted to nutrient poor conditions. Central Appalachian peatlands have a patchy vegetation distribution that is the result of chemical and hydrologic gradients (Walbridge 1994; Rentch et al. 2008). There have been many studies examining the relation between plant community composition and soil chemistry, soil moisture and acidity-alkalinity gradient influences on peatlands (Seabloom et al. 2001, Bragazaza and Gerdol 2002, Clement et al. 2002, Kennedy et al. 2003, Weiss et al. 2003, Pastor et al. 2002, Chapin et al. 2004, Kennedy and Murphy 2004, Kirk and Kronzucker 2005, Magee and Kentula 2005).

Anthropogenic disturbance has the ability to shape plant communities by altering environmental conditions. The composition of wetland plant communities can indicate the

biological integrity of the wetland, often with great sensitivity (Matthews 2003, Veselka et al. 2010). While most of the well documented studies on the relations between plant communities and disturbance are from severe disruptions, many land-use impacts are low-level or incremental (Galatowitsch et al. 2000). A variety of studies conducted outside of West Virginia have examined plant community composition in wetlands and their driving factors in development. My goal in this thesis was to assess the interactions between wetland vegetation, edaphic and landscape-scale factors in central Appalachian peatlands. Specific objectives were to: 1) Characterize wetland-scale plant communities; 2) Quantify influential edaphic factors and landscape-scale stressors; 3) Quantify plant community dynamics in relation to known landscape conditions; and 4) Identify indicator species of environmental quality.

LITERATURE REVIEW

Peatlands

In the unglaciated Appalachian Mountains in West Virginia far south of the northern US and Canada, peatlands are locally abundant (Franci et al. 2004). Peatland development is based on the creation of a water and peat surplus (McNamara et al. 1992, Mitsch and Gosselink 1993). Cool mountain climates are important for peatlands because the cooler climate has the ability to slow decomposition and evapotranspiration, thereby helping to create the necessary surplus for development. Peatlands are classified into different types based on hydrology. Fens are peatlands that receive both precipitation and some groundwater that contributes additional nutrients. Fens can be further characterized as rich vs. poor depending on the degree of groundwater influence (Walbridge 1994).

Peatlands in which plants rely exclusively on precipitation for all their nutrients are called ombrotrophic peatlands or bogs. Transitional peatlands are often called poor fens and have a combination of bog and fen characteristics. Fens often succeed into bogs creating a peat layer that eventually isolates the flora from groundwater which then isolates the plant communities from groundwater nutrients (Kao et al. 2003).

Bogs are generally nutrient poor compared to fens because of their isolation from groundwater. Soil water chemistry plays a significant role in the plant community development as it is the means by which nutrients are obtained by growing plants (Heinselman 1970). Parameters of soil water chemistry include available nutrients, cation-exchange capacity, pH, and mineral concentration.

Soil chemistry is also important in determining how peatlands are classified (Heinselman 1970, Tiner 1999, Bragazaza and Gerdol 2002, Rentch et al. 2008). Peatlands are among the few ecosystems in which pH is a predominant factor in vegetation community development with pH influencing nutrient availability (Chapin et al. 2004). Generally ombrotrophic bogs have lower productivity than minerotrophic fens (Mitsch and Gosselink 1993). The lack of nutrient availability has resulted in floristic assemblages with plant functional groups that have special adaptations to the low-nutrient environment. Central Appalachian Peatlands (Fig 1). The peatlands found in the Central Appalachian Mountains are technically classified as poor fens; however, they support bog flora (Moorhead et al. 2000, Muzika et al. 1996, Rheinhardt et al. 1999, Walbridge 1994).

The wetlands in northern West Virginia are believed to vary in age from Pleistocene (18,000 years before present (BP)) to present (Diehl 1981). These central Appalachian wetlands were not created by retreating glaciers like their counterparts in the

Northeastern United States. Instead, these peatlands have developed where landform and underlying lithology inhibits drainage. Diehl (1981) found that the diversity of geologic settings do not influence the type of wetland that occurs; rather this was dependent on water levels and the geologic or geomorphic features influence the presence or absence of a wetland but not its type. Despite differences in geologic formation, Francl et al. (2004) asserts that the greatest difference between northern boreal bogs and West Virginia peatlands is their state prior to human influence.

Originally these wetlands were dominated by red spruce (*Picea rubens*), balsam fir (*Abies balsamea*), and great laurel (*Rhododendron maximum*) (Fortney and Rentch 2003). Their present state has been greatly influenced by anthropogenic factors. The West Virginia Appalachians were logged and repeatedly burned. This burning, combined with wind and water erosion degraded the rich organic soils (Fortney and Rentch 2003). Other anthropogenic influences on the landscape include both active and reclaimed coal mines as well as agriculture, mostly in the form of pastures.

Ultimately, removal of the forests created isolated areas in which elevated water tables supported new wetland formation (Francl et al. 2004). Additionally, the role of beaver (*Castor canadensis*) was and continues to be influential in wetland development (Bonner et al. 2009, Walbridge 1994)(Fig 2). The post disturbance succession has created wetlands that are unique in both their history and habitat.

The central Appalachian peatlands are unique because of their formation, history, hydrology and plant communities (Fig 3). While these wetlands receive groundwater, the acidity of the underlying geology creates a low pH causing bog plant communities to grow in these fens (Losche and Beverage 1967). Because of this unique relation, Moorhead et al.

(2000) advocates further exploration into the interactions between geomorphic setting and plant community variability. Research in this area has found that wetland community plant composition is heavily influenced by soil moisture regimes and water chemistry (Walbridge 1994). Soil properties in relation to geomorphic location also may influence plant communities in Appalachian mountain fens (Moorhead et al. 2000).

A variety of studies conducted outside of West Virginia have examined plant community composition in wetlands and the driving factors in development. There have been many studies examining the relation between plant community composition and soil chemistry (Bedford et al. 1999, Boutin and Keddy 1993, Chapin et al. 2004, Clement et al. 2002, Kennedy and Murphy 2004, Pastor et al. 2002, Weiss et al. 2003). The connection between soil moisture and plant community patterning have been well documented (Goslee et al. 1997, Kennedy and Murphy 2004, Kirk and Kronzucker 2005, Magee and Kentula 2005, Seabloom et al. 2001, and Walbridge 1994). Some studies have also found litter to be influential in plant community development (Holden et al. 2004, Weltzin et al. 2005). There have been many studies on the role of wetlands and nutrient cycling (Morris 1991, Bedford 1996, Driscoll et al. 1998, Green and Galatowitsch 2001, Mahaney 2001, Kao et al. 2003, Poe et al. 2003, Weiss et al. 2003, Kirk and Kronzucker 2005, Lucassen et al. 2005, Tokida et al. 2005). Few of these studies have been conducted on peatlands and even fewer have taken place in the central Appalachians.

Landscape-Scale Influences

Anthropogenic disturbances have the ability to shape plant communities by altering environmental conditions. These disturbances come in a variety of forms. Plant community response to disturbance has been documented in a variety of studies (Morris 1991,

Mensing et al.1998, Galatowitsch et al. 2000, Mahaney 2001, Aznar et al. 2003, Campbell et al. 2003, Johnston 2003, Lavoie et al. 2005). Studies have examined the spatial relations between disturbance and wetlands (Galatowitsch et al. 2000, Aznar et al. 2003). Others examined how specific species respond to a specific disturbance (Johnston 2003). Plant succession in disturbed wetlands has also been well documented (Seabloom et al. 2001, Campbell et al. 2003, DeBerry and Perry 2004). The research is as varied as the types of disturbances.

In the central Appalachians, disturbances primarily come in the form of active and abandoned coal mines, agriculture and urbanization. Sedimentation, invasive species and nutrient enrichment are a few of the products of disturbance. Sedimentation has been found to inhibit growth, change nutrient distribution and change species composition (Wardrop and Brooks 1998, Craft and Casey 2000, Mahaney 2001, Werner and Zedler 2002, Harter and Mitsch 2003, Houlahan and Findlay 2004, Mahaney et al. 2004). The introduction of invasive species influences competition and alters wetland community types (Green and Galatowitsch 2001, Maurer and Zedler 2002, Farnsworth and Meyerson 2003, Mahaney et al. 2004, Magee and Kentula 2005). Agricultural effects on soil nutrients and water quality have been detrimental to wetland function and health (Green 1989, Bruland et al. 2003, Kao et al. 2003, Rejmankova 2005). Increases in flooding and erosion have been documented as a result of agriculture (Reidel et al. 2005, Meyles et al. 2006). Eckles et al. (2002) studied the functional capacity of wetlands on agricultural sites and found that continued anthropogenic disturbance significantly affects a wetland's ability to maintain a sustainable functional condition.

Mining impacts from both active and abandoned coal mines are potentially detrimental to local wetlands. Acid mine drainage is a product of coal mining that lowers pH. Acid mine drainage is the formation and movement of acidic water rich in metals. This acidic water forms through the chemical reaction of surface and groundwater with rocks that contain sulfur-bearing minerals, resulting in sulfuric acid (US EPA 2006). The resulting fluids may be highly toxic and when mixed with groundwater, surface water, and soil, may have harmful effects on humans, animals, and plants (US EPA 2006). Mining also has the ability to change watershed hydrology (Negley and Eshleman 2006). Changes to the physical land surface and deforestation change infiltration rates and alter water table elevations (Fig 4)(Bonta et al. 1997).

Wetlands serve as sinks for many types of nutrients. Because of this, wetlands have been used to treat acid mine drainage since the 1980s (Kittle et al. 1995). However, in natural wetlands waters with low pH and high iron and sulfur can cause extensive ecological damage (Fig 4) (Mitsch and Gosselink 1993). Although some wetlands have the ability to treat acid mine drainage, the acid mine drainage has detrimental effects on wetland vegetation, nutrient cycling, and decomposition (Kittle et al. 1995). In the West Virginia Appalachians, wetlands have already been found beneficial in treating acid mine drainage (Stephens 2003). While some of the values of these wetlands have been assessed, there is a lack of information on the effects of mining to nearby natural wetland function.

Study Area

The study area for this research consists of the mountainous areas of Tucker and Randolph counties (Fig 5). These two counties are in the north-central part of West Virginia in two ecoregions (Fig 6). The northern part of our study area is within the central

Appalachian ecoregion, specifically the Forested Hills and Mountains section which are the highest and most rugged areas within the ecoregion (Woods et al. 1999). The southern part of our study area is within the Ridge and Valley ecoregion specifically the Northern Dissected Ridges.

The central Appalachian forested hills and mountains are characterized by highly dissected hills, mountains, and ridges with steep, narrow valleys. Local relief varies widely and cool, steep-gradient streams are common on the landscape. These streams have low buffering capacity and many, including some without acid mine drainage, are too acidic to support fish (Woods et al. 1999). The northern dissected ridges of the Ridge and Valley ecoregion are characterized by broken, dissected, almost hummocky ridges. Elevations range from about 244-1,265 m with variable local relief (Woods et al. 1999). Most of the soils are acidic, steep, often stony and have low nutrient characteristics (Woods et al. 1999). The climate throughout the study area is highly variable due to differences in elevation. The average daily maximum temperature is 14° C (58° F) and the average daily minimum temperature is 2°C (35°F)(Losche and Beverage 1967). Winters are generally long and summers are mild. Local topography is conducive to the formation of frost pockets causing lower temperatures in depressional areas (Walbridge 1994). Prevailing westerly winds bring substantial precipitation to the windward side of the mountains (Woods et al. 1999). Rainfall from May through September exceeds potential evapotranspiration. For this study wetland selection was restricted to those areas ≥ 800 m in elevation due to the influences of elevation on climatological conditions and soil temperature (Francl et al. 2004).

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Fig 1 Sundew (*Drosera rotundifolia*) is a carnivorous plant found in peatlands. Sundew is also listed on the West Virginia Rare, Threatened and Endangered plant species list and was found throughout the study area.

Fig 2 Beaver (*Castor canadensis*) play an active role influencing wetland development.

Fig 3 A photo of an emergent wetland study site in Dolly Sods, Tucker County, West Virginia, USA. This is representative of a site with minimal recent disturbance in the watershed.

Fig 4 A photo of a scrub-shrub wetland that receives acid mine drainage in Tucker County, West Virginia, USA. This is representative of a site with anthropogenic disturbance in the watershed.

Fig 5 Study area within Randolph and Tucker counties, West Virginia, USA. The study area was limited to areas ≥ 800 m in elevation.

Fig 6 Study area within Randolph and Tucker counties, West Virginia, USA. The study area encompassed two ecoregions: Forested Hills and Mountains and Northern Dissected Ridges and Knobs.

CHAPTER II

Vegetation, edaphic and landscape level influences in central Appalachian fens

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Abstract

Local and landscape-scale factors influence peatland floristic assemblages. Our goal in this paper was to assess the interactions between wetland vegetation communities, edaphic factors, and surrounding land cover in central Appalachian peatlands. Specifically we quantified plant community dynamics in relation to edaphic factors and land cover and identified species level responses to human altered landscapes. Cluster analysis on vegetation data identified 3 vegetation groups; an emergent floristic assemblage, a shrub dominated group, and a group with mixed shrub and emergent vegetation. We found that wetlands with emergent vegetation cover were more often associated with natural land cover, higher pH and lower $\text{NH}_4\text{-N}$. Shrub dominated floristic assemblages were associated with higher anthropogenically altered landscapes, higher pH and higher $\text{NH}_4\text{-N}$. The mixed floristic assemblage was associated with lower pH and lower mining in the surrounding watershed. Recursive partitioning results indicated edaphic factors were more influential than land cover for our three vegetation groups. The only landscape-scale factor that was used as a classifier was mining. Nutrient and pH-alkalinity gradients and to a lesser extent surrounding land cover influenced floristic assemblage. We found that vegetation did reflect changes in the landscape; however, species level response proved to be an ineffective technique for detecting the subtle changes in rural landscapes. Wetland vegetation at the community level can be an effective indicator of watershed degradation even in areas with less pronounced anthropogenic disturbance.

Keywords: central Appalachians, land use, peatland, soils, vegetation, wetland

Introduction

The relations between soil chemistry and wetland classification are interdependent in northern peatlands (Wheeler and Proctor 2004). Specifically, nutrients play an important role in peatland development. The lack of nutrient availability has resulted in floristic assemblages with plant functional groups that have special adaptations to the low nutrient environments. The peatlands found in the central Appalachian Mountains are technically classified as fens; however, they support bog flora (Moorhead et al. 2000, Muzika et al. 1996, Rheinhardt et al. 1999, Walbridge 1994). These wetlands were not created by retreating glaciers like their counterparts in the northeastern United States and Canada (Diehl 1981). Instead, the central Appalachian peatlands have developed where landform and underlying lithology inhibit drainage (Moorhead et al. 2000). Diehl (1981) found that the diversity of geologic settings do not influence the type of wetland that occurs. Wetland presence or absence was dependent on water levels and the geologic or geomorphic influence but not wetland type (Diehl 1981). Despite differences in geologic formation, Franci et al. (2004) asserts that the greatest difference between northern boreal bogs and central Appalachian peatlands is their state prior to human influence. Originally these wetlands were dominated by red spruce (*Picea rubens*), balsam fir (*Abies balsamea*), and great laurel (*Rhododendron maximum*) (Fortney and Rentch 2003). Their present state has been greatly influenced by anthropogenic factors such as logging and both active and historic mining (Fortney and Rentch 2003). Other anthropogenic influences on the landscape include agriculture, mostly in the form of pastures, roads and suburban development. Additionally, the role of beaver (*Castor canadensis*) was, and continues to be

influential in wetland development (Bonner 2005, Walbridge 1994). This post disturbance succession has created wetlands that are unique in both their history and habitat.

The unique formation, history, and hydrology of central Appalachian wetlands have created complex mosaics of plant communities (Fortney and Rentch 2003). The lack of buffering capacity from the underlying geology creates a lower pH causing bog plant communities to grow in these fens (Losche and Beverage 1967). Wetland plant community composition in the central Appalachians is heavily influenced by soil moisture regimes and water chemistry (Walbridge 1994, Bonner et al. 2009). Soil properties and chemistry also influence plant communities in central Appalachian mountain peatlands (Moorhead et al. 2000). Because of these unique relations further study into the interactions between wetland edaphic factors and landscape variables is needed to better understand their influence on plant communities.

A variety of studies conducted outside of West Virginia have examined plant community composition in wetlands and their driving factors in development. There have been many studies examining the relation between plant community composition and soil chemistry (Bedford et al. 1999, Boutin and Keddy 1993, Chapin et al. 2004, Clement et al. 2002, Kennedy and Murphy 2004, Pastor et al. 2002, Weiss et al. 2003). The connection between soil moisture and plant community patterning has been well documented (Goslee et al. 1997, Kennedy et al. 2003, Kirk and Kronzucker 2005, Magee and Kentula 2005, Seabloom et al. 2001). There also have been many studies on the role of wetlands and nutrient cycling (Morris 1991, Bedford 1996, Driscoll et al. 1998, Green and Galatowitsch 2001, Mahaney 2001, Kao et al. 2003, Poe et al. 2003, Weiss et al. 2003, Kirk and Kronzucker 2005, Lucassen et al. 2005, Tokida et al. 2005) and acidity-alkalinity gradient

influences on peatland vegetation (Vitt and Chee 1990, Chapin et al. 2004, Bragazaza and Gerdol 2002). Few of these studies have been conducted on peatlands and even fewer have taken place in the central Appalachians.

In addition to local influences, anthropogenic disturbances are responsible for landscape-scale stressors on wetland plant communities. Human impacts can alter wetlands with on-site disturbance or watershed-level degradation (Johnston et al. 2009). Sedimentation (Johnston 2003), changes in soil moisture regimes (Walbridge 1994, Bonner et al. 2009), the introduction of invasive species (Mahaney et al. 2004, Magee and Kentula 2005, Drohan et al. 2006), agricultural inputs (Green 1989, Rejmankova 2005) and acid mine drainage (Kittle et al. 1995) all influence wetland floristic assemblage. The sensitivity of wetland plant assemblages to land use impacts indicate that they may be sensitive indicators for land use change. This sensitivity makes wetland vegetation assessment an important part of evaluating wetland condition (Johnston et al. 2009). The composition of wetland plant communities can indicate the biological integrity of the wetland, often with great sensitivity (Matthews 2003, Veselka et al. 2010). The relations between plant communities and surrounding land use make plants ideal biological indicators. Often indicator species can mean many different things. They can be species that indicate the likely presence or absence of a set of other species; they can be indicators used for habitat management or species that reflect the effects of a disturbance (Lindenmayer et al. 2000). This is due to species niche habitat preferences (DeCaceres et al. 2010). The concept of species level indicators is an appealing and potentially important concept because of the impossibility of monitoring everything (Lindenmayer et al. 2000). If indicator species could be identified, they would be a powerful management tool.

While most of the well documented studies on the relations between plant communities and disturbance are from severe disruptions, many land-use impacts are low-level or incremental (Galatowitsch et al. 2000). Few of these studies have been conducted on peatlands and even fewer have taken place in the rural Appalachians. Our goal in this paper was to assess the interactions between wetland vegetation, land use, and edaphic factors in central Appalachian peatlands. Our specific objectives were to: 1) Characterize wetland-scale plant communities; 2) Quantify influential edaphic factors and landscape-scale stressors; 3) Quantify plant community dynamics in relation to known landscape conditions; and 4) Identify indicator species of environmental quality.

Study Area

Our study was conducted in north-central West Virginia (Fig. 1). Highly dissected hills, mountains, and ridges with steep and narrow valleys characterize the area. Local relief varies widely and cool, steep-gradient streams are common on the landscape. Wetlands in our study ranged from 850-1200 m in elevation. The wetlands in the study are classified as poor fens, a type of peatland, due to low nutrient levels, low pH and cool temperatures. They support bog flora similar to peatlands of higher latitudes (Moorhead et al. 2000). Land use in the study area is varied with 51% comprised of public lands (National Land Cover Database 2001). These public lands are in the form of national forest, state parks, and a national wildlife refuge. Since the 1970s, other areas have been converted from forest and grassland areas into second home developments (Fortney and Rentch 2003). There is some active agriculture in the form of livestock and pasture. Less than 1% of our study area is classified as urban or suburban. There is historic and current

mining in our study area; some portions of the area has been extensively mined for Bakerstown coal and acid producing Upper Freeport coal. When assessing land cover, landscape development indexes (LDI) are used (Brown and Vivas 2005). The landscape development index (LDI) score for the area averaged 2.87 on a scale of 1-9 with low numbers representing less developed areas (Brown and Vivas 2005).

Data collection

We sampled vegetation from 30 sites in Tucker and Randolph counties, West Virginia during the summers of 2005 (n=7) and 2006 (n=23) (Fig 1). Wetlands were selected using stratified random sampling designed to span multiple human disturbance gradients and a range of wetland types and qualities in our sampling region. Potential sites were categorized by the amount of anthropogenic land cover in each watershed. Sites were separated based on watersheds with all natural land cover and those with anthropogenic land cover. Wetlands were also stratified based on National Wetlands Inventory (2004) vegetation cover classes. Wetlands with emergent or scrub-shrub vegetation cover were selected. Sites were stratified into 4 categories; no anthropogenic cover and emergent vegetation, no anthropogenic cover and scrub-shrub vegetation, anthropogenic cover and emergent vegetation, anthropogenic cover and scrub-shrub vegetation. Most of the study area is geologically dominated by shale and sandstone except for the Greenbrier formation, which is dominantly limestone and found in Canaan Valley. All wetlands chosen for this study were underlying shale and sandstone (Franci et al. 2004).

Vegetation was measured using stratified random sampling, stratified based on community type. Square quadrats were randomly placed within each wetland plant

community and cover was visually estimated using Daubenmire (1968) cover classes (0-5%, >5-25%, >25-50%, >50-75%, >75-95%, >95-100%) (Barbour et al. 1987). The quadrats were nested plots in the following sizes: 25 m for trees, 5 m for shrubs and 1 m for herbaceous, chosen to match the relative size of the vegetation sampled. Herbaceous species were sampled first to avoid disturbance followed by the shrub plots and finally trees. Herbaceous and shrub plots were measured for cover while trees were measured using diameter at breast height (dbh). All plants were identified to species if possible using Strausbaugh and Core (1977) and Gleason and Cronquist (1991) and were assigned to a Daubenmire cover class. The USDA Plants Database (USDA NRCS 2011) was used for species symbol codes.

Watershed boundaries were delineated for each wetland site using a weighted flow accumulation grid (ESRI Redlands, CA). Land cover was calculated within each watershed using the National Land Cover Database (NLCD 2001). Road length was derived from TIGER roads (2000) data. Wetland area, wetland perimeter, and stream length were derived from National Wetlands Inventory (2004) data.

Soil sampling sites were located within the established vegetation quadrat. One sample was taken from each vegetation quadrat and analyzed separately. Soil samples were collected from a depth of 0-25 cm and analyzed at Brookside Laboratories (Brookside, Ohio) for total exchange capacity by summation (Ross 1995), pH (mineral 1:1 in H₂O)(McLean 1995), organic matter and estimated nitrogen release (loss on ignition at 360°)(Schulte and Hopkins 1996), Mehlich III extractable S, P, Ca, Mg, K, Na, B, Fe, Mn, Cu, Zn, Al (Mehlich 1984), saturated paste extract for H, other bases, soluble salts, chlorides

(Gavlak et al. 2003), KCI-extractable NO₃-N, NH₄-N and nitrogen (Dahnke 1990). Soil chemistry was averaged by wetland for this analysis.

Analytical Methods

Analysis was performed on all plant species that met the criteria of: (1) occurring in a minimum of three sites, and (2) being identified to the species level. Percent cover data were used from each plot and averaged for individual species to give a mean species cover for each wetland. Vegetation data and environmental data comprised of National Land Cover Database (NLCD) land cover classes, road length, wetland area, wetland perimeter and stream length were analyzed for similarity using cluster analysis with Wards linkage and Bray Curtis distance metric (Maechler et al. 2005). Clusters were pruned to three groups based on the length of the cluster tree stems and minimal chaining. Analysis of similarity (ANOSIM) was performed to evaluate if there was a statistical difference among the different group types (Clarke 1993). ANOSIM statistic R ranges from -1 to + 1. Values closer to +1.0 signify a higher level of within group similarity. ANOSIM was run with 999 permutations to assess the statistical significance of R.

Nonmetric multidimensional scaling (NMDS) was used to summarize the wetland vegetation and land use clusters. NMDS solutions from 2 to 6 dimensions were calculated using Bray Curtis distance coefficients. A 3-dimensional solution was used because stress did not improve noticeably in more dimensions. The data were transformed and double standardized (Wisconsin method) by dividing species by their maxima and then sites by their totals (Oksanen et al. 2009). NMDS was run several times to minimize likelihood that the final stress value would not be the global minimum for the configuration (Clarke 1993).

Environmental and soils data were analyzed for collinearity using Spearman's rank correlation. Any variable pair with a correlation of $p > |0.7|$ was considered correlated and one of the pair was removed. Using the `envfit` function in R, environmental and soils data that were not found to be collinear were plotted against the weighted average position of the wetland species in ordination space to project environmental vectors in the ordination diagram. The position of the vectors and how rapidly they change determine their maximal correlation with the ordination space (Oksanen et al. 2009).

Multivariate analysis of variance (MANOVA), analysis of variance (ANOVA) and Tukey's HSD was used to determine significant differences between soil chemistry variables and vegetation groups (Fox 2009). Recursive partitioning was used to detect which edaphic factors and land cover variables were likely to divide groups with respect to their vegetation assemblages using RPART version 2.12.1 (Therneau and Atkinson 1997, De'Ath and Fabricius 2002). Recursive partitioning performs a complete search of all possible splits exploiting an information measure of node impurity. This allows for the selection of the covariate showing the best split. The variables that yield the greatest improvement to deviance were chosen as the splitting variable for each node. The optimal sized tree was chosen using v-fold cross validation runs on data choosing the tree size with the minimum cross validated error.

Indicator species analysis (Dufrene and Legendre 1997) was used to quantify links between specific wetland species and the environmental degradation clusters. Indicator Values (IV) were calculated for each wetland plant. Indicator values are based on the average relative abundance and relative frequency of the species in each group and range from 0-1. The higher the indicator values the more abundant the species in that group. To

evaluate the ability of plants selected as indicator species, coefficient of conservatism values (CC) were assigned to all species in the data set. CC values are a well known component of floristic quality index and are used to help rank the quality of natural areas (Rentch and Anderson 2006). CC values are based on the idea that plant species exhibit different tolerance to disturbance as well as different habitat requirements. Species are assigned CC values with low numbers indicating species are adapted to habitat degradation and high numbers indicating species that are restricted to high quality natural areas. CC values range from 1-10. Mean CC values have proven successful metrics of anthropogenic disturbance (DeKeyser et al. 2003; Matthews 2003; Taft et al. 1997). All statistical analysis was conducted using R (R Development Core Team, Vienna Austria) ($\alpha = 0.05$).

Results

There were 37 out of 98 different plant species were included in the analysis from 30 different wetlands containing 117 plots (Table 1). Wetland sites ranged from having 3 to 15 different species of those species used in the analysis. There were 7 NLCD land cover classes found in the study area. The largest percentage of land cover belonged to the forest cover class (82%) smaller average land covers belonged to mining (4%), pasture (4%), transitional (2%), urban (1%), row crops (0.2%), and wetlands 6%.

Cluster analysis

The results from quantifying plant community dynamics using cluster analysis yielded 3 groups. Sedges and forbs dominated one group, this group was named emergent. One group was dominated by woody species and was named shrub. The last group had a combination of sedges, woody species and forbs and was named mixed (Fig. 2). The

number of sites with each group was herbaceous = 5, shrub = 10, mixed = 15. Analysis of similarity (ANOSIM) was run to examine group structure and indicated that there was more between group similarity than within group similarity ($R=0.576$, $P=0.001$).

Vegetation in the mixed group (Fig. 2) consisted of herbaceous species such as *Juncus brevicaudatus*, *Eriophorum virginicum*, *Juncus canadensis*, and *Drosera rotundifolia*, and the shrub species *Photinia pyrifolia*, *Viburnum cassinoides*, and *Vaccinium myrtilloides*.

Vegetation in the emergent group consisted of sedges, grasses and forbs including *Onclea sensibilis*, *Carex scoparia*, *Glyceria canadensis*, *Dicanthelium clandestinum*, *Galium tinctorum*, *Scirpus polyphyllus* and *Polygonum saggitatum*. Vegetation in the shrub group was dominated by woody species with smaller amount of herbaceous species. Woody species found were *Hypericum densiflorum*, *Hypericum mutilum*, *Spirea alba*, and *Salix sericea*. Non-woody species included *Pteridium aquilinum*, *Typha latifolia* and *Solidago uliginosa*.

Identification of influential edaphic and landscape level variables

The emergent vegetation group had lower average organic matter, estimated nitrogen release, soluble sulfur, $\text{NH}_4\text{-N}$, nitrogen, iron and other bases (Table 2). The emergent group had the highest average manganese. It had an average pH that was close to the pH found in the shrub group. The shrub group had the highest average pH, estimated nitrogen release, total exchange capacity, magnesium, potassium, sodium, boron, and iron. It had the lowest average copper, zinc and aluminum. The mixed group had the highest average organic matter, soluble sulfur, hydrogen, aluminum, $\text{NH}_4\text{-N}$, nitrogen, and other bases. It had the lowest average total exchange capacity, pH, phosphorus, calcium, magnesium, potassium, manganese and $\text{NO}_3\text{-N}$. MANOVA showed a significant difference

among vegetation (Wilks $\lambda=0.053$, $p=0.03$). The emergent group had significantly less organic matter and hydrogen than both the mixed and shrub group. The shrub group had significantly higher calcium than the mixed group. The emergent group had significantly higher manganese than the mixed group. NMDS showed there were 6 soil variables that were statistically correlated with wetland vegetation groups; hydrogen ($R^2=0.45$ $p=0.001$), organic matter ($R^2=0.36$, $p=0.007$), magnesium ($R^2=0.31$, $p=0.013$), NO₃-N ($R^2=0.23$, $p=0.031$), total exchange capacity ($R^2=0.23$, $p=0.043$) and manganese ($R^2=0.22$, $p=0.047$)(Fig. 3).

Low non-natural land cover combined with the second highest forest and wetland cover was associated with emergent vegetation (Table 3). Higher levels of mine, urban and transitional land cover were associated with the shrub dominated vegetation group. The mixed vegetation group had intermediate levels of non-natural land cover and higher forest and wetland cover than the shrub group. NMDS showed there were 2 landscape variables that were statistically correlated with wetland vegetation groups; forest ($R^2=0.15$, $p = 0.119$) and row crops ($R^2=0.14$, $p = 0.0133$).

Quantification of local and landscape level influences

Recursive partitioning yielded a five leaf tree with an error of 0.133. The cross validation error was 1.13 and the model misclassification rate was 0.0667. The five leaf tree was the optimal tree size available to classify the vegetation groups within 1 standard error while minimizing cross validation error. The final classification tree model identified four variables as major classifiers for wetland vegetation groups: hydrogen, mining, NH₄-N, and total exchange capacity (Fig. 4). Sixteen of the 30 sampling sites had hydrogen greater

than or equal to 57.5%. The majority of the sites were from the mixed group. Of those 16 sites, 14 had mining land cover less than 9.92%, 13 samples were from the mixed group and one sample was from the shrub group. Two sites from the shrub group had higher hydrogen and higher mining land cover. The remaining sampling sites had a lower percentage of hydrogen and belonged primarily to the shrub and emergent groups. The majority of the shrub group had sites with higher levels of $\text{NH}_4\text{-N}$. The emergent group had sites with lower $\text{NH}_4\text{-N}$ and higher levels of total exchange capacity. Two samples from the mixed group were found to have lower hydrogen, lower $\text{NH}_4\text{-N}$ and lower total exchange capacity. One sample from the herbaceous group had higher levels of $\text{NH}_4\text{-N}$. Out of 10 shrub sites 7 were found in areas with lower hydrogen and higher $\text{NH}_4\text{-N}$. Out of the 5 emergent sites 4 were found where hydrogen and $\text{NH}_4\text{-N}$ were lower but total exchange capacity was higher.

Hydrogen was the classifier for the first split (Table 4). $\text{NH}_4\text{-N}$, pH, calcium, and other bases were alternates for the primary node. Of the 5 variables in the primary node only $\text{NH}_4\text{-N}$ was nutrient related. The second classification split resulted in a terminal node. The determinant at the terminal node was mining. Competing in that split were manganese, magnesium, $\text{NO}_3\text{-N}$, and transitional land cover. Manganese and mining had the same improvement values. Two of the competing splits were nutrient related while two were land cover variables. Magnesium was the only alternate that was a cation. $\text{NH}_4\text{-N}$ was the primary classifier chosen for node 3 on the classification tree. Other competing variables were organic matter, nitrogen, copper and stream length. Nitrogen related alternates ($\text{NH}_4\text{-N}$, organic matter, nitrogen) dominated this node. Stream length had the second highest improvement number followed closely by organic matter and nitrogen. The

final node had 4 out of the 5 potential classifiers with the same improvement scores. TEC was chosen for the tree; however, calcium, manganese, and NH₄-N all had the same improvement score. The fifth classifier, pH, had a slightly lower improvement score. Of the potential classifiers in this branch 3 are cation related while the other two are nutrient related. Examining the competing variables shows that the first split is cation dominated; the second split to a terminal node was landcover and nutrient dominated; the third split was nutrient and land cover dominated and the fourth split to a terminal node was cation dominated.

To quantify the relations between vegetation communities and influencing variables, optimal threshold levels for each node of the tree were determined. Hydrogen had a threshold level of 57.5% base saturation. The only landscape variable selected as a classifier, mining, had a threshold level of 9.92%. The other two node threshold levels were NH₄-N (8.17 ppm) and total exchange capacity (7.69 ME/100g). NMDS found 6 soil variables and 2 landscape-level variables correlated with vegetation groups. Of the six variables correlated, recursive partitioning used 2 (hydrogen and total exchange capacity) as classifiers. Mining and NH₄-N, the other 2 classifiers, were not statistically correlated with vegetation groups in NMDS. The differences seen between the NMDS and recursive partitioning are due to the different applications of the methods. NMDS was used to describe the significant edaphic and landscape variation among the vegetation groups. Recursive partitioning was used to differentiate and describe the major edaphic and landscape variable differences among the vegetation groups. Our results showed that some of the significant variation found in NMDS was also useful for differentiating among the vegetation groups in the recursive partitioning results.

Indicator species analysis

To determine species level indicators for environmental degradation, cluster analysis was performed using National Land Cover Database (NLCD) land cover classes, road length, wetland area, and stream length. We identified 3 dominant classes of environmental conditions; mining, roads and natural with cluster analysis. Landscape variables were examined for each group to determine the condition of the grouping (Table 3). The natural group had the highest amount of forest and the lowest amounts of human altered land cover. The mine group had the highest amount of mine land cover, the highest amount of pasture cover and the highest amount of wetland area. The road group had much higher road length than the other 2 groups. The number of sites within each group was mine=11, natural=11 and road=8. The environmental grouping was overlaid in NMDS ordination space and the mine group was clustered in the top center of the ordination while the natural and road groups were clustered towards the bottom of the ordination. NMDS showed some overlap among all groups (Fig. 5). ANOSIM was used to confirm the cluster analysis grouping ($R = 0.71$, $P < 0.001$).

Indicator species analysis generated 5 species out of 37 as indicators of environmental groups. The road group and natural group each had 2 indicator species and mining group had one indicator species (Table 5). *Dicanthelium clandestinum* (IV= 0.45) was the best indicator for group natural and *Juncus canadensis* (IV=0.59) was the best indicator for group roads. The mine group indicator was *Glyceria canadensis* (IV= 0.36). The less important indicator for group natural was *Galium tinctorum* (IV= 0.23) and for the road group was *Viburnum nudum var. cassnoides* (IV= 0.30). Of the three groups, the natural group has the best environmental condition and the roads and mining groups have

degraded conditions. Out of the 37 species in the study, the range of CC values was from 3 to 8 with the average being 5. Only four species had a CC of 3 indicating degraded habitat whereas there were 7 species with a CC value of 7 or 8 indicating mostly natural areas. The CC value for mining group indicator species was 7 (*Glyceria canadensis*). For road group the CC values were 4 (*Juncus canadensis*) and 6 (*Viburnum cassinoides*). For the natural group the CC values were 3 (*Dicanthelium clandestinum*) and 5 (*Galium tinctorum*). When examining all species there were an average of 8.00 (SE=3.61) species found at sites in the mine group, 8.36 (SE=2.97) species found in sites in the road group and 10.6 (SE=3.24) species found at sites in the natural group. The average tolerance calculated by site for each group was 5.547 (SE=0.43) for the mine group, 5.03 (SE=0.63) for the road group and 5.79 (SE=0.28) for the natural group. Using all species the average tolerance scores for each group were similar. When examining the indicator species the natural group had the lowest CC values and the mining and road groups had similar average CC scores. We expected indicator species with the highest CC values to have been associated with the natural group. Additionally, when ANOSIM was run to compare the vegetation cover between the different condition groups the results indicated poor within group similarity compared to between group similarity ($R=0.048$, $P=0.195$) suggesting that there was little difference in the vegetation between groups derived from landscape variables.

Discussion

Wetland plant community response to edaphic influences

Hydrogen, $\text{NH}_4\text{-N}$ and total exchange capacity were the best classifiers of central Appalachian peatland vegetation. Peatlands are one of the few ecosystems whose

development is dominated by pH and are classified based along pH-alkalinity gradients (Chapin et al. 2004). Hydrogen, the basis for pH, and other cations proved to be important classifiers for our vegetation groups. The role of pH in bog and fen development has been well documented (Losche and Beverage 1967, Wieder et al. 1981, Walbridge 1994, Chapin et al. 2004). Vitt and Chee (1990) found pH to be the best separator of different peatland vegetation primarily due to the influence of pH on bryophytes.

Previous studies of wetland vegetation communities and soil chemistry have also found wetland vegetation to be limited by N and P (Bedford et al. 1999). In our study nutrients also played an important role in plant community development in addition to pH. Nutrients in peatlands are typically lower; however, the nutrients are relatively labile and turn over quickly (Bridgham et al. 1996). Peat accumulations as well as the hydrologic source of nutrients and vegetation characteristics play an interdependent role in nutrient storage in peatland ecosystems (Pastor et al. 2002).

This study demonstrates that both base saturation and nutrients are influential factors for wetland vegetation community development. As found by Bragazaza and Gerdol (2002) pH-alkalinity and nutrients gradients do not parallel each other. While nutrients generally increase with alkalinity this increase may also encompass shifts in nutrient limitation (Bedford et al. 1999). Thompson et al. (2011) and Rentch et al. (2008) found soil nutrient status was not strongly correlated with wetland plant communities. Bedford et al. (1999) however, found that nitrogen or P availability may control floristic assemblages in peatlands. Bryophytes reflect pH-alkalinity gradients while vascular species reflect nutrient availability (Bragazaza and Gerdol 2002). In this study we found both pH-alkalinity and nutrients to be important drivers influencing vascular floristic assemblages

Wetland plant community response to landscape level influences

In addition to edaphic factors, land use was influential in plant species composition. Mining was one of the classifiers of our vegetation groups. Mining contributes to changes in water chemistry and watershed hydrology (Negley and Eshleman 2006). Deforestation and changes to physical land surface can alter water table elevations and change infiltration rates (Bonta et al. 1997). The majority of the shrubs found in this study had facultative status indicating that they preferred slightly drier conditions (Reed 1997). Out of seven shrub species only two were obligate wetland species (Table 1). The increased dominance of shrubs may be indicative of changes in wetland hydrology either on site or at the watershed level. Wetlands with higher herbaceous plant cover were associated with more natural land cover and indicative of higher quality watersheds. Wetlands with mixed shrub and herbaceous cover may be indicative of moderately altered watersheds. Mining was the only landscape-scale variable chosen as a discriminant and may have influenced wetland edaphic conditions. The two sites with the highest mining cover of any of the sites studied were also found to have high hydrogen. The hydrogen levels at those sites were above average for all vegetation groups and likely a result of nearby mining activity. In all cases the amount of degradation within the watersheds was small for our study area. Even with minimal degradation, wetland vegetation was reflective of changes in watershed land use. Plant community response to disturbance has been documented in a variety of studies (Galatowitsch et al. 2000; Mahaney 2001; Campbell et al. 2003; Lavoie et al. 2005). Some studies have examined the spatial relations between disturbance and wetlands (Galatowitsch et al. 2000, Aznar et al. 2003). Others have studied how one species such as *Salix spp.* respond to a specific disturbance like sedimentation (Johnston 2003). However,

most of these studies have taken place in areas with highly urbanized, agricultural and fragmented landscapes. This study area with less pronounced anthropogenic influences showed that vegetation is still an indicator of disturbance even when the magnitude is reduced.

Indicator species

Analyzing vegetation at the wetland level can be time consuming and requires a great amount of knowledge of the local flora. Indicator species are often used as an effective way to evaluate environmental conditions. The fixed position of plants makes sampling simple and increases the likelihood that indicators based on vegetation will be spatially correlated with nearby stressors (Lindenmayer et al. 2000). Indicators are often promoted in environmental management because of their ease of use (Godefroid and Koedam 2003). We expected to find that indicator species CC scores were indicative of watershed condition. Using mean CC has been beneficial when applied to broad-scale disturbance (DeKeyser et al. 2003; Matthews 2003; Cohen 2004; Taft et al. 1997). With natural land cover dominating, the study area resulted in small differences in the environmental clusters. This small-scale disturbance was not detectable using indicator species and CC scores. The fact that the vegetation in each of the environmental groups was similar also presents a strong case for avoiding the use of this method when applied to map derived landscape variables. In detecting minor landscape disturbance, wetland plant communities prove to be better indicators than indicator species themselves. The information provided by a group of plant species can often reveal more about wetland condition than that provided by individual species (Galatowitsch et al. 2000; Johnston et al. 2009).

Species level response proved to be an ineffective technique for detecting the subtle changes in rural landscapes. The ability to determine species level response could be a powerful tool for prediction, monitoring, and management of wetlands (Lindenmayer et al. 2000). To develop indicator species capable of detecting subtle disturbance more quantitative research needs to be done between species traits and environments fostering a better understanding between indicator species and land use. Identifying indicators of landscape condition was effective when looking at vegetation on the community level. Wetland communities can be effective indicators of landscape condition even in areas with less pronounced anthropogenic disturbance.

Local vs. landscape level influences

While there were relations between land cover and vegetation groups, edaphic factors had a bigger influence on floristic assemblage. The dominance of edaphic factors as predictive variables for vegetative assembly are indicative of a stronger influence by local factors. There is still some debate as to whether floristic assemblages are more strongly controlled by landscape or local-level factors (Wright et al. 2003). The role of local hydrology, especially drainage can exert great influence on floristic assemblage (Critchley et al. 2002). At the local level, edaphic factors can be variable and are affected by landscape-scale factors (Cohen 2004). Vegetation and soils are both dynamic and interacting systems. Changes in the surrounding landscape has the ability to impact edaphic variables as seen by the two sites with higher hydrogen and mining. At those sites it is likely that acid mine drainage and changes in hydrology are affecting the soil chemistry.

Edaphic variable similarities

Examining competing splits in the tree proved to be useful for understanding the relation of edaphic and land use variables and plant communities. Many of the surrogates were the same type of variable: cations, nutrients, anions, or micronutrients. The relative importance of these variables was better understood when examined in the group context. In some cases examining the surrogates showed competing splits of equal value. When splits occur with similar competing values, trees can be simplified by reducing the number of variables (De'Ath and Fabricius 2000). Examining competing splits can have useful implications for management as well. In some cases alternative variables may be more cost-effective to test or monitor. In the case of our first node, hydrogen was the determinant, but pH may be a more cost effective variable to measure.

Conclusion

Overall the 3 wetland vegetation groups showed consistent relations with characteristic sets of edaphic factors and to a lesser extent land cover. These relations demonstrate the importance of edaphic factors influence on central Appalachian peatlands. They also show the complexity and interactions between local and landscape level factors. These relations are further complicated by anthropogenic disturbance as seen by the selection of mining as a determinant. While our study area contains lower levels of landscape development, human disturbance in the form of climate change is expected to alter local climate and influence wetland vegetation (Heijmans et al. 2001). Climate change, in particular precipitation, will be especially influential due to the complex relations between local and landscape-scale variables found in central Appalachian peatlands (Wieder et al. 1981, Walbridge 1994, Yavitt 1994, Rentch et al. 2008).

Understanding the interaction between these local and landscape-level variables is important for further understanding floristic community shifts as a result of anthropogenic disturbance. Similar studies incorporating hydrologic measurements as well as bryophyte assemblages will yield a more complete and informative picture. This information can be used to help managers and land owners prepare for potential change as a result of climate change impacts.

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Table 1 Species codes, latin names, coefficient of conservatism number (CC No.), and facultative status (Rentch and Anderson 2006) for 30 wetlands from Tucker and Randolph counties, West Virginia, USA during 2004 and 2005

Code	Species	CC No. ^a	Facultative status ^b
CAECE	<i>Carex echinata</i> Murr. ssp. <i>echinata</i>	8	OBL
CAFO6	<i>Carex folliculata</i>	7	OBL
CAGY4	<i>Carex gynandra</i>	5	OBL
CALU5	<i>Carex lurida</i>	4	OBL
CASC11	<i>Carex scoparia</i> var <i>scoparia</i>	5	FACW
DICL	<i>Dichanthelium clandestinum</i>	3	FAC
DRROR	<i>Drosera rotundifolia</i> var <i>rotundifolia</i>	8	OBL
ELTE	<i>Eleocharis tenuis</i>	5	FACW
ERV18	<i>Eriophorum virginicum</i>	8	OBL
GATI	<i>Galium tinctorium</i>	5	OBL
GELI3	<i>Gentiana linearis</i>	7	OBL
GLCA	<i>Glyceria canadensis</i>	7	OBL
GLST	<i>Glyceria striata</i>	5	OBL
HYDE	<i>Hypericum densiflorum</i>	6	FAC
HYMU	<i>Hypericum mutilum</i>	5	FACW
IMCA	<i>Impatiens capensis</i>	4	FACW
JUBR4	<i>Juncus brevicaudatus</i>	6	OBL
JUCA3	<i>Juncus canadensis</i>	4	FACW
JUEF	<i>Juncus effusus</i>	3	FACW
MEAR4	<i>Mentha arvensis</i>	3	FACW
ONSE	<i>Onoclea sensibilis</i>	5	FACW
OSCI	<i>Osmunda cinnamomea</i>	6	FACW
PHPY4	<i>Photinia pyrifolia</i>	6	FACW
POSA5	<i>Polygonum sagittatum</i>	4	OBL
PTAQ	<i>Pteridium aquilinum</i>	3	FACU
RHMA4	<i>Rhododendron maxium</i>	5	FAC
RUHI	<i>Rubus hispidus</i>	5	FACW
SASA	<i>Salix sericea</i>	5	OBL
SCPO2	<i>Scirpus polyphyllus</i>	5	OBL
SOUL	<i>Solidago uliginosa</i>	5	OBL
SPAL2	<i>Spiraea alba</i>	6	OBL
STPU	<i>Stellaria pubera</i>	5	FACW
TYLA	<i>Typha latifolia</i>	4	OBL
VAAN	<i>Vaccinium angustifolium</i>	6	FACU
VAMA	<i>Vaccinium macrocarpon</i>	8	OBL
VAMY	<i>Vaccinium myrtilloides</i>	6	FAC
VINUC	<i>Viburnum nudum</i> var. <i>cassinoides</i>	6	FACW

a-Coefficients range from 0-1 (taxa are adapted to severe habitat degradation), 2-3 (taxa associated with more stable although degraded habitat), 4-6 (species can persist under moderate degradation), 7-8 (taxa associated with mostly natural areas with small amounts of degradation), 9-10 (taxa that are restricted to high quality natural areas)

b- Obligate Wetland (OBL) Species occur in wetlands with an estimated probability > 99%, Facultative Wetland (FACW) Species occur in wetlands with an estimated probability 67% - 99%, Facultative (FAC) Species occur in wetlands with an estimated probability 34% - 66%. Facultative Upland (FACU) Species occur in wetlands with an estimated probability 1-33%

Table 2 Average for edaphic variables by vegetation group, MANOVA results testing for significant differences in soil variables among the vegetation groups and Tukey's HSD compared paired means on 30 wetlands in Tucker and Randolph counties, West Virginia, USA. Significant values ($\alpha = 0.05$) are in bold

Variable	<u>Mixed (n=15)</u>		<u>Emergent (n=5)</u>		<u>Shrub (n=10)</u>		$F_{2,27}$	P^a
	x	S.E.	x	S.E.	x	S.E.		
Total Exchange Capacity (ME/100g)	9.45	3.05	9.70	2.23	10.85	3.28	0.67	0.52
pH	3.89	0.36	4.12	0.72	4.16	0.39	1.31	0.29
Organic Matter (%)	36.4 a	16.10	7.73 b	3.32	33.91 a	18.52	6.45	0.01
Soluble Sulfur (ppm)	139.12	206.00	34.57	9.09	52.50	28.41	1.47	0.25
Phosphorus (ppm)	16.37	10.33	17.83	1.24	16.74	7.06	0.05	0.95
Calcium (ppm)	341.65 a	174.36	547.31 a,b	112.68	508.86 b	183.31	4.46	0.02
Magnesium (Ppm)	59.35	23.94	72.40	7.19	93.54	50.95	2.94	0.07
Potassium (ppm)	57.33	25.49	62.18	20.14	75.25	36.32	1.14	0.34
Sodium (ppm)	22.65	4.94	19.49	0.15	27.21	16.38	1.11	0.34
Hydrogen (%)	60.87 a	6.49	47.90 b	6.3	57.1 a	4.37	7.37	0.00
Iron (ppm)	349.89 a	125.45	314.91 a	103.29	472.7 a	153.34	3.46	0.05
Manganese (ppm)	15.28 a	9.16	49.77 b	12.75	27.41 a,b	20.49	5.68	0.01
Copper (ppm)	1.08	0.92	1.56	0.9	0.86	0.51	1.31	0.29
Zinc (ppm)	5.81	4.60	99.88	5.05	5.19	1.53	2.81	0.08
Aluminum (ppm)	852.26	216.36	805.59	263.9	804.26	202.29	0.18	0.84
NO3N (%)	12.53	10.76	36.38	10.56	30.40	35.58	2.25	0.13
NH4N (%)	27.83	26.61	10.34	1.33	25.27	24.90	1.04	0.37

^a Means followed by the same lowercase letters are not different ($P > 0.05$) across vegetation group

Table 3 Averages with standard errors (SE) for landscape variables for the mining, roads and natural degradation groups and the mixed, shrub and emergent vegetation groups for 30 wetlands in Tucker and Randolph counties, West Virginia, USA during 2004 and 2005

Variable	Landscape groups						Vegetation Groups					
	<u>Mining (n=11)</u>		<u>Natural (n=11)</u>		<u>Roads (n=8)</u>		<u>Mixed (n=15)</u>		<u>Emergent (n=5)</u>		<u>Shrub (n=10)</u>	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Wetland Area (m ²)	19930.64	1532.09	2926.54	372.13	9472.12	956.89	10175.13	2076.33	8449.4	5243.41	13233	2067.4
Road length (m)	3277.55	801.36	3935.73	817.96	6847.88	1034.12	5082.73	893.99	2835.2	1399.2	4371.2	846.01
Stream length (m)	4394.91	371.2	6340.91	431.23	6392.75	1111.01	5552.2	735.82	6838.4	850.67	5176.1	379.5
Mine (%)	6.25	1.92	1.01	0.53	5.54	1.63	2.89	0.94	1.25	1.25	7.46	1.98
Forest (%)	78.75	4.59	89.26	2.92	78.69	3.42	83.78	2.92	91.21	3.86	76.49	4.63
Pasture (%)	5.36	1.91	3.09	1.64	3.76	1.13	3.16	0.82	4.13	3.58	5.51	1.91
Row crops (%)	0.05	0.04	0.32	0.13	0.27	0.27	0.19	0.15	0.56	0.23	0.05	0.04
Wetland (%)	4.77	1.35	8.4	2.47	6.34	1.68	6.96	1.7	2.47	0.89	7.88	2.02

Table 4 Recursive partitioning results with discriminant (top variable) and competing variables for each node for 30 wetlands in Tucker and Randolph counties, West Virginia, USA

Node 1		Node 2		Node 3		Node 4	
Variable	Improvement	Variable	Improvement	Variable	Improvement	Variable	Improvement
H<57.5	5.03	Mines <9.92	3.02	NH4-N <8.18	4.01	Total exchange capacity <7.69	2.67
NH4-N <5.55	4.81	Mn <34.88	3.02	Stream length <6886.5	3.83	Calcium < 407.44	2.67
pH <4.375	4.12	Mg <65.67	1.88	Organic matter<12.46	3.57	Manganese <16.375	2.67
Ca <450	4.12	Transitional <6.06	1.7	Nirtrogen <.52	3.57	NH4-N <5.55	2.67
Other bases <8.65	4.07	NO3-N <32.82	1.63	Copper <1.46	2.61	pH< 3.88	1.33

Table 5 Indicator species analysis- statistically significant indicators for environmental degradation clusters from 30 wetlands in Tucker and Randolph counties, West Virginia, USA

Species	Indicator group	Indicator value	<i>P</i>	Relative frequency	Relative abundance
<i>Dicanthelium clandestinum</i>	Natural	0.45	0.014	0.45	1
<i>Galium tinctorum</i>	Natural	0.23	0.248	0.27	0.83
<i>Glyceria canadensis</i>	Mine	0.36	0.044	0.36	1
<i>Juncus canadensis</i>	Road	0.59	0.001	0.63	0.95
<i>Viburnum nudum</i> var. <i>cassanoides</i>	Road	0.30	0.091	0.38	0.8

Fig 1 Study area within Randolph and Tucker counties, West Virginia. The study area was limited to areas ≥ 800 m in elevation

Fig 2 Nonmetric multidimensional scaling (NMDS) ordination of wetland plant species collected from 30 wetlands in Tucker and Randolph counties, West Virginia from 2004 to 2005. A complete list of plant names with codes can be found on Table 1. Numbers correspond to vegetation groups with 1=Mixed, 2= Emergent and 3= Shrub

Fig 3 Nonmetric multidimensional scaling (NMDS) ordination of wetland plant species collected from 30 wetlands in Tucker and Randolph counties, West Virginia from 2004 to 2005. Numbers correspond to vegetation groups with 1=Mixed, 2= Emergent and 3= Shrub. Arrows are land use or edaphic vectors that had correlations to the ordination axis. Correlations are at the $p= 0.05$

Fig 4 Recursive partitioning tree for vegetation communities from 30 wetlands in Tucker and Randolph counties, West Virginia from 2004 to 2005 . Nodes display number of sites in each group: Mixed/Emergent/Shrub. Classifiers chosen were hydrogen (%), mines (%), NH4-N (ppm) and total exchange capacity (ME/100g)

Fig 5 Nonmetric multidimensional scaling of environmental degradation clusters and environmental vectors that had strong correlation to the ordination from 30 wetlands in Tucker and Randolph counties, West Virginia from 2004 to 2005. Numbers represent groups with 1= Mine, 2= Natural and 3=Road

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CHAPTER III

CONCLUSION

Wetlands have value because of the ecosystem services they provide to people. The closer the wetland is in proximity to human development, the greater its potential value (Mitsch and Gosselink 2000). Yet, eventually human pressures can overwhelm any benefits wetlands may provide. Wetlands in a region with moderate but not excessive development will have the greatest value because an adequate human population benefits from its presence without overwhelming it (Mitsch and Gosselink 2000).

Wetlands are multiple-value systems and can be important for many different reasons. The ecosystem values of wetlands include flood mitigation, stormflow abatement, water filtration and wildlife habitat. Wetlands and wetland functions are inextricably linked to their surroundings. Better understanding the relations between edaphic factors and landscape-scale variables will help to inform wetland conservation. This knowledge can be integrated systematically with watershed scale conservation and sustainable development. Enhancing our understanding of wetlands means expanding research to cover multiple levels of anthropogenic disturbance as well as encompassing different wetland types. This body of knowledge may help develop local, regional, and national perspectives on wetland trends.

Climate change, and any other future anthropogenic impacts will be better understood when our fundamental knowledge of the relations between edaphic and landscape factors on wetlands and their values increase. Wetlands vulnerability to hydrologic changes makes them particularly susceptible to the effects of climate change

(Erwin 2009). The degradation of wetlands due to existing anthropogenic disturbance may be exacerbated by climate change (Kingsford 2011). Modeling the effects of climate change in wetlands is a big unknown (IPCC 2001). While the body of research on the ecological and hydrologic changes as a result of climate change is growing, the diversity of wetland types makes specific future changes more difficult to forecast (Erwin 2009). This is critically important in relation to peatlands.

Peatland ecosystems are long-term sinks for atmospheric CO₂ with 30% of the world's soil carbon pool accumulated in wetlands (Parish et al. 2008). They have the ability to sequester and store carbon for thousands of years and degradation of these ecosystems is a major and growing source of greenhouse gas emissions (Parish et al. 2008). The low rates of decomposition in these sphagnum dominated systems allow for the highest potential amounts of peat accumulation (Thormann et al. 1999). The influence of invasive species, shifts in plant ranges and distribution, and hydrologic changes have the ability to tip the balance in these systems between production and decomposition. This shift has the ability to change the flux of greenhouse gases in these systems (Heijmans et al. 2001). Peatlands are found in over 180 countries (Parish et al. 2008). These systems are diverse and the types of plants and animals found in each region vary as much as the anthropogenic disturbance in their surrounding watersheds. Expanding monitoring and research efforts in these systems will help predict potential feedbacks on the global carbon cycle (Belyea and Malmer 2004).

The diffuse populations of the central Appalachians benefit greatly from their wetlands. The impacts of climate change have already been seen in the melting of permafrost peatlands. Current research is predicting coastal, tropical and mountain

peatlands to be particularly vulnerable to climate change (Parish et al. 2008). Our study found that rural Appalachian landscape-scale stressors were found to influence wetland vegetation. Building on this research to better understand the influence of landscape-scale and local-scale hydrology will increase our ability to predict future impacts from climate change or other anthropogenic disturbance. Our ability to predict the effects of future disturbance also increases our ability to assess their impact on wetland functions and values. A better understanding of these ecosystems may contribute to future decision making and conservation.

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APPENDICES

Appendix A. Landscape scale variables derived from watershed boundaries delineated for each wetland using a weighted flow accumulation grid (ESRI Redlands, CA) for 30 wetlands in Tucker and Randolph counties West Virginia, USA.

Site	Bedrock	Area(m ²)	Perimeter(m)	Road length(m)	Stream length(m)	Mines (%)
1_18	sand	16129	519	4329	4328	0.61
3_2	shale	986	122	7675	7587	0
3_36	shale	4920	334	3440	7044	0
4_8	shale	13444	672	6140	4749	10.16
4_9	shale	7093	375	7915	5718	9.05
4_20	shale	19238	863	4278	4432	8.13
5_6	sand	2960	242	4300	6103	0
5_7	sand	1872	170	0	5565	0
6_2	sand	2642	249	3618	3617	0
7_1	shale	5032	465	2931	6960	0
7_2	shale	15397	835	5591	5071	0
7_3	shale	10538	498	6255	2997	0
7_95	shale	26639	661	0	2888	0
9_1	sand	3251	216	2190	4490	0
9_5	sand	7444	525	4757	6813	5.65
9_11	sand	9887	444	4857	6007	0
10_1	sand	8869	521	5845	5844	9.15
10_2	sand	12712	679	13655	13655	0.64
10_3	sand	5790	354	5359	5359	9.67
11_1	shale	2367	194	7297	6517	2.91
12_3	shale	16146	663	3207	5999	21.52
12_10	shale	19238	863	4278	4432	8.13
13_1	sand	15939	752	270	2055	0
13_3	sand	3646	226	4353	6421	4.25
14_1	sand	24381	698	5967	5723	6.5
15_2	shale	2123	213	0	8877	0
15_3	shale	2393	222	7489	6569	3.96
16_1	shale	14156	527	523	5782	10.13
16_2	shale	22788	856	7480	3910	7.52
16_3	shale	29186	1394	130	3724	6.26

Appendix A. Continued.

Site	Transitional	Forested	Pasture	Row crops	Urban	Wetland
1_18	1.84	84.91	6.48	0	2.39	2.48
3_2	0	77.76	18.42	0.56	0.38	0.22
3_36	0	98.07	0	1.23	0	0.7
4_8	3.04	77.02	1.81	0	0.14	7.65
4_9	3.49	68.25	2.88	0	0.89	15.38
4_20	4.75	65.88	15.18	0	2.65	0.73
5_6	1.22	91.38	2.01	0	0.23	2.53
5_7	0	97.06	0.41	0.06	0	23.41
6_2	0.09	92.84	0.29	0.67	0.2	1.98
7_1	1.87	96.12	0.93	0.87	0	3.81
7_2	0.55	95.14	0.06	0.44	0	2.42
7_3	0.03	91.59	2.16	2.13	0.26	9.32
7_95	0	97.14	0	0	0	0.06
9_1	0	99.94	0	0	0	16.79
9_5	4.63	70.98	1.78	0	1.9	1.02
9_11	0.58	95.27	1.43	0.03	0	2.88
10_1	5.65	74.67	2.19	0	1.91	5.31
10_2	2.04	78.07	8.83	0	4.99	1.52
10_3	4.51	73.68	9	0	1.93	7.6
11_1	5.24	76.17	6.06	0	1.58	18.46
12_3	6.87	50.2	14.15	0	5.09	5.37
12_10	4.75	65.88	15.18	0	2.65	6.12
13_1	1.43	97.15	0.49	0	0.4	0.52
13_3	4.89	76.54	1.75	0	1.9	12.57
14_1	7.37	68.49	2.83	0.06	1.3	14.76
15_2	0	96.77	0.09	0.12	0	2.74
15_3	3.18	79.22	4.08	0	0	9.17
16_1	0.09	77.72	1.05	0	1.3	10.25
16_2	6.47	76.37	2.36	0	1.21	4.92
16_3	0.09	87.34	1.19	0	0	4.89

Appendix B. Species codes and associated latin names for species meeting the criteria of: (1) occurring in a minimum of 3 sites out of the 30 wetlands sampled in Tucker and Randolph counties, West Virginia, USA, and (2) being identified to the species level. All plants were identified using Strausbaugh and Core (1977) and Gleason and Cronquist (1991). Species codes are from the USDA Plants Database (USDA NRCS 2011).

Code	Species
CAECE	<i>Carex echinata</i> Murr. ssp. <i>echinata</i>
CAFO6	<i>Carex folliculata</i>
CAGY4	<i>Carex gynandra</i>
CALU5	<i>Carex lurida</i>
CASC11	<i>Carex scoparia</i> var <i>scoparia</i>
DICL	<i>Dichanthelium clandestinum</i>
DRROR	<i>Drosera rotundifolia</i> var <i>rotundifolia</i>
ELTE	<i>Eleocharis tenuis</i>
ERV18	<i>Eriophorum virginicum</i>
GATI	<i>Galium tinctorium</i>
GELI3	<i>Gentiana linearis</i>
GLCA	<i>Glyceria canadensis</i>
GLST	<i>Glyceria striata</i>
HYDE	<i>Hypericum densiflorum</i>
HYMU	<i>Hypericum mutilum</i>
IMCA	<i>Impatiens capensis</i>
JUBR4	<i>Juncus brevicaudatus</i>
JUCA3	<i>Juncus canadensis</i>
JUEF	<i>Juncus effusus</i>
MEAR4	<i>Mentha arvensis</i>
ONSE	<i>Onoclea sensibilis</i>
OSCI	<i>Osmunda cinnamomea</i>
PHPY4	<i>Photinia pyrifolia</i>
POSA5	<i>Polygonum sagittatum</i>
PTAQ	<i>Pteridium aquilinum</i>
RHMA4	<i>Rhododendron maxium</i>
RUHI	<i>Rubus hispidus</i>
SASA	<i>Salix sericea</i>
SCPO2	<i>Scirpus polyphyllus</i>
SOUL	<i>Solidago uliginosa</i>
SPAL2	<i>Spiraea alba</i>
STPU	<i>Stellaria pubera</i>
TYLA	<i>Typha latifolia</i>
VAAN	<i>Vaccinium angustifolium</i>
VAMA	<i>Vaccinium macrocarpon</i>
VAMY	<i>Vaccinium myrtilloides</i>
VINUC	<i>Viburnum nudum</i> var. <i>cassinoides</i>

Appendix C. Vegetation cover for by site for 30 wetlands in Tucker and Randolph counties, West Virginia, USA. This includes only species that met the criteria of: (1) occurring in a minimum of three sites, and (2) being identified to the species level. Daubenmire cover class midpoints were used from each plot and averaged for individual species to give a mean species cover for each wetland. Species code definitions are listed in Appendix B.

Site	CAECE	CAFO6	CAGY4	CALU5	CASC11	DICL	DRROR	ELTE	ERV18
1_18	3.6	8.7	8.3	0	0.4	0	0.7	24.7	16.6
3_2	0	0	0.5	0	0	5.5	0	0	0
3_36	0	0	0	2	0	1.7	0	0	0
4_8	0	0	1	0	0	0	0	0	23.8
4_9	0	0	0	5.5	0.2	0	1.5	12.5	2.5
4_20	0	13	0	0	12	0	0	0	12.2
5_6	0	0	0	0.8	0	0	0	0	0
5_7	0	0	0	0	0	0	0	0	0
6_2	13	0	0	0	0	0	0	0	1
7_1	0	0	0	0.8	28.8	23.8	0	0	0
7_2	0	0	0	0	0	0	0	0	0
7_3	8.8	0	0	0	0	0	0	18.8	0
7_95	0	0	61.7	0	0	0	0	0	18.3
9_1	0	0	16.3	0	0	0	0.2	0	23.3
9_5	0	11.3	0	0	0	0	0	0	5.7
9_11	13.3	0	0	0	0	0	2.3	0	10
10_1	0	26.7	0	0	0	0	0	0	10
10_2	1.7	3	12	0	0	0	0	0	16.2
10_3	0	23.3	0	0	0	0	0	0	0
11_1	0	20	0	0	0	0	0	0	20
12_3	0	0	0	0	0	0	0	0	0
12_10	0	0.7	0	0	0	0	0	0	0
13_1	0	25	0	0	0	0	0	0	20.7
13_3	8.3	0	2.7	0	3.3	2	0	0	0
14_1	0	15	0	0	0	0	1	0	12
15_2	0	0	26.3	0	0	2.5	0	0	0
15_3	0	0	0	3	2.5	0	0.5	5	3
16_1	18	0	0	0	0	0	0	0	2.2
16_2	2.5	0	0	0	0	0	0	0	7.5
16_3	0	0	0	0	7.5	0	0	8.8	0

Appendix C. Continued.

Site	GATI	GELI3	GLCA	GLST	HYDE	HYMU	IMCA	JUBR4	JUCA3
1_18	0	1	0.4	0	1.6	0	0	1.1	0
3_2	0	0	0	0	0	0	0	0	0
3_36	13.7	0	0	0	0	0	0.7	0	0
4_8	0	0	0	7.5	22.5	1.3	0	0	0
4_9	0	0	0	3.5	10.2	2.7	0	0	1.2
4_20	0.4	0	0	0	24	0	0	0	0
5_6	0	0	0	0	42.5	6.3	0	0	0
5_7	0	0	0	0	31.7	0	0	0	0
6_2	0	0	0	0	1	2	0	2	0
7_1	3.8	0	0	0	0	0	13	0	0
7_2	0	0	0	0	20	0	0	0	0
7_3	0.3	0	0	0	5	0	0	0	0
7_95	0	0	0	0	0	0	0	0	1
9_1	0	0	0	0	0	0	0	4.2	0
9_5	0	0	0	10	0	0	0	0	18.3
9_11	0	0.7	0	0	0	0	0	3	1.7
10_1	0	0	0	0	1	0	0	0	6.7
10_2	0	0	0	0	4.2	0.2	0	0	7
10_3	0	0	0	0	17.7	0	0	0	0
11_1	0	0	0	0.3	13.8	3.8	0	0	0
12_3	0	0	0	0	13.3	0	11.7	0	0
12_10	0	0	0	0	24	0	0	0	0
13_1	0	0	0	0	0	0	0	0	0
13_3	0	0	0	0	11.7	0	0	0	0
14_1	0	0	0	0	0.6	0	0	0	0
15_2	6	0	0	0	0	0	0.5	0	0
15_3	0	0	0	10	8	0.5	0	0	1.5
16_1	0	0	7.6	0	13.4	0	0	2.2	0
16_2	0	0	0.3	0	0	2.5	0	0	0
16_3	3.8	0	22.5	16.3	0	0	0	0	0

Appendix C. Continued.

Site	JUEF	MEAR4	ONSE	OSCI	PHPY4	POSA5	PTAQ	RHMA4	RUHI
1_18	10.7	0	0	0	0	0	0	0	16.3
3_2	0.5	0	7.5	5	0	0	0	0	0
3_36	5	0	0	0	0	6.3	0	0	0
4_8	0.5	0	0	0.5	0.8	0	0	0	38.8
4_9	3.7	0	0	0	0.7	0	0	0	0.5
4_20	18	0.2	0	0	0	0.4	0	0	19.4
5_6	0	0	0	0	0	0	0	0	15.5
5_7	0.7	0	0	0	0	0	0.3	0	0
6_2	0	0	0	0	55	0	0	0	5
7_1	0.3	1	10	0	0	1.8	0	0	0
7_2	0	0	0	0	0	0	0	0	0
7_3	0	0	0	0	0	0	0	0	19
7_95	0	0	0	25	0.3	0	0	2.7	7.7
9_1	0	0	0	0.3	0	0	0	17.3	25
9_5	0	0	0	18.3	41	0	3.3	0	13.3
9_11	1.7	0	0	0	0	0	0	1.7	22.3
10_1	0.7	0	0	0	25	0	0	0	25
10_2	0	0	0	0	11.4	0	0	0	31.8
10_3	0	0	0	0	0.7	0	0	0	36.7
11_1	18.8	0	0	0	0.3	0	0.5	0	32.8
12_3	0	0	0	0	0	0	0.7	0	11.7
12_10	0.3	0	1	0	23.3	0	10	0	3
13_1	12.7	0	0	0	3	0	2	0	23
13_3	0.3	0	0	0	13.3	0	0	0	49.3
14_1	0.4	0	0	0	0	0	0	0	55
15_2	0	0	1.3	0	0	0	0	0	0
15_3	20	0	0	0.5	0	0	0	0	77.5
16_1	1.6	0	0	0	0	0.8	0.4	0	20
16_2	0	0.5	0	0	0.3	0	0	0	20
16_3	3.8	0	0	0	0	0	0	0	0

Appendix C. Continued.

Site	SASE	SCPO2	SOUL	SPAL2	TYLA	VAAN	VAMA	VAMY	VINUC
1_18	0	0	19.3	0	0	0	12.9	0	0
3_2	0	37.5	0	0	0	0	0	0	0
3_36	0	16.7	21.7	0	0	0	0	0	0
4_8	0	0	12.5	0	0	0	0	0	0
4_9	0	0	13.5	0	6.5	0	0	0	0
4_20	0	0.2	28.8	0	12	0	0	0	0
5_6	0	8.8	0	0	0	0	0	0	0
5_7	0	0	25.7	0.7	0	0	0	0	0
6_2	0	0	0	0	20	0	0	0	0
7_1	0	0	0	0	0	0	0	0	0
7_2	0	0	4.7	76.7	0	0	0	0	0
7_3	0	0	9.5	0	0	27.5	0	0	0
7_95	0	0	0	0	0	0	0	0	0
9_1	0	0	0	0	0	0	0	3.8	0
9_5	0	0	0	0	0	0	0.3	16.7	2.7
9_11	13.3	0	5	1	0	25.3	0.7	0	0
10_1	0	0	15	0	0	23.3	0	2.3	6.7
10_2	0	0	2.2	0	0	0	13	5	0.4
10_3	0	0	0	0	0	0	0	23.7	0
11_1	0	0	2	0	0	0	0	12.5	0
12_3	28.3	0	0	28.3	0	0	0	8.3	0
12_10	29.3	0	12.3	0	1.3	0	0	19.7	0
13_1	0	0	0.7	0	0	0	0	3.3	0
13_3	0	0	0.7	0	0	0	0	5	0
14_1	0	0	2.6	0	9	0	0	0.6	0
15_2	0	0	19	0	0	0	0	0	0
15_3	0	0	2.5	0	0	4	0	7.5	0
16_1	0	0	24.8	14	4	0	0	2	2
16_2	2	0	10	0	10	0	0	1.3	0
16_3	0	0	0	0	0	0	0	0	0

Appendix D. Soil chemistry data for 30 wetlands in Tucker and Randolph counties West Virginia, USA. All soil samples were run by Brookside Laboratories (Brookside, Ohio).

Site	TEC (ME/100g)	pH	Organic Matter(%)	ENR (lb/A)	Soluble Sulfur(ppm)	P (lb/A)
1_18	11.59	4.27	43.85	129.10	36.20	34.00
3_2	8.49	4.90	2.25	65.00	27.00	10.00
3_36	7.72	3.25	9.56	78.17	23.83	19.50
4_8	13.88	3.92	40.78	126.33	60.67	13.33
4_9	12.83	3.90	39.72	116.90	130.40	7.50
4_20	11.55	4.55	47.65	123.63	51.25	14.63
5_6	4.20	4.40	9.30	118.00	37.57	12.00
5_7	7.03	3.27	29.99	107.50	45.00	28.50
6_2	12.59	3.83	46.29	130.00	565.00	8.25
7_1	12.79	3.47	9.62	94.17	44.33	18.67
7_2	14.04	4.45	60.28	130.00	36.25	11.50
7_3	7.66	3.36	7.78	78.13	24.50	12.63
7_95	11.96	3.80	33.70	114.60	680.00	8.60
9_1	5.26	3.31	31.63	102.75	51.75	31.13
9_5	7.20	3.15	44.95	108.33	41.83	16.17
9_11	9.04	4.28	37.85	124.40	45.80	12.20
10_1	14.19	3.90	27.74	118.83	45.17	17.00
10_2	8.57	3.87	49.45	129.80	36.60	40.50
10_3	6.18	4.00	74.88	130.00	37.60	14.80
11_1	6.82	4.04	39.46	116.43	38.71	7.00
12_3	14.32	4.04	5.64	96.00	41.60	10.80
12_10	9.86	4.43	14.65	115.75	40.25	22.25
13_1	6.21	3.98	30.94	115.50	39.33	12.67
13_3	8.10	4.35	11.23	94.50	37.25	9.75
14_1	14.27	4.16	41.23	127.88	169.75	12.38
15_2	11.33	4.40	6.93	109.00	39.50	20.00
15_3	12.08	4.00	25.08	107.00	237.25	8.50
16_1	11.10	4.40	40.14	129.20	35.80	22.10
16_2	9.70	4.25	50.96	117.25	46.25	24.75
16_3	8.19	4.58	10.28	121.60	38.20	21.00

Appendix D. Continued.

Site	Ca (%)	Mg (%)	K (%)	Na (%)	Other bases (%)	H (%)
1_18	602.10	62.00	57.40	25.40	8.86	59.40
3_2	637.25	64.25	51.75	20.50	7.60	46.75
3_36	453.50	91.17	70.00	17.00	5.10	31.33
4_8	523.17	69.33	43.67	25.83	9.57	65.00
4_9	629.00	84.60	37.30	72.70	7.86	52.30
4_20	516.00	111.25	150.50	28.75	8.30	53.50
5_6	196.43	34.29	32.29	18.71	8.54	56.43
5_7	215.67	43.50	73.17	18.67	7.97	52.50
6_2	398.50	92.00	24.75	26.75	9.75	66.00
7_1	529.50	84.17	65.33	18.83	7.57	51.00
7_2	641.50	221.25	90.00	25.25	8.50	54.75
7_3	361.38	91.50	55.75	20.00	6.33	41.13
7_95	15.85	26.20	21.20	25.60	9.84	66.60
9_1	148.75	34.63	40.38	17.75	8.60	58.75
9_5	188.67	48.17	103.33	16.67	8.20	56.00
9_11	530.20	44.20	26.80	31.20	8.84	58.00
10_1	533.67	58.50	64.00	33.50	9.60	66.00
10_2	290.20	46.40	58.60	19.90	9.66	66.20
10_3	199.80	44.80	89.20	18.40	9.40	64.40
11_1	227.00	47.00	68.14	21.00	9.31	63.43
12_3	536.80	88.20	74.80	17.80	9.32	63.20
12_10	500.75	93.75	99.50	19.50	8.55	56.50
13_1	209.17	45.17	38.50	23.00	9.43	64.50
13_3	421.00	57.25	64.25	18.50	8.70	58.00
14_1	552.00	110.38	48.63	21.13	9.08	61.13
15_2	608.50	63.00	93.00	20.50	8.60	57.00
15_3	446.50	82.00	99.00	21.00	9.40	63.50
16_1	528.30	98.50	99.30	22.40	8.60	56.80
16_2	801.00	90.75	52.00	22.50	8.90	60.00
16_3	507.80	59.40	30.80	20.60	8.24	53.40

Appendix D. Continued.

Site	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Al (ppm)	NO3-N (ppm)	NH4-N (ppm)	Nitrogen (%)
1_18	0.34	223.40	27.10	1.35	6.43	1032.0	2.06	6.47	1.12
3_2	0.58	454.50	67.25	1.14	2.87	547.5	26.53	3.65	0.12
3_36	0.28	212.33	25.83	2.08	3.10	582.8	19.70	4.00	0.45
4_8	0.42	363.17	12.33	0.82	3.97	952.2	34.27	19.82	1.03
4_9	0.59	692.80	14.50	0.66	6.77	506.5	2.42	11.08	0.86
4_20	0.68	600.25	28.25	0.78	4.67	768.4	14.01	24.01	1.29
5_6	0.61	443.14	14.29	0.34	5.13	870.1	7.00	8.30	0.30
5_7	0.40	272.33	6.17	0.71	3.73	827.7	90.80	93.87	0.89
6_2	0.52	569.75	28.25	2.93	14.05	1055.3	2.20	22.23	1.28
7_1	0.44	263.50	109.2	1.47	10.38	725.5	100.25	33.83	0.44
7_2	0.65	681.25	15.50	0.45	4.47	448.8	22.65	11.63	1.64
7_3	0.28	227.88	13.75	0.74	-2.19	985.5	12.19	5.80	0.36
7_95	0.47	506.00	26.20	3.27	14.71	1197.0	22.89	20.93	0.80
9_1	0.25	206.88	1.75	0.57	2.10	842.0	12.13	32.46	0.94
9_5	0.42	331.83	8.67	0.43	4.96	812.2	10.48	8.05	1.21
9_11	0.32	279.20	17.00	1.39	4.56	951.8	31.38	18.68	0.87
10_1	0.51	250.17	7.00	0.51	3.30	760.3	37.27	36.05	0.69
10_2	0.29	209.30	9.80	0.98	4.61	831.5	3.77	31.63	1.51
10_3	0.42	276.00	13.00	0.51	3.63	547.4	20.40	91.90	1.67
11_1	0.50	488.86	8.71	0.46	3.35	1003.9	3.09	7.51	1.06
12_3	0.42	350.60	68.80	2.04	8.79	862.6	99.28	18.12	0.27
12_10	0.38	308.75	21.25	1.46	5.03	1143.5	22.95	27.50	0.58
13_1	0.31	320.17	5.17	0.35	2.41	903.3	15.05	14.58	1.14
13_3	0.51	488.25	16.75	0.39	5.60	576.8	11.90	30.48	0.27
14_1	0.48	405.25	14.50	0.59	7.90	909.3	4.08	6.13	1.20
15_2	0.38	282.00	19.00	2.60	6.27	1054.5	33.65	4.90	0.40
15_3	0.74	465.50	31.50	1.69	11.71	375.8	9.40	77.63	0.60
16_1	0.56	451.70	54.80	0.78	5.28	780.4	3.35	23.56	1.10
16_2	0.54	563.00	38.25	0.59	4.06	882.5	7.23	14.83	1.20
16_3	0.42	362.20	27.60	0.53	476.79	1117.6	1.78	5.30	0.39

Appendix E. R code examples

```
> #cluster analysis example
> library(vegan);library(cluster);library(labdsv); library(psych);library(mvpart)
> ward.NLCD<-hclust(vegdist(NLCDvariables[,2:13],method="bray"),method="ward")
#land cover variables
> plot(as.hclust(ward.NLCD))
> plclust(ward.NLCD,hang=-
0.5,hmin=0,square=TRUE,labels=NLCDvariables$Site,axes=TRUE,frame.plot=TRUE,main="
Cluster Analysis-Wards Linkage and Bray Curtis Distance Metric",sub="",xlab="Group
Membership",ylab="Agglomeration Level")
> rect.hclust(ward.NLCD,3)
> ward.NLCD3<-cutree(ward.NLCD,3)
> NLCDvariables3<-cbind(ward.NLCD3,NLCDvariables)

>#anosim to confirm cluster strength
> NLCD.anosim<-anosim(BCdist.gis,NLCDvariables3$ward.NLCD3,permutations=9999)
>#NMDS example
> NMDS2.NLCD<-metaMDS(NLCDvariables3[,3:15],k=2)#land cover variables
> NMDS3.NLCD<-metaMDS(NLCDvariables3[,3:15],k=3)#3 dimensions
> NMDS3.NLCD
> plot(NMDS2.NLCD$points,type="n") #Plot
> text(NMDS2.NLCD,labels=NLCDvariables3$ward.NLCD3,cex=.8)
> envfit3.NLCD<-envfit(NMDS2.NLCD,NLCDvariables3[,3:15])#correlations of land cover
variables to ordination axis
> envfit3.NLCD
> plot(envfit3.NLCD,veg,cex=.8,p.max=.1) #plot with correlations
> plot(envfit3.NLCD,veg,cex=.8,p.max=.05,col="red")
> plot(NMDS2.gis,veg,type="n",xlab="NMDS Axis 1",ylab="NMDS Axis 2")
> text(NMDS2.gis,veg,labels=gis.variables.spp3b$ward3.vegmembership, cex=.8)

>Indicator species analysis example
> inval.NLCD<-indval(veg.gis,ward.NLCD3)
> inval.NLCD
> grNLCD<-inval.NLCD$maxcls[inval.out$pval<=0.05] #multi step process to find
significant indicators
> grNLCD<-inval.NLCD$indcls[inval.out$pval<=0.05]
> grNLCD<-inval.NLCD$pval[inval.out$pval<=0.05]
> grNLCD

>#descriptive statistics
> describe.by(NLCDvariables3,ward.NLCD3) # summary statistics for each variable by
group
```

```

>#recursive partitioning example
>CH2.alltree<-
mvpert(as.factor(ward.CH2g3)~TEC+pH+OrgMtr+ENR+SolSulf+P+Ca+Mg+K+Na+Other+
H+B+Fe+Mn+Cu+Zn+Al+NO3N+NH4N+Nitro+Road.length+stream.length.m.+mines+transi
tional+forested+pasture+row.crops+urban+wetland+slope,data=CH2.cluster3,xv="p")

>#manova/anova/Tukey's HSD example
> soilMANOVA<-manova(as.matrix(CH2soilvar)~as.factor(ward.CH2g3))
> summary.aov(soilMANOVA)
>OmttrAOV<-aov(OrgMtr~as.factor(ward.CH2g3),data=CH2soilvar)#for organic matter,
repeat for each variable found significant in MANOVA
> TukeyHSD(aov(OrgMtr~as.factor(ward.CH2g3),data=CH2soilvar)) #Tukey HSD for
organic matter

```