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Floristic Quality Index: Ecological and management implications in created and natural wetlands

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FLORISTIC QUALITY INDEX: ECOLOGICAL AND MANAGEMENT IMPLICATIONS IN CREATED AND NATURAL WETLANDS

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APPROVAL SHEET

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DEDICATION

To my wife, Linda, and two sons, Grayson and Jordan.

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ABSTRACT

We applied the Floristic Quality Index (FQI) to vegetation data collected across a chronosequence of created wetland (CW) sites in Virginia ranging in age from one to 15 years post-construction. At each site, we also applied FQI to a nearby forested reference wetland (REF), for a total of 30 sites (15 created, 15 reference). We tested the performance of the index against a selection of community metrics (species richness, diversity, evenness, percent native species) and site attributes (age, soil physiochemical variables). The relationship between FQI and community and environmental variables was analyzed with Spearman's rank order correlation coefficient and Canonical Correspondence Analysis (CCA). Calculation of FQI with all species (including non-natives) did not increase the number of significant correlations ($p<0.05$) with community attributes and/or environmental parameters when compared with FQI based on native species alone. Further, vegetation layer-based FQI calculations improved the sensitivity of the index to differences in floristic quality between sites when compared with an "overall" index calculated across layers, and a modified, abundance-weighted FQI showed a unique correspondence with community and environmental variables in the CW herbaceous layer and REF herbaceous and shrub-sapling layers. These results suggest that a "natives only", layer-based version of the index should be used in wetland assessment in Virginia, and an abundance-weighted FQI may be a useful tool for assessing floristic quality in certain layers. An abundance-weighted format is perhaps desirable because such an index preserves the "heritage" aspect of the species conservatism concept inherent in floristic quality assessment, and also entrains the "ecology" aspect of site assessment based on relative abundances of the inhabiting species. FQI did not successfully relate CW sites to REF sites, bringing into question the applicability of the FQI concept in comparing created wetlands to reference wetlands, and by analogy, the use of forested reference wetlands in general to assess vegetation development in created sites. Based on correlations with soil nutrient variables and ordination results, we propose a conceptual model of vegetation development in created wetlands described as the "Initial Conditions" model, which is expressed in terms of initial site conditions, soil chemistry, species diversity, and floristic quality.

FLORISTIC QUALITY INDEX: ECOLOGICAL AND MANAGEMENT IMPLICATIONS IN CREATED AND NATURAL WETLANDS

1.0 INTRODUCTION

"[Wetlands are] those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions."

In defining the term "wetland", the U.S. Army Corps of Engineers (Corps) and the U.S. Environmental Protection Agency (EPA) identify vegetation as a distinguishing characteristic of wetland systems (Environmental Laboratory 1987). This definition is provided in the regulatory context of wetland policy in the U.S., but vegetation is also an important aspect of how wetlands are defined in the scientific community. This is exemplified in the National Research Council's (1995) recent wetland definition, which states, in part, that "[c]ommon diagnostic features of wetlands are hydric soils and hydrophytic vegetation."

The attributed emphasis on plants in wetland systems underscores the importance of studying wetland vegetation dynamics from both a regulatory and scientific platform. In both venues (regulatory and scientific), our understanding of wetland vegetation proceeds from the observation that wetland plants retain certain adaptations allowing persistence in an anaerobic soil environment (Cronk and Fennessey 2001). This is an important attribute of wetland plant species that has direct application in wetland creation, in that hydrophytic species are expected to colonize properly created wetland substrates, and the degree to which such colonization occurs can be monitored.

The idea of wetland creation is at the focus of the wetland compensation program set forth in Section 404 of the Clean Water Act (33 U.S.C. s/s 1251 et seq.), which is primarily administered by the Corps. In more general terms, wetland creation is a component of a larger category of activities referred to as "wetland mitigation" – the suite of alternatives available to the regulated public for replacing wetland functions lost to commercial and residential development, ditching and draining, impounding, or other activities that impact wetlands. Mitigation can also include wetland restoration, enhancement, and preservation; however, wetland creation is unique in its potential to result in a net increase of wetland habitat by converting upland areas to wetlands (DeBerry et al. 2004).

Compensatory wetland mitigation is a requisite of the regulatory permitting program administered by the Corps under the Clean Water Act. Although tidal wetland permits are issued for projects in the coastal zone, the majority of wetland permits in the U.S. are issued for non-tidal, headwater wetlands (Dahl 2000). Thus, wetland mitigation for such permits must include some compensatory replacement of proposed wetland impacts by way of non-tidal wetland creation or equivalent. Permit applicants are then required to monitor created wetland sites against performance standards that are typically enumerated in a wetland permit (USACE 2002). This is often referred to as "compliance monitoring," and is used by the Corps to gauge the effectiveness of the created wetland project over time. The performance of vegetation within the created site is a key criterion in the assessment of mitigation success.

Lack of consistency in evaluation techniques for compliance monitoring, particularly in the vegetation criterion, is an emerging problem that requires the attention of regulatory agencies, scientists, and resource managers (Erwin et al. 1989, Streever and Portier 1994, Hammer 1996, Campbell et al. 2002). The problem is exacerbated in forested wetland creation, because the age and successional stage of vegetation development on young created sites will be markedly different than the proposed community – a mature forested system that may have developed over decades. Further, if reference sites (e.g., natural forested wetlands) are used as ecological benchmarks for gauging the success of created sites, the disparity between the age of the created site (e.g., 1-5 years following planting, dominated by saplings) and that of the reference site is often difficult to reconcile when analyzing typical vegetation parameters monitored in the field. Use of the Floristic Quality Index may improve this aspect of compliance monitoring by allowing utilization of vegetation properties that are not directly dependent upon quantitative measures within the vegetation system.

Floristic Quality Index (FQI) is the term given to the calculation and subsequent analysis of weighted metrics developed for evaluating the "quality" of native plant communities (Swink and Wilhelm 1979, 1994). In concept, the FQI approach provides a robust tool for vegetation compliance monitoring by focusing on conservative attributes of the inhabiting species rather than on specific quantitative characteristics of the vegetation. Plant "conservatism" is a term used in floristic quality assessment to describe the relative tolerance of species to anthropogenic disturbance as expressed in species-specific "C-values" ranging from zero to ten, with tolerant species at the lower end of the scale and intolerant species at the higher end (Mushet et al. 2002). C-values are assigned by a panel of botanical experts familiar with the flora of a particular region (Andreas and Lichvar 1995).

In natural wetlands, FQI is typically evaluated by testing for linear relationships against a gradient of human alteration in which sites are ranked according to some disturbance criteria such as hydrologic modification, eutrophication, sedimentation, destruction of vegetation, buffer encroachment, or watershed development (Fennessey 1998, U.S. EPA 2002b). This approach is problematic in assessing created wetlands because created sites in general are subjected to similar disturbance regimes involving mass grading during site construction (DeBerry et al. 2004), leaving little discernable "gradient" upon which to rank disturbance. Therefore, evaluating the effectiveness of FQI in created wetland assessment requires an alternative set of criteria that can represent relative biological integrity (Karr and Dudley 1981) in the context of floristic quality.

Site age is one such criterion that may be used as a surrogate measure of disturbance gradient, since older sites are less likely to show the effects of disturbance related to site construction (Odum 1969). Soil physiochemical properties may also be useful in this regard, because soils provide a window to an onsite record of the physical, chemical, and biological attributes in residence at a site over recent time (i.e., time since the last soil disturbing event) (Odum 1985, Richardson et al. 2001, Lopez and Fennessey 2002). Finally, community-level vegetation indices such as species richness, diversity, evenness, and percent native species have been used to assess vegetation quality in wetlands (Balcombe et al. 2005, Matthews et al. 2005, Spieles 2005), and can function as independent measures of relative floristic quality against which FQI may be tested.

Recognizing the need for better tools to assess vegetation on young wetland sites from both a regulatory and scientific perspective, our purpose was to evaluate the performance of FQI on vegetation data collected from a chronosequence of non-tidal created wetland sites in Virginia, and to analyze the ecological and management implications of using FQI as a tool for performance evaluation and assessment. Further, we proposed several versions of the index and tested each against a background of community-based measures including species richness, diversity, evenness, and percent native species, as well as abiotic factors including soil physiochemical properties and site maturity (age). The results of these analyses may be used to evaluate FQI as a predictor of vegetation development in the context of ecological succession, created wetland project objectives, and reference wetlands.

Given that species conservatism tends to increase with time since disturbance (Swink and Wilhelm 1994), it was hypothesized that FQIs of created sites would show an increasing trend across the chronosequence, and therefore would be positively correlated with site age. Further, because many soil physiochemical properties in created wetlands have been shown to be correlated with site age and vegetation development (Reinhartz and Warne 1993, Bischel-Machung et al. 1996, Noon 1996, Nair et al. 2001, Campbell et al. 2002, Johns et al. 2004), we hypothesized that FQI would be positively correlated with all measured soil parameters except soil pH and % sand, which we expected to show negative correlations (Bischel-Machung et al. 1996, Nair et al. 2001, Campbell et al. 2002, Lopez and Fennessey 2002). In addition, we hypothesized that FQI in reference sites would show analogous positive correlations with site age and soil physiochemistry. In this respect, FQI could be used to infer successional development from both a management and ecological perspective, and relate vegetation data from created sites and reference sites in a meaningful way.

2.0 LITERATURE REVIEW

2.1 WETLAND CREATION

Section 404 of the Clean Water Act specifies permitting procedures and compensatory mitigation requirements for dredge and fill activities in waters of the United States (i.e., the body of environmental resources, including wetlands, that are regulated by the Clean Water Act in the United States). The federal definition of wetlands included in Environmental Laboratory (1987) (see preamble to Section 1.0) is based on the presence of three diagnostic criteria: hydrophytic vegetation, hydric soils, and wetland hydrology. All of these factors contribute to the aquatic resource functions attributed to wetlands within the regulatory context of wetland legislation in the United States.

Wetland mitigation is described as the process whereby those aquatic resource functions lost or adversely affected by activities authorized under a wetland permit are replaced (USACE 2002). This is typically accomplished by wetland creation (i.e., creating wetland habitats from originally non-wetland habitats) (National Research Council 2001). Permits issued for wetland impacts are often conditioned with a compliance monitoring requirement to assess the success of the wetland creation project. Monitoring may be required for five to ten years following construction of the site, but usually no longer. Vegetation and hydrology are the two parameters most often required by regulatory agencies for monitoring created sites (USACE 2004). In general, lack of consistent vegetation sampling methodology and assessment techniques is a problem that has inhibited meaningful comparisons among sites (Greiner 1994, Mitsch and Gosselink 2000, Balcombe et al. 2005b, Spieles 2005). Further, the information obtained from routine monitoring efforts (e.g., estimated areal coverage of plants) is generally not sufficient to make reliable inferences about how the community will change over time. This is due to the complexity of biotic and abiotic factors that contribute to species abundance and distribution (Huston 1994), for which a summary of species abundance alone will not be sufficient to address.

The processes involved in vegetation development on created wetland sites have been studied in the context of species composition and life history strategy (Noon 1996, Heaven et al. 2003, DeBerry and Perry 2004), biomass and primary production (Whigham et al. 2002, DeBerry and Perry 2004), seed bank composition (Galatowitsch and van der Valk 1996, Brown 1998), geomorphic setting (Whittecar and Daniels 1999, Morgan and Roberts 2003, Spieles 2005), site age (Noon 1996, Atkinson et al. 2005, Balcombe et al. 2005a,b), wetland hydrology (Niswander and Mitsch 1995, Odland 1997, Atkinson et al. 2005), soil development (Reinhartz and Warne 1993, Noon 1996, Brown and Bedford 1997, Stauffer and Brooks 1997, Campbell et al. 2002), and reference wetlands (Galatowitsch and van der Valk 1996, Campbell et al. 2002, Heaven et al. 2003, Balcombe et al. 2005a,b). Most of these factors are not considered in minimum compliance monitoring standards established for created wetlands (Spieles 2005), yet all may be important in the successional development of vegetation within a created site.

2.2 SUCCESSION

Because ecological succession plays an important role in the types and amount of vegetation inhabiting created wetlands (Noon 1996, Spencer et al. 2001, Campbell et al. 2002, DeBerry and Perry 2004), recently disturbed sites or newly created wetlands are expected to be markedly different in composition, diversity, and biomass relative to mature reference vegetation assemblages (Connell and Slatyer 1977, van der Valk 1981, Smith 1990). As a result, typical vegetation assessment criteria (e.g., species richness, percent cover, density, frequency, etc.) are not conducive to direct comparisons between recently created sites and mature reference wetlands (Hammer 1996). Hence, a review of general successional concepts and more specific applications to regenerating vegetation in wetlands is warranted.

2.2.1 Ecological Succession: A Historical Perspective

The concept of "ecological succession" was originally articulated by authors such as Clements (1916), Gleason (1917, 1927), Cooper (1926), and Tansley (1935) to explain the observation that species replacement occurs as sites mature. Ecological succession is defined as the "unidirectional, sequential change in the relative dominance of species...in a community" (Smith 1990). Whether this process of replacement is understood on the basis of Clements' (1916) "superorganism" concept (i.e., the climax community, which represents the most advanced assemblage of vegetation capable under a prevailing climatic condition and, therefore, the end of succession), or Gleason's (1927) antithetical "individualistic" concept (i.e., the climax as an expression of the random processes of species colonization, competition, and replacement), the basic premise of replacement in a unidirectional sequence remains, with ecological complexity and organization increasing at each stage of development (Smith 1990).

This bipartisan understanding of succession was perpetuated by authors in the mid-1900's, with Odum (1969) revising Clements' views toward an "ecosystem" concept (i.e., the ecosystem as a holistic entity – a product of successional development with its own emergent properties and predictable attributes in time), and authors such as Connell and Slatyer (1977) and Peet and Christensen (1980) adopting Gleason's more reductionist views, but focusing on population dynamics such as competition, regeneration, facilitation, inhibition, and mortality as the primary determinants of successional change. This latter view – the "population" concept – considers the process of succession in terms of differences in colonizing ability, growth, and longevity of different species in response to changing environmental conditions (Smith 1990), with changes in species composition occurring gradually along gradients of environmental condition and interspecific competition. This is arguably the prevailing view in the more recent work on succession in wetlands. Other important concepts include the idea of multiple stable states (Scheffer et al. 2001), that disturbance regimes play important roles in determining which stable state is attained, and that the seed bank is an important factor in determining community characteristics (van der Valk 1981).

2.2.2 Succession in Wetlands

Gleason's (1917, 1927) arguments were applied specifically to wetlands in van der Valk's (1981) working model of vegetation succession in wetlands. The model uses four general characteristics of wetlands that lead to vegetational change: 1) destruction of the existing vegetation; 2) changes in physical or chemical properties of the environment; 3) competition; and, 4) establishment. The model also focuses on the composition of the seedbank as a major determinant in vegetation establishment and replacement, and refers to the complex suite of site characteristics in items 1-4 above as the "environmental sieve", which allows only those species with the appropriate life history traits (i.e., life-span, propagule longevity, and germination requirements) to become established and persist in a wetland system. Although it provided a functional basis for predicting vegetation succession in wetlands, van der Valk's model is limited in scope by its focus on emergent wetlands in prairie marshes (Leck 1989). An understanding of vegetation development from emergent (immature) to forested (mature) wetlands must also integrate concepts of forest succession.

2.2.3 Forest Succession in Wetlands

Developing a working model of succession in forested systems has presented a challenging problem to researchers. This is due in part to the structural complexity of the vertical dimension in forests (i.e., the stratification of the community into overstory, understory, groundcover, and extensive belowground biomass) (Ponge et al. 1998), and to the difficulty of studying a community type with system dynamics that could operate over hundreds of years (Shugart and West 1980). Through the application of succession models coupled with long-term ecological research, the concept of succession in forested systems has largely been understood from work in terrestrial environments (Bormann and Likens 1979, Bazzaz 1996, Barbour et al. 1999), but little research has concentrated on forested wetlands (Mitsch and Gosselink 2000). This is perhaps because wetlands have been considered intermediary steps in a "hydrarch succession" sequence (Wilson 1935, Mitsch and Gosselink 2000) that follows the development of vegetation from an open water system (lake) to a terrestrial system. Thus, interest in the end-members of such a sequence would place emphasis on the study of the terrestrial system as the climax sere (Smith 1990), leaving forested wetlands to occupy a less important temporal role in the consciousness of early researchers.

The hydrarch sequence is a concept of autogenic succession, which presupposes that changes in the community are brought about by the plants themselves (Smith 1990, Barbour et al. 1999). However, the recent conception of wetlands as pulsed systems (Niering 1987, Odum et al. 1995) limits the usefulness of traditional concepts of autogenic succession and the climax, in that the development of wetland vegetation is viewed in response to environmental conditions (i.e., allogenic succession) controlled in part by the hydroperiod, or the periodic/episodic fluctuation of water levels within the wetland system. It is now understood that succession in wetlands is likely the consequence of autogenic and allogenic factors combined (Mitsch and Gosselink 2000). Therefore, an appropriate model of forest dynamics in wetland ecosystems should consider the autogenic effects of initial floristic composition (Egler 1954, Walker et al. 1986, Niering 1987, Huston and Smith 1987, Noon 1996), gap dynamics (Shugart and West 1980, King and Allen 1996), and nutrient retention (Vitousek and Reiners 1975), as well as allogenic processes related to other environmental variables (Niering 1987, Mitsch and Gosselink 2000). One approach toward such a synthesis is the study of "chronosequences" made up of sites of different ages but similar geomorphic setting. The chronosequence concept allows researchers to view floristic composition and environmental variables at sites of different developmental stages following disturbance (Stevens and Walker 1970, Spencer et al. 2001, Frelich 2002).

2.2.4 Disturbance and Diversity

An important consideration in the construction of a chronosequence is the effect of time and disturbance regime on community properties. A common model used to describe the relationship between species diversity and disturbance regime is the "intermediate disturbance hypothesis" (Connell 1978, Hobbs and Huenneke 1992, Pollock et al. 1998), which states that diversity should be highest at intermediate frequencies or intensities of disturbance. In wetlands, drawdown frequency (i.e., frequency of dry periods) has often been considered a disturbance factor related to hydrologic regime that supports this diversity-disturbance relationship (van der Valk and Davis 1978, van der Valk 1981, Keddy 2000). Hydrologic regime has in fact been demonstrated as an important mechanism in determining relative dominance of species in created wetlands (Niswander and Mitsch 1995, Odland 1997, Atkinson et al. 2005).

One other consideration is that of initial conditions related to soil development, wetland hydrology, and the viable source of propagules present at the time of catastrophic disturbance such as created wetland construction. The "initial floristic composition" model proposed by Egler (1954, 1977) states that all species involved in succession are present at the outset, and shifts in species dominance over time simply reflect the unfolding of that initial flora (Ehrlich and Roughgarden 1987) mediated by differences in reproduction, dispersal, germination, and growth characteristics (Wilson et al. 1992). The assumption that no species arrivals will occur after the initiation of succession suggests that all species involved in succession are present in the soil seed bank from the beginning. This idea has been criticized as unrealistic, since new seeds are expected to arrive from nearby habitats over time (Connell and Slatyer 1977, Wilson et al. 1992). However, an alternative interpretation is that all species found in the region (i.e., within a site or in nearby habitats) that could participate in the succession are widely distributed and dispersed, and therefore, from a regional perspective, would be present from the start and could enter the site at any time (Wilson et al. 1992). This interpretation seems consistent with Egler's (1954) original meaning of the concept, and has been applied to descriptions of vegetation development in created wetlands (Noon 1996, Stauffer and Brooks 1997). Therefore, initial site conditions such as soil nutrient content and hydrologic regime that regulate species distribution and abundance are viewed as deterministic factors in initial floristic composition (Keddy 2000), and changes in floristic quality of a site over time (see Section 2.3 below) may be dependent on initial conditions.

2.3 FLORISTIC QUALITY INDEX (FQI)

Swink and Wilhelm (1979, 1994) originally advanced the FQI concept as a means for evaluating the "quality" of plant communities. Quality is a relative term used to approximate similarity of a particular plant species assemblage to presettlement conditions in a similar habitat type (Noss 1985, Maser 1990). Implicit in FQI application is the notion that areas with species assemblages closer to those of presettlement times are more reflective of truly native, non-disturbed habitat (Wilhelm and Ladd 1988, Swink and Wilhelm 1994, Nichols 1999), and the assumption that disturbance represents a mode of introduction for "non-conservative" (e.g., invasive or exotic) species.

The FQI approach is based on the concept that different plant species have evolved varying degrees of tolerance to disturbance or environmental stress (Odum 1985, Hobbs and Chapin 1991, Huenneke 1992), and exhibit varying degrees of fidelity to specific habitat integrity (Herman et al. 1997, Mushet et al. 2002). Conceptually, this combination of tolerance and fidelity indicates the degree of "species conservatism" (Swink and Wilhelm 1979, 1994, Rooney and Rogers 2002), which is specified by the "coefficient of conservatism" (C), a numerical assignment between 0 and 10 applied to plant species by a panel of experts on the native flora of a particular region (Andreas and Lichvar 1995, Alix and Scribailo 1998, Nichols 2001). A species with a C-value of 10 always occurs within undisturbed natural plant communities, and a species with a C-value of 0 is not found in natural plant communities and, in general, is highly tolerant of disturbance (Wilhelm and Ladd 1988, Matthews 2003). In Virginia, a list of C-values was recently developed by a panel of botanists and wetland experts for most wetland plants occurring in the state (Virginia Department of Environmental Quality 2004). The C-value assignment criteria used in the development of this list are provided in Table 2-1.

Table 2-1. Virginia Wetland Plants C-value List ranking criteria (Virginia Department of Environmental Quality 2004).

C-Value Range	Ranking Criteria
0	Non-native species.
1-3	"Weedy", opportunistic, disturbance-tolerant species with a characteristically broad ecological amplitude. Due to natural or human disturbances, these species are often opportunistic invaders of natural areas.
4-7	Plants with an intermediate range of ecological tolerances. These taxa typify a stable phase of some native community, but persist under minor disturbances.
8-10	Disturbance-intolerant, localized, and/or edaphically restricted species with a characteristically narrow ecological amplitude. These species generally exhibit relatively high degrees of fidelity to a narrow range of synecological parameters.

Studies evaluating the effectiveness of FQI as a tool for assessing wetlands typically rank sites according to some anthropogenic disturbance criterion and test for linear correlations between FQI and disturbance rank (Fennessey 1998, Mack et al. 2000, U.S. EPA 2002b, Wilcox et al. 2002). This procedure has limited application in created wetland assessment because created sites in general are subjected to similar disturbance regimes involving mass grading during site construction (DeBerry et al. 2004). For this reason, it is difficult to define meaningful disturbance ranks for young sites, although site age may be used as a surrogate for disturbance since older sites are less likely to exhibit properties of the indiscriminate disturbance event coincident with site construction (Odum 1969, Marks and Bormann 1972). Community-level vegetation indices such as species richness, diversity, evenness, and percent native species may also be useful in assessing FQI performance (Matthews et al. 2005, Bowles and Jones 2005). Such indices have been widely used to describe vegetation in wetlands (Auclair et al. 1976, Keddy 2000, Balcombe et al. 2005, Spieles 2005), and are considered to reflect "intrinsic floristic quality" of plant assemblages based on the assumption that each of these indices expresses a fundamental property of the ecosystem (Huston 1994), and communities that maximize such measures tend to exhibit higher degrees of biological integrity (Karr and Dudley 1981, Magurran 1988, Karr 1991).

The application of FQI in wetland assessment may also benefit from the integration of soil biogeochemical parameters in its analysis (Lopez and Fennessey 2002). As Odum (1969, 1985) points out, ecosystems in general develop from a state of immaturity with open mineral cycling toward a state of maturity with structural complexity and closed mineral cycling. Therefore, anthropogenic disturbance can be a factor influencing soil development by establishing “immature” conditions once a site is disturbed (Pickett and White 1985). Given the assumption that highly conservative species tend to inhabit sites less disturbed by anthropogenic effects (i.e., those most likely to reflect pre-settlement conditions), wetland soil development could represent an important consideration in the overall assessment of floristic quality.

2.4 WETLAND SOILS

The soil profile is a medium with a finite vertical dimension through which observations about the history of a site can be made. Soils provide a window to an onsite record of the physical, chemical, and biological attributes in residence at a site over recent time (i.e., time since the last soil disturbing event) (Odum 1985, Richardson et al. 2001, Lopez and Fennessey 2002). This window is of particular interest to scientists studying wetland systems, in that wetland soil systems maintain a broad range of chemical reactions when compared with terrestrial soil systems, and because wetlands retain the capacity to recycle organic carbon and nutrients in three different compartments: soil, water, and atmosphere (Vepraskas and Faulkner 2001).

Soil development tends to be more advanced on older sites (Odum 1969, Marks and Bormann 1972, Odum 1985, Chadwick and Graham 2000), with an increase in organic matter and biogenic nutrient subsidies, increased horizonation, lower bulk density, slower rates of nutrient exchange, and increased importance of detritus-based energy cycles relative to young soils. In wetlands, this is due to the fact that soil-forming processes such as mineral fractionation and weathering, incorporation of organics, and soil oxidation/reduction (redox) processes are time-dependent (Jenny 1941, Stevens and Walker 1970, Mausbach and Richardson 1994) and are inevitably linked to the colonizing vegetation (Craft 2001) and to the depletion of free oxygen in the soil (Mitsch and Gosselink 2000, Megonigal et al. 2004).

2.4.1 The Role of Plants in Wetland Soil Development

Soil properties can be affected by plant composition, species diversity, and successional development of the standing vegetation (Marks and Bormann 1972, Hooper and Vitousek 1997). Accumulation of detritus in wetland systems has been implicated as a controlling factor in the development of hydric soils, which are characterized by chemically reducing conditions (i.e., anoxia) (Vepraskas 1994, Whittecar and Daniels 1999). In this respect, vegetation provides a feedback mechanism for the development of substrates that typically characterize natural wetland communities by providing organic matter in the form of detritus to initiate microbially-mediated reduction (Stauffer and Brooks 1997). In addition, because soils provide a cumulative record of the nutrient and mineral content in residence at a site (Lopez and Fennessey 2002), soil physiochemical variables offer a reasonable indicator of the overall disturbance/stress condition (Chapin 1991, Plaster 1992). Therefore, soil physiochemistry and fertility will likely reflect conditions related to age, disturbance, and vegetation development, and may provide a useful characterization of the overall substrate suitability for native plant species.

Wetland plants retain a diversity of adaptations that allow establishment, growth, and persistence in anaerobic soil conditions (Cronk and Fennessey 2001). The types of plants that may colonize a saturated or inundated soil must have adaptations that allow for rapid growth and survival in a poorly oxygenated soil environment. The most extensive literature source on early recruitment and colonization of recently disturbed wetland substrates comes from studies in wetland creation and restoration sites, which describe a diversity of hydrophytes that can become established in such environments (Wilson and Mitsch 1996, Noon 1996, Reinhartz and Warne 1993, Whigham et al. 2002, Campbell et al. 2002, DeBerry and Perry 2004). Under these conditions, aboveground biomass equivalency with adjacent natural wetlands can be achieved even in the early stages of plant development (Whigham et al. 2002, DeBerry and Perry 2004), indicating that early colonizers allocate a significant proportion of growth to areal plant components. This is presumably facilitated by enhanced photosynthetic capacity due to solar radiation exposure in the emergent macrophyte community (Brinson et al. 1981), and by the plants themselves – the colonizing species are generally annuals, or facultative annuals, with the capacity to persist under potentially stressful, low-nutrient conditions (van der Valk 1981, DeBerry and Perry 2004). As the vegetative community develops, biomass turnover contributes organic matter to the soil, and the complex suite of biogeochemical transformations that control factors such as nutrient availability, pH, and cation exchange capacity is initiated (Craft 2001).

Energy flow in freshwater wetland systems is detritus-based (Day 1984, Mitsch and Gosselink 2000). As young sites mature, biogeochemical energetics shift toward increased complexity and closed mineral cycles (Odum 1969, 1985). This shift is facilitated by the incorporation of biogenic organic products into the soil profile, which also functions to increase water holding capacity in the system, thereby influencing soil redox state, mineral cycling, and microbial community development (D'Angelo et al. 2005). It follows, then, that if the vegetative community in wetland sites proceeds along a successional trajectory from emergent to forested cover types, the potential sources of organic carbon will be augmented with a parallel increase in structural complexity in the community. Forested systems support a diversity of growth forms, including trees, shrubs, and understory herbaceous plants, and the quality of the detritus improves accordingly (i.e., more protein- and nutrient-rich organic products from leaves, fruits, flowers, tubers, etc.). In addition, plant community development results in the production of a deep root system, which supports a diversity of soil microbiota and further influences the redox state of soil via gas transport through the vascular tissues down the profile (Ehrenfeld and Toth 1997, Craft 2001).

As the biogeochemical environment "improves" with respect to bioavailable nutrient and organic carbon sources, an associated response in redox processes mediated by organic matter inputs further influences the availability of growth-limiting nutrients such as N and P (Armstrong and Boatman 1967, Gambrell and Patrick 1978, Koerselman et al. 1990, Aerts et al. 1992). The structural complexity of the system increases, and nutrient availability gradients may become established across the wetland substrate in response to hydrologic regime and other factors (e.g., pH, variable nutrient inputs, etc.) (Aerts et al. 1990, Bridgham et al. 1995, Bragazza and Gerdol 2002).

Such gradients are also influenced by allogenic processes such as nutrient inputs from exogenous sources in wetland systems (Craft and Richardson 1993, Craft et al. 1995, Craft and Richardson 1997, Cirmo 1998, Chiang et al. 2000). These inputs are regulated by physical controls such as hydrologic regime and geomorphic setting (Megonigal and Day 1988, Mausbach and Richardson 1994, Richardson et al. 2001), by the condition of the contributing upgradient watershed (Brinson et al. 1984, Craft and Richardson 1993, Qualls et al. 2001, Newman et al. 2001), and by the source-sink and redox functional status of the wetland for nutrient subsidies (Bridgham and Richardson 1993, Cirmo 1998). The distribution and abundance of plants may change in accordance with resource limitations established by such gradients (Burke et al. 2003), and a feedback mechanism is established whereby organic carbon inputs from the plant community moderate the soil biogeochemical setting within the established hydrologic regime, and the resultant biogeochemical setting moderates the distribution and abundance of plant species over the successional stages of vegetation community development.

2.4.2 Soil Development in Created and Restored Wetlands

Created wetlands are typically formed via excavation of surface soils from uplands, with the intention of flooding or intercepting groundwater to support wetland hydrology (DeBerry and Perry 2004). Atkinson et al. (1998) also describe a type of created wetland termed “accidental”, which occurs in surface mined landscapes where flat benches are graded out along the sides of mountains and abandoned after surface mining activity ceases. Wetland restoration usually involves reestablishment of a preexisting hydrologic regime in, for example, a drained agricultural field (Whigham et al. 2002). In all cases, some amount of wholesale soil disturbance is usually associated with the initiation of the system. Therefore, created and restored wetlands offer an opportunity for researchers to observe changes in biogeochemical cycling and development over time, since time zero (t=0) is considered the initial soil condition after disturbance but prior to vegetation development.

Several studies in created wetlands cite positive relationships between soil physiochemical variables and site age. Age is usually assessed by chronosequences of available sites within similar geomorphic settings. For example, on accidental wetlands in southwestern Virginia, Atkinson and Cairns (2001) were able to look at a group of sites of known age and make comparisons between the groups (e.g., 20 years vs. 2 years). They noted that decomposition rates were higher in the 20-year class relative to the 2-year class. In a related study of sites ranging from 10 to 30 years in age, a positive relationship was noted between development of redoximorphic features (e.g., oxidized rhizospheres) and site age (Atkinson et al. 1998). Similar relationships have been observed in created wetland chronosequences with respect to organic matter content in Pennsylvania (Campbell et al. 2002), Texas (Noon 1996, Johns et al. 2004), and Florida (Nair et al. 2001). The progressive increase in organic matter with site age has also been accompanied by increases in denitrification capacity (Johns et al. 2004), C:N ratios (Nair et al. 2001), and plant species diversity (Reinhartz and Warne 1993), and decreases in bulk density, pH, soil chroma, and coarse mineral fractions (Bischel-Machung et al. 1996, Nair et al. 2001, Campbell et al. 2002). Therefore, predictable patterns in site age and soil chemistry may be used to differentiate sites with respect to vegetation community development.

2.5 COMMUNITY ORDINATION

Vegetation community data are often complex and multidimensional. The reason for this is that species co-occur and often overlap in ecological settings, making direct comparisons difficult (Ludwig and Reynolds 1988). The goal of most community ecology studies is to seek and describe patterns within the complex array of community data. This is often achieved by focusing on the strongest relationships in species composition, and then relating those associations to environmental gradients (McCune and Grace 2002). This can be done using direct gradient analysis (i.e., the position of species in relation to measurements of environmental variation) or indirect gradient analysis (i.e., the position of species in relation to measures of the species themselves) (Legendre and Legendre 1998). In either approach, the process typically begins with a matrix comprised of some measure of species abundance used to describe the vegetation community.

Deriving meaningful relationships among large data sets of species abundance values requires some method of data reduction. Community ordination is a data reduction approach that has been widely used in analysis of ecological data (Pielou 1984, Digby and Kempton 1987, Ludwig and Reynolds 1988, Legendre and Legendre 1998, McCune and Grace 2002). The process of community ordination involves summarizing a multivariate data set into a smaller number of composite variables, also referred to as "synthetic" variables because they represent a unitless expression of the combined variation in the original data set (McCune and Grace 2002). The most common ordination procedures used in community ecology include principle components analysis (PCA), correspondence analysis (CA), Bray-Curtis ordination, detrended correspondence analysis (DCA), non-metric multidimensional scaling (NMS), and canonical correspondence analysis (CCA) (Legendre and Legendre 1998). Most of these approaches have in common the calculation of eigenvalues, which correspond to axes that explain the variance of the original data set, and eigenvectors, which are linear projections of eigenvalues. This is similar to linear least-squares regression, except that the eigenvector represents a best fit based on perpendicular (not vertical) differences between points and the line (eigenvector), and can be used to explain data in more than two dimensions (Ludwig and Reynolds 1988). The collective approach, termed eigenanalysis, can be used to ordinate sites relative to species (i.e., sites in species space), or *vice-versa.*

PCA was the one of the first indirect gradient ordination techniques to be used in community ecology (McCune and Grace 2002). The technique is most applicable to data with linear relationships among variables (Ludwig and Reynolds 1988). However, because ecological community data are rarely linear in nature, the mathematical model upon which PCA is based tends to produce an "arch effect" or horseshoe-shaped arrangement of points when plotted in two dimensions (Minchin 1987). Although some researchers believe that the arch effect does not imply inferiority in the model (Allen and Shugart 1983), most believe that it unnecessarily distorts the underlying gradients in the original data set beyond meaningful interpretation (Minchin 1987, Legendre and Legendre 1998, McCune and Grace 2002). CA addresses this problem by using a weighted averaging technique (also termed "reciprocal averaging"); however, CA is still subject to the arch effect (although less pronounced than PCA), and exaggerates the distinctiveness of outliers (e.g., rare species) (McCune and Grace 2002).

PCA and CA are non-polar ordination techniques; that is, axes are based on maximum variance in the data set rather than dissimilarity between paired objects (Causton 1988). The ordination procedure proposed by Bray and Curtis (1957) is considered "polar" because it arranges data in reference to endpoints or "poles" that are determined based on dissimilarity between the points. Historically, this method was advantageous for researchers because of its computational simplicity. One problem with the technique is that outliers can easily be selected as endpoints, which can yield results that are unrepresentative of the underlying gradients in the overall data set (Legendre and Legendre 1998).

Hill and Gauch (1980) proposed DCA as a modification to CA that was developed to minimize the arch effect. The procedure uses a detrending step that involves "slicing" an ordination axis into segments of arbitrary length and re-centering each segment on the axis. Although the procedure has been used extensively in community ecology (Peet et al. 1988, Parker 1989), the detrending step has been criticized because of its tendency to distort the original data set, and because the number of segments chosen has a large effect on the final ordination output (Wartenberg et al. 1987, Minchin 1987, Jackson and Somers 1991).

NMS differs fundamentally from other ordination approaches in that it is not an eigenvector technique (i.e., it does not maximize the variability associated with individual axes in the ordination). Instead, NMS uses ranked distances in the data set and seeks solutions that minimize "stress", which is measured as a departure from monotonicity (a monotonic series has successive values that either increase or stay the same, but do not decrease) (McCune and Grace 2002). NMS does not produce the pronounced arch effect of other methods, and has been described as a robust procedure that is generally superior to other indirect gradient analyses (Minchin 1987).

In contrast with other methods, CCA can be considered direct gradient analysis in that it directly relates species composition to measured environmental variables (ter Braak 1986, Palmer 1993, McCune and Grace 2002). The technique was proposed by ter Braak (1986, 1987) to provide the benefit of the direct gradient approach to community ordination. This procedure is unique because it has the capacity to constrain the ordination of a species abundance matrix by multiple linear regression of another matrix containing environmental parameters (McCune and Grace 2002). CCA uses a weighted averaging approach to calculate site scores from the abundance matrix, then calculates regression coefficients from weighted least-squares multiple regression of site scores on environmental variables. New site scores are then based on fitted values from the regression coefficients, and these are called LC scores because they represent “linear combinations” of environmental variables (McCune and Grace 2002). The direct gradient analysis approach of CCA is appropriate for studies in which researchers desire to understand community gradients in relation to a specific set of environmental variables (Palmer 1993). The approach also has the advantage of allowing researchers to explore explanatory variables by simple correlation with site scores. In addition, the method can be modified by progressive data fragmentation (*sensu* Peet 1980), in that column vectors in the environmental data matrix can be iteratively removed until a statistically significant eigenvalue solution is achieved.

3.0 METHODS

3.1 STUDY SITES

Fifteen non-tidal created wetland sites (created wetlands, CW) from the Coastal Plain (11 total) and Piedmont (6 total) physiographic provinces in Virginia were selected from a pool of 22 available sites provided by the Virginia Department of Transportation (VDOT) and satisfying the following criteria:

1) The sites are created non-tidal wetlands developed as compensatory mitigation for impacts to waters of the United States regulated under Section 404 of the Clean Water Act.
2) The established objective of each CW site is to create a functioning non-tidal forested wetland system.
3) The sites range in age from one to 15 years following construction.
4) The sites are at least one hectare in size.
5) The sites have satisfied the Corps definition of wetland hydrology (saturation to the soil surface for at least 12.5% of the growing season; Environmental Laboratory 1987).

In addition, 15 reference wetlands (REF) were selected from nearby locations (one at each mitigation site), reflecting the proposed community type for the respective CW. Reference wetlands are forested systems within which there has been no recent disturbance or clearing, such that the predominant cover type is canopy-sized trees supporting a stratified understory.

Reference site selection is based on the "minimal impairment" concept, which recognizes that it is unrealistic to expect the reference condition to be pristine (i.e., exhibiting no anthropogenic disturbance), because there are few natural habitats remaining that have been unaffected by human alteration. However, those that are "minimally impaired", that is, sites "that exhibit the least degree of detrimental effect" (U.S. EPA 2002a), are typically identifiable within a particular region. The reference wetlands selected for this study were generally over 40 years in age (time since last significant disturbance).

The individual study sites are described in more detail below. The following descriptions are arranged in reverse chronological order by CW site. Each site description is followed by a brief characterization of the attendant reference wetland for that site. The name provided for each site represents the project name used by VDOT. The site identification number reflects the post-construction age of the CW site (for convenience, the site identification number for each CW site was also given to each respective REF site). Representative photographs of the sites are provided in Appendix A. The locations of the mitigation sites in general are depicted on Figure 3-1.

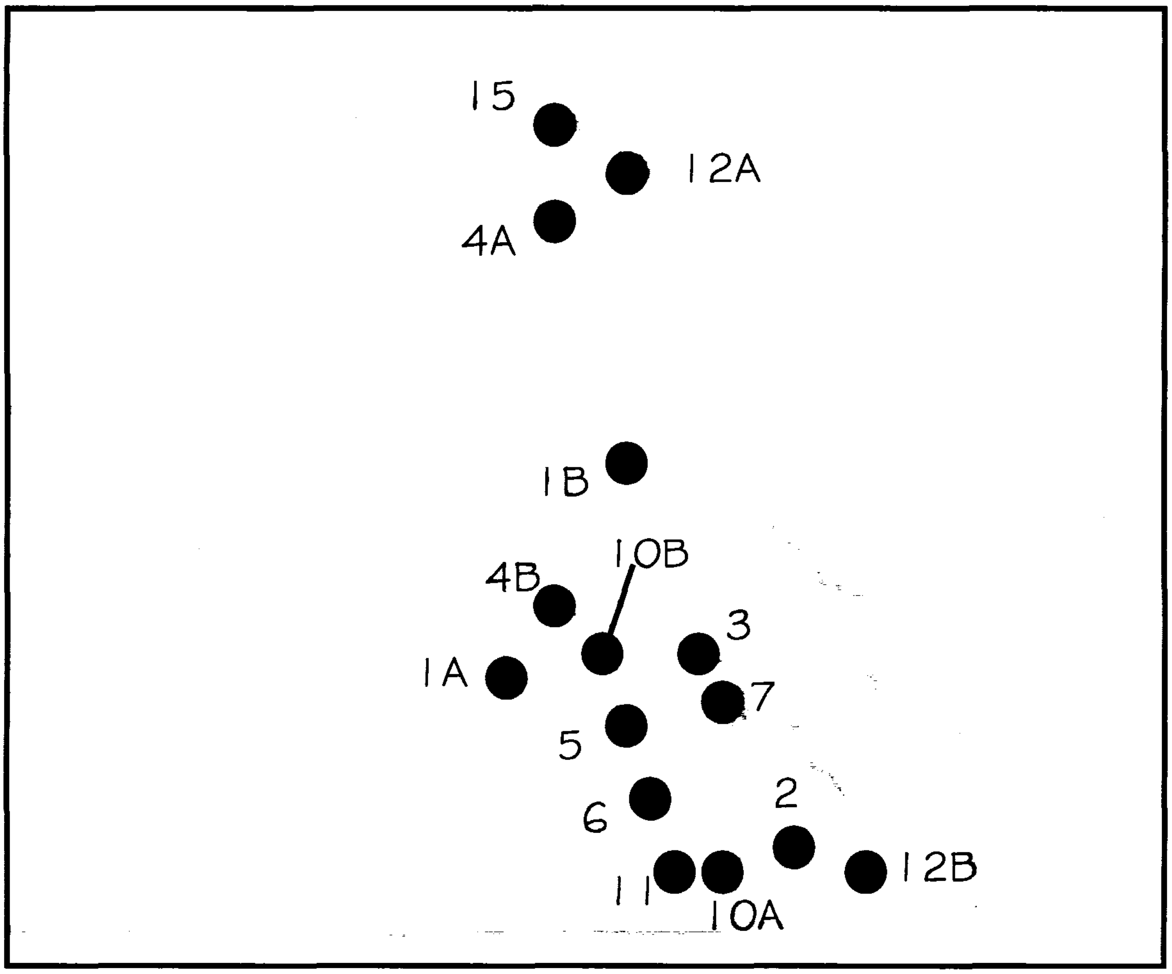

Figure 3-1. General location of the 15 study sites throughout Eastern Virginia.

Site Key:

1A – Reedy Creek
1B – Mattaponi
2 – Southwest Suffolk
3 – Mount Stirling
4A – Manassas
4B – Powhite Parkway
5 – Fort Lee
6 – Stony Creek
7 – Charles City
10A – Franklin Bypass
10B – Proctor's Creek
11 – Courtland
12A – Route 7
12B – Bowers Hill
15 – Sleeter Lake

15 – Sleeter Lake
Year Built: 1989

Age when sampled:

15 years

Size: 1.4 ha

County: Loudoun, VA

Quad: Purcellville, VA

Reference site age:

72 years

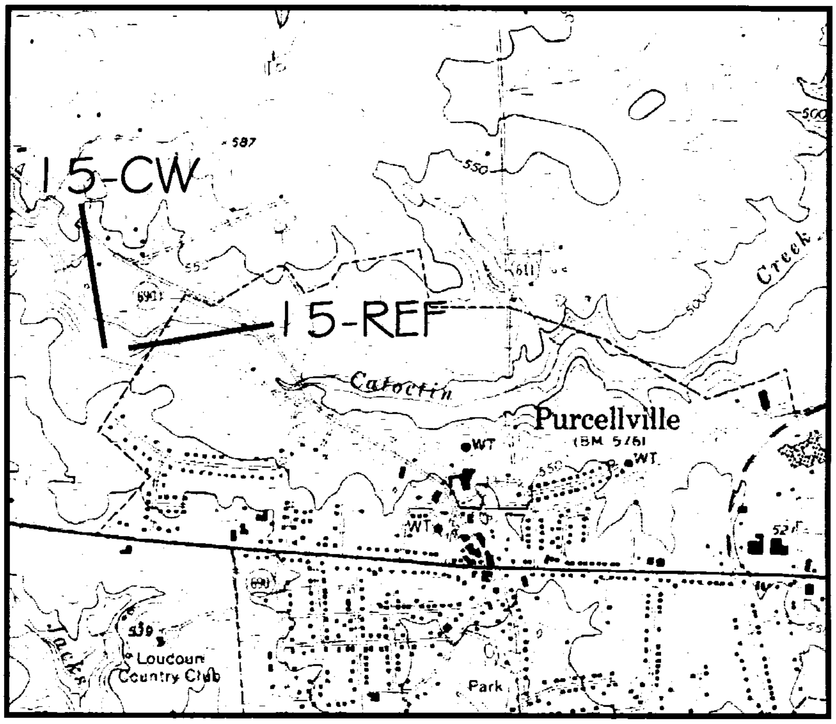

Figure 3-2. Sleeter Lake (15-Sleet) location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Sleeter Lake mitigation site is located in the Town of Purcellville approximately 15 km west of Leesburg, Virginia (Figure 3-2). The site parallels Catoctin Creek, abutting U.S. Route 7 Bypass (not shown) along its the northern perimeter, and may be accessed via public roads in an adjacent neighborhood to the southeast. This setting is in the northern Piedmont physiographic province of Virginia. The presence of shallow bedrock is evident in the predominance of regolith and other coarse textured materials high in the soil profile. The surrounding landscape is characterized by a mixture of agriculture and moderate-density residential development. The primary hydrologic regime is contributed by overbank subsidies from the adjacent Catoctin Creek, but some groundwater discharge is evident along side slopes in the narrow floodplain valley. The reference wetland is adjacent to and just south of the mitigation site, and is comprised of an approximately 72 year-old hardwood stand at the base of a seepage slope flanking the south perimeter of the Catoctin Creek floodplain.

12B – Bowers Hill

Year Built: 1992

Age when sampled:

12 years

Size: 10.9 ha

City: Chesapeake, VA

Quad: Bowers Hill, VA

Reference site age:

78 years

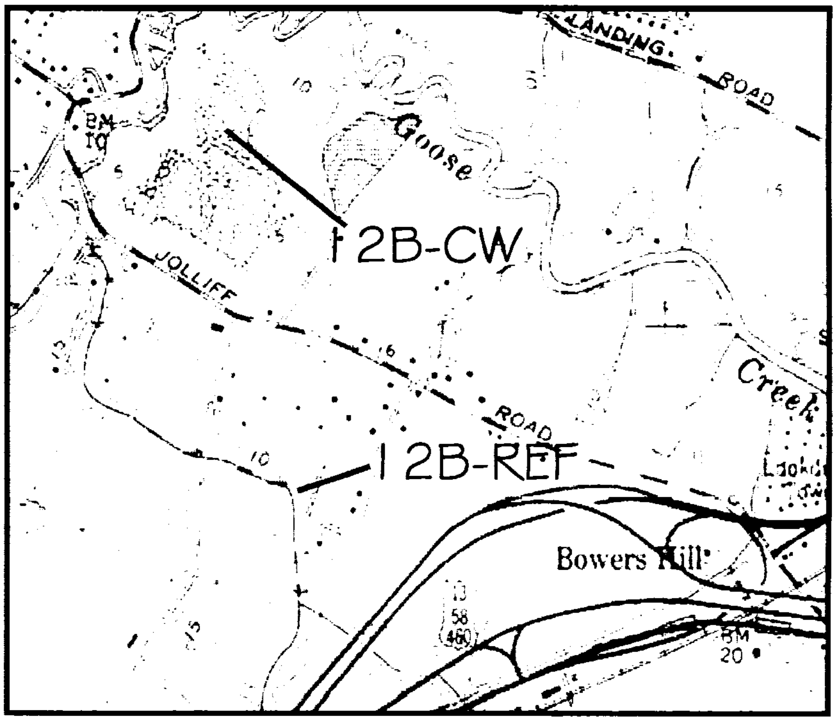

Figure 3-3. Bowers Hill (12B-Bwrh) location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Bowers Hill mitigation site is located in the City of Chesapeake, Virginia near the Interstate 664/U.S. Route 58 interchange (Figure 3-3). The site is in an abandoned surface mine near Goose Creek, northeast of Joliff Road, and bordering Interstate 664 (not shown) along its eastern perimeter. This setting is in the southeastern Coastal Plain physiographic province of Virginia, which is characterized by nearly level topography and mineral soils of maritime origin. The surrounding landscape includes moderate-density residential communities, some agriculture, and forested land. The primary hydrologic regime is assumed to be surface capture of precipitation and groundwater discharge. The reference wetland is approximately 0.8 km south of the mitigation site in a 78 year-old hardwood-floodplain complex along an unnamed tributary of Goose Creek. The site is accessible from Branchview Way along its eastern boundary.

12A – Route 7

Year Built: 1992

Age when sampled:

12 years

Size: 2.5 ha

County: Fairfax, VA

Quad: Seneca, VA

Reference site age:

39 years

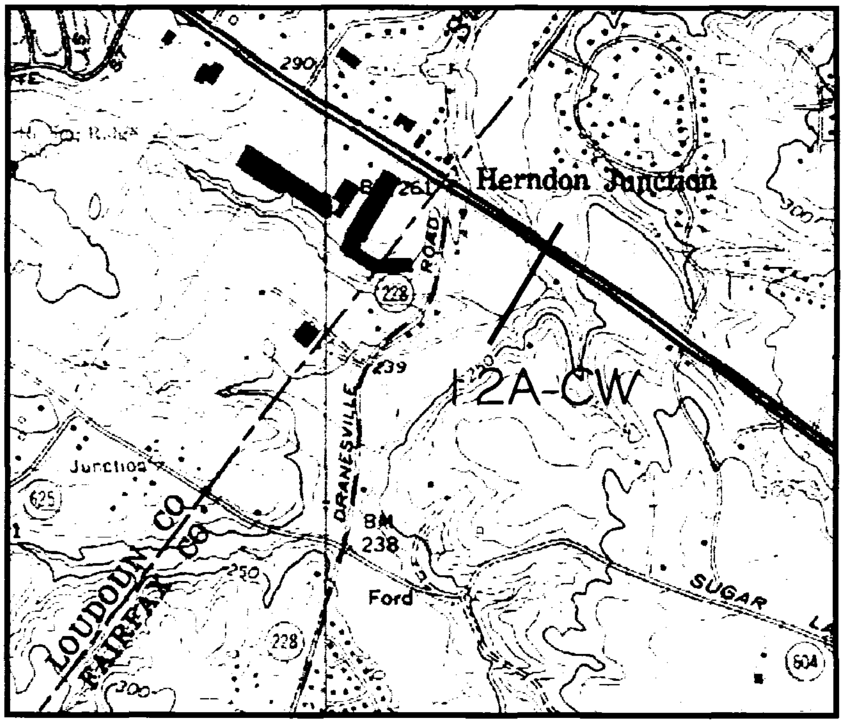

Figure 3-4. Route 7 (12A-Rte7) created site location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Route 7 mitigation site is located just east of the Fairfax County/Loudoun County line on the north side of State Route 7 near Herndon, Virginia (Figure 3-4). The site lies within the floodplain of Sugarland Run, and is accessed from Route 7 to the south. This setting is within the northern Piedmont physiographic province of Virginia. The surrounding landscape is characterized by a mixture of high-density residential neighborhoods and commercial properties. The hydrologic regime is contributed by overbank flooding from the adjacent Sugarland Run, groundwater discharge, and surface capture. The reference wetland is located approximately 8.7 km east on Route 7, bordering Difficult Run to the east and Route 7 to the south (Figure 3-5). Access is provided by a small utility road to the north. The forest is an approximately 39 year-old mixed deciduous hardwood stand in the Difficult Run floodplain.

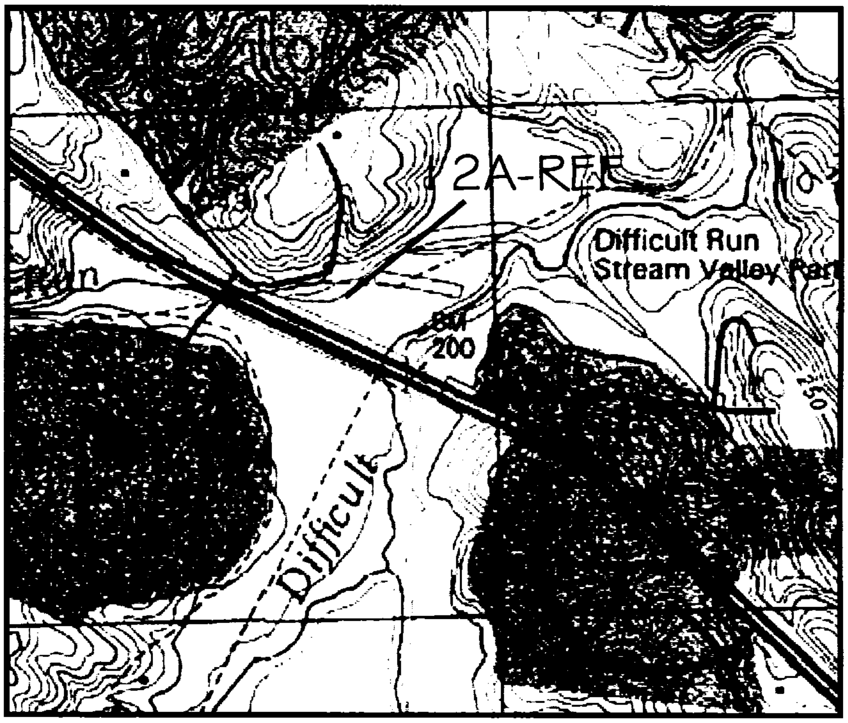

Figure 3-5. Route 7 (12A-Rte7) reference site location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

11 – Courtland Bypass

Year Built: 1993

Age when sampled:

11 years

Size: 4.1 ha

County: Southampton, VA

Quad: Courtland, VA

Reference site age:

65 years

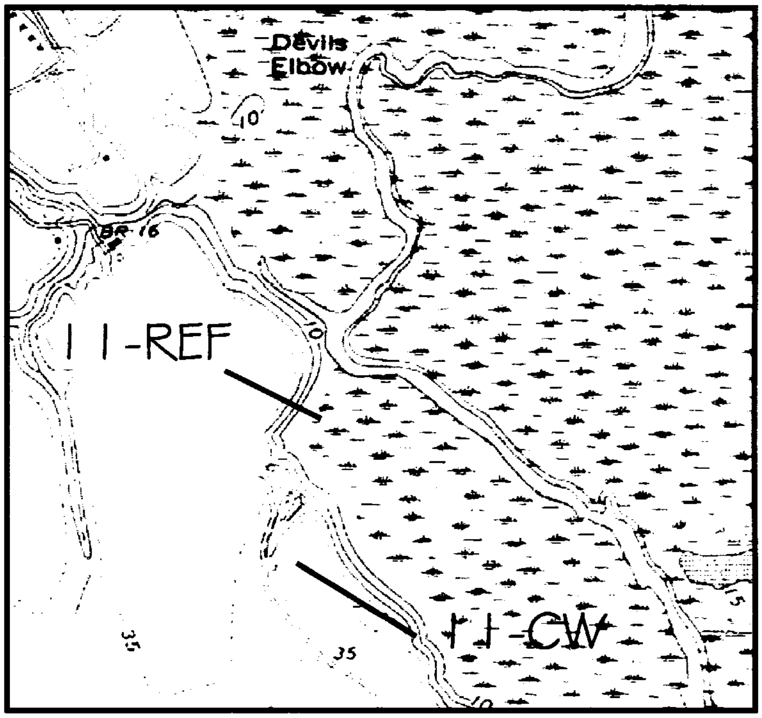

Figure 3-6. Courtland Bypass (11-Court) location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Courtland Bypass mitigation site is located southwest of the Town of Courtland in Southampton County, Virginia (Figure 3-6). The site is adjacent to the Nottoway River floodplain, and is accessed from U.S. Route 58 Bypass (not shown) along its southern perimeter. This setting is in the Coastal Plain physiographic province of Virginia, with gentle topography and a prevalence of sandy soils along the perimeter of broad bottomland hardwood systems underlain by silty clay loam substrates with a high accumulation of organics. The surrounding landscape is mostly agricultural, but a significant portion of the landscape is forested. Site hydrology is derived from groundwater discharge and surface capture. The reference wetland lies along the perimeter of the Nottoway River floodplain just northwest of the mitigation site. The forest stand is approximately 65 years in age and comprised of deciduous hardwoods with some bald cypress (*Taxodium distichum*) in the canopy.

10B – Proctor's Creek

Year Built: 1994

Age when sampled:

10 years

Size: 4.1 ha

County: Chesterfield, VA

Quad: Drewrys Bluff, VA

Reference site age:

43 years

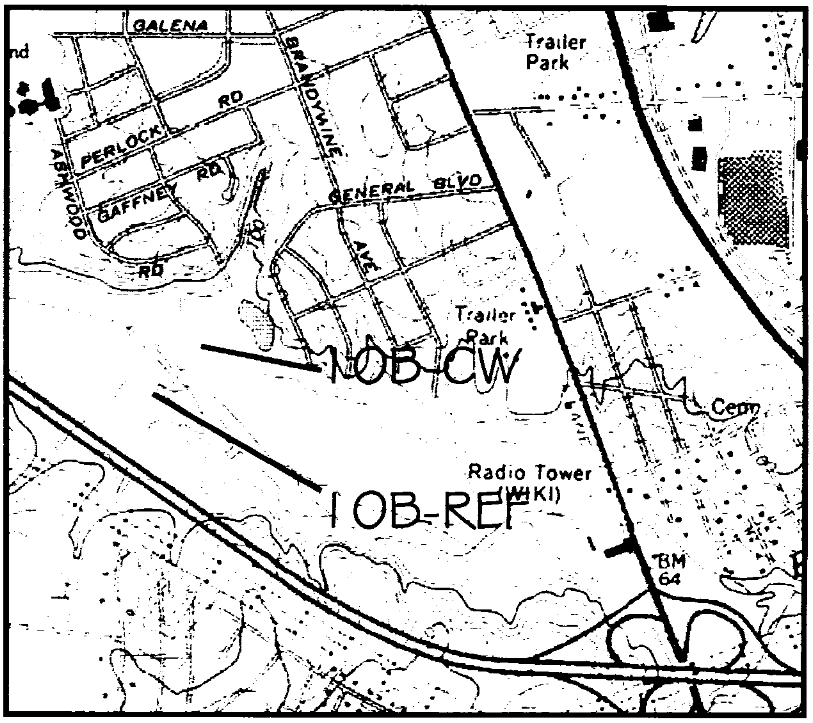

Figure 3-7. Proctor's Creek (10B-Prct) location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Proctor's Creek mitigation site is located north of State Route 288 and west of U.S. Route 1 near the Town of Chester, Virginia (Figure 3-7). The site lies within the floodplain of Proctor's Creek, and is accessed via neighborhood roads to the north. This location, along the eastern rim of the Piedmont physiographic province, is accompanied by coarse-textured alluvial sediments along watercourses, often with a significant accumulation of fine textured soils (silts and clays) along the outer margins of floodplains. The surrounding landscape is mostly medium-density residential, with urbanizing commercial and industrial development along U.S. Route 1 to the east. Source hydrology is presumably derived from groundwater discharge along the toe-of-slope of the adjacent floodplain escarpment, but it is assumed that flood stage in Proctor's Creek also contributes surface water. The reference wetland is located along both sides of Proctor's Creek immediate south of the mitigation site. The mixed deciduous-pine forested wetlands throughout this area are approximately 43 years old.

10A – Franklin Bypass

Year Built: 1994

Age when sampled:

10 years

Size: 11.6 ha

County: Southampton, VA

Quad: Franklin, VA

Reference site age:

87 years

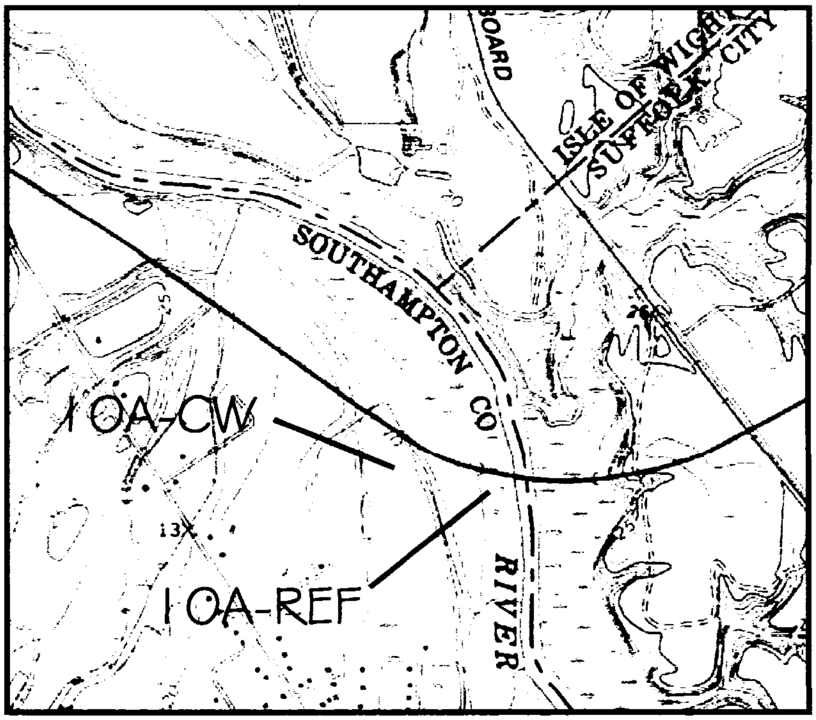

Figure 3-8. Franklin Bypass (10A-Fkln) location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Franklin Bypass mitigation site is located generally southeast of the Town of Franklin in Southampton County, Virginia (Figure 3-8). The site is adjacent to the Nottoway River floodplain, and is accessed from U.S. Route 58 Bypass (not shown) along its southern perimeter. This setting is similar to the Courtland Bypass site in the Coastal Plain physiographic province of Virginia. The surrounding landscape is mostly agricultural, but a significant portion of the landscape is forested. Site hydrology is derived from groundwater discharge and surface capture. The reference wetland lies along the perimeter of the Nottoway River floodplain just northwest of the mitigation site. The forest stand is approximately 87 years in age and comprised of deciduous hardwoods dominated by swamp black gum (*Nyssa biflora*).

7 – Charles City

Year Built: 1997

Age when sampled:

7 years

Size: 16.8 ha

County: Charles City, VA

Quad: Brandon, VA

Reference site age: 82 years

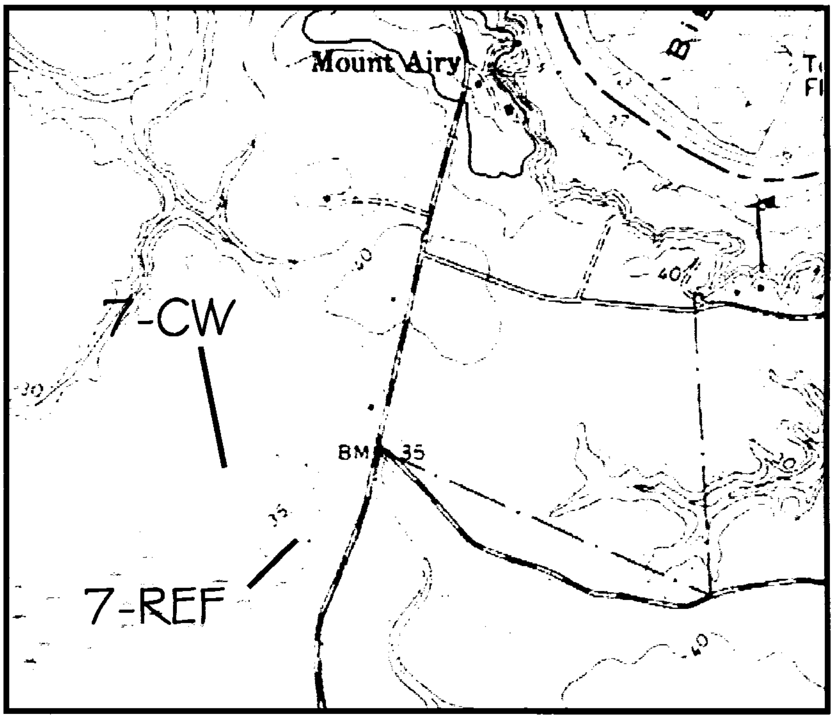

Figure 3-9: Charles City County (7-ChsCty) location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Charles City County mitigation site is found in the headwaters of Barrows Creek, generally east of Route 623 near the Mount Airy region of Charles City County, Virginia (Figure 3-9). Access is provided by an unimproved gravel driveway at the entrance to Claddagh Farm off of Route 623. This portion of the Virginia Coastal Plain is characterized by large regions of argillic (clayey) deposition. The surrounding landscape is mostly in agricultural production and/or timber management. Site hydrology is derived from surface capture. The reference wetland is immediately to the south in a forested hardwood stand that is approximately 82 years old.

6 – Stony Creek

Year Built: 1999

Age when sampled:

6 years

Size: 2.6 ha

County: Sussex, VA

Quad: Stony Creek, VA

Reference site age:

57 years

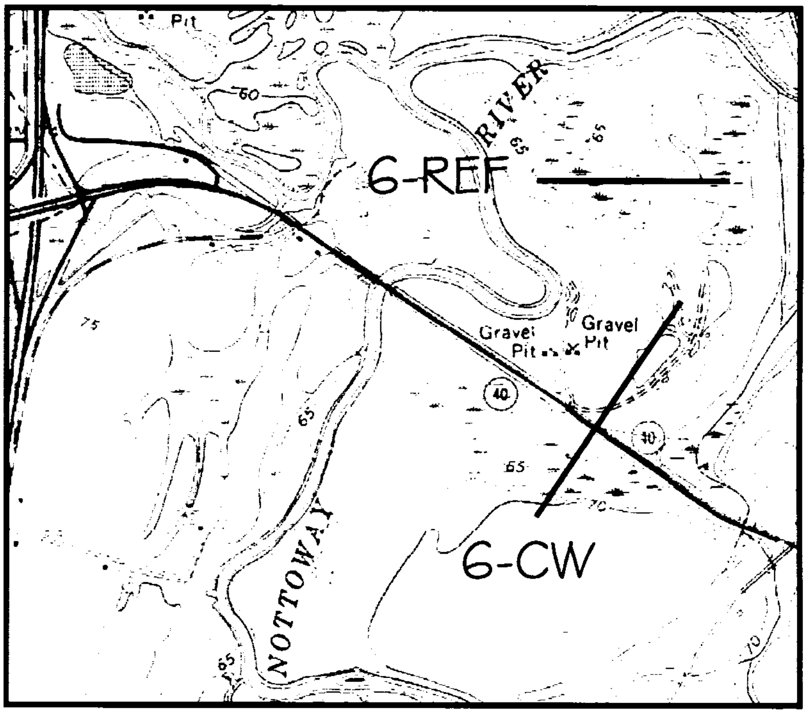

Figure 3-10. Stony Creek (6-Stony) location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Stony Creek mitigation site is located east of the Town of Stony Creek and north of State Route 40 in the floodplain of the Nottoway River (Figure 3-9). Access is provided by an unimproved gravel driveway off of Route 40. This setting is in the inner Coastal Plain physiographic province in Virginia, which is characterized by gentle topography and large regions of sandy deposition near watercourses. The surrounding landscape is mostly agricultural fields and forest. Site hydrology is derived from groundwater discharge, overbank flooding from the Nottoway River, and surface capture. The reference wetland is directly north of the mitigation site in a forested stand of hardwoods that is approximately 57 years old.

5 – Fort Lee

Year Built: 1999

Age when sampled:

5 years

Size: 9.7 ha

County: Prince George

Quad: Hopewell, VA

Reference site age:

56 years

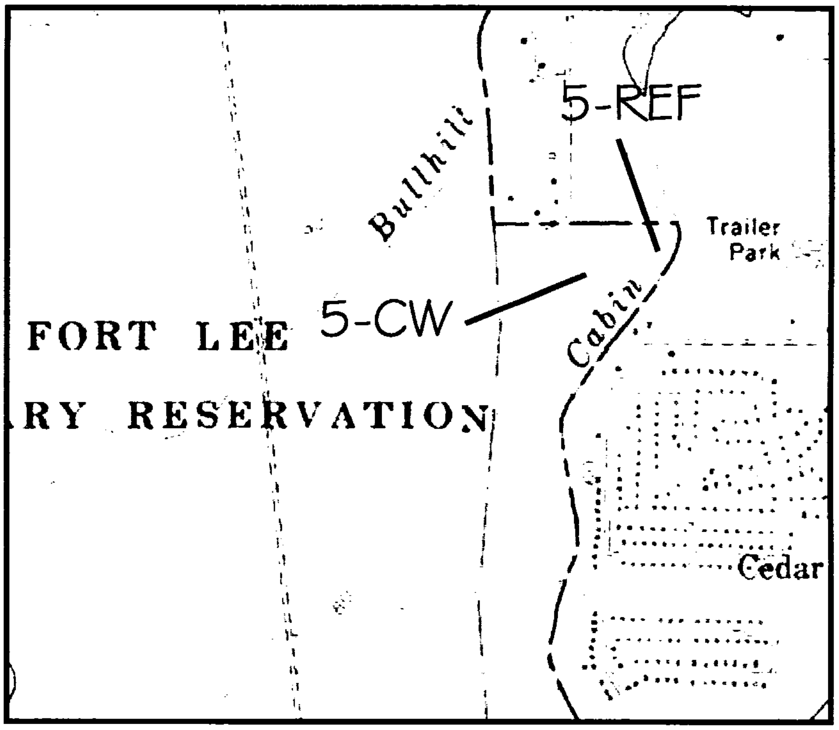

Figure 3-11. Fort Lee (5-FtLee) location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Fort Lee mitigation site is located generally east of Fort Lee Military Reservation, bounded on the west by Interstate 295 (not shown) and on the east by the Hopewell city line along Cabin Creek in Prince George County, Virginia (Figure 3-11). Access is provided by a VDOT pull-off on Interstate 295. This location is essentially along the innermost portion of the Coastal Plain physiographic province. The surrounding landscape is comprised of a mosaic of high-density residential and commercial development to the east and forested land to the west. Source hydrology is derived from groundwater discharge and surface capture from small tributaries in the Cabin Creek watershed. The reference wetland is located just off the northeast corner of the mitigation site, and is characterized by a mixed deciduous-pine cover with trees approximately 56 years old.

4B – Powhite Parkway

Year Built: 2000

Age when sampled:

4 years

Size: 9.1 ha

County: Chesterfield, VA

Quad: Bon Air, VA

Reference site age:

69 years

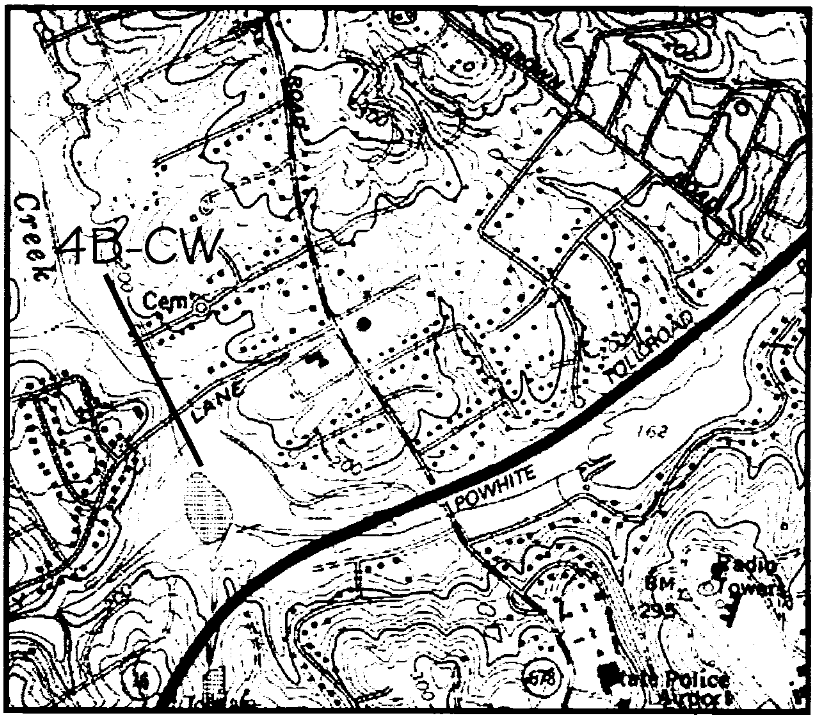

Figure 3-12. Powhite Parkway (4B-Pwhte) created site location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Powhite Parkway mitigation site is located southeast of Piney Lane and northwest of Powhite Parkway in the Powhite Creek floodplain in Chesterfield County, Virginia (Figure 3-12). The site is accessed via a small foot-path off of Piney Lane. This setting is along the eastern rim of the Piedmont physiographic province as described for the Proctor's Creek site above. The surrounding landscape is comprised of suburban residential development, with a large concentration of commercial development along Midlothian Turnpike to the south (not shown). Source hydrology is derived from Powhite Creek floodwater, groundwater discharge, and surface capture. The reference wetland is located in the Powhite Creek floodplain approximately 4.1 km downstream of the mitigation site (Figure 3-13). The reference site is within a City of Richmond park

(Powhite Park), with access via neighborhood roads to the southeast. The deciduous hardwood forest in this location is approximately 69 years old.

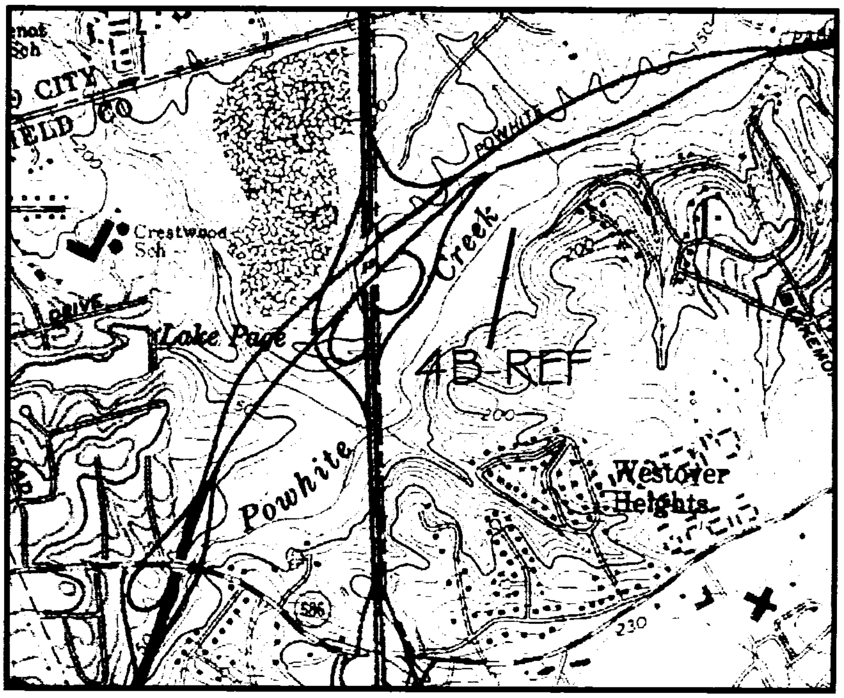

Figure 3-13. Powhite Parkway (4B-Pwhte) reference site location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

4A – Manassas

Year Built: 2000

Age when sampled:

4 years

Size: 10.8 ha

County: Prince William

Quad: Nokesville, VA

Reference site age:

79 years

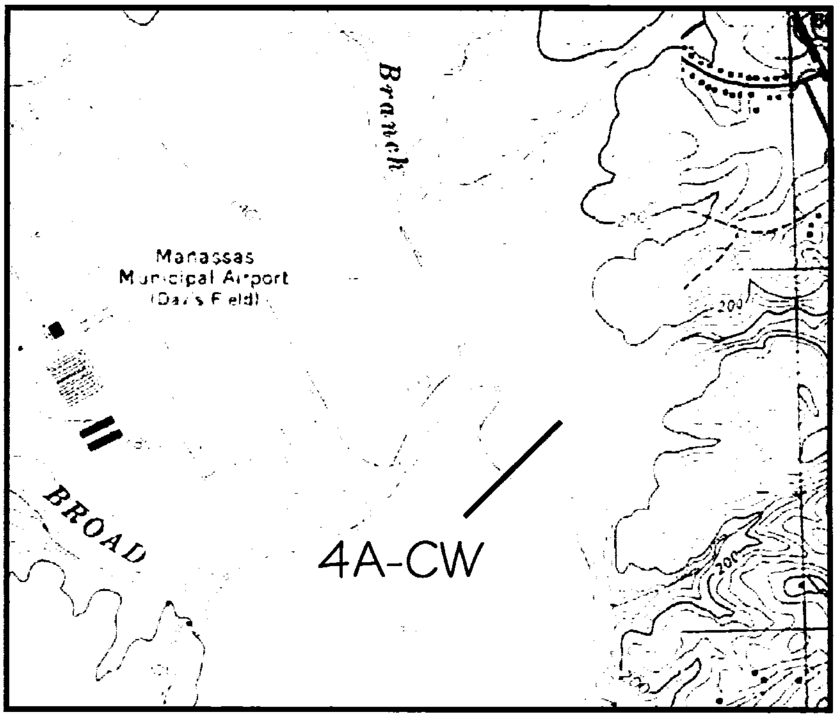

Figure 3-14. Manassas (4A-Manas) created site location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Manassas mitigation site is located east of Manassas Municipal Airport and southwest of Prince William Parkway (not shown) along the Broad Run floodplain in Prince William County, Virginia (Figure 3-14). Access is provided via a VDOT gravel driveway from Clover Hill Road (not shown), which intersects with Prince William Parkway to the north. This setting is within the northern Piedmont physiographic province of Virginia as described for Route 7 mitigation site above. The surrounding landscape is mostly forested and/or agricultural, but suburban residential development is encroaching to the north and west due to the completion of Prince William Parkway and other road systems. The hydrologic regime is contributed by surface drainage from unnamed tributaries in the Broad Run watershed. The reference wetland is located approximately 6.3 km northeast of the mitigation site in Bull Run

Regional Park, a public facility owned by Northern Virginia Regional Park Authority (Figure 3-15). The reference site is within the floodplain of Cub Run, a large tributary of Bull Run, and is accessed via private roads in the park campground to the west. The deciduous forest at this location is approximately 79 years old.

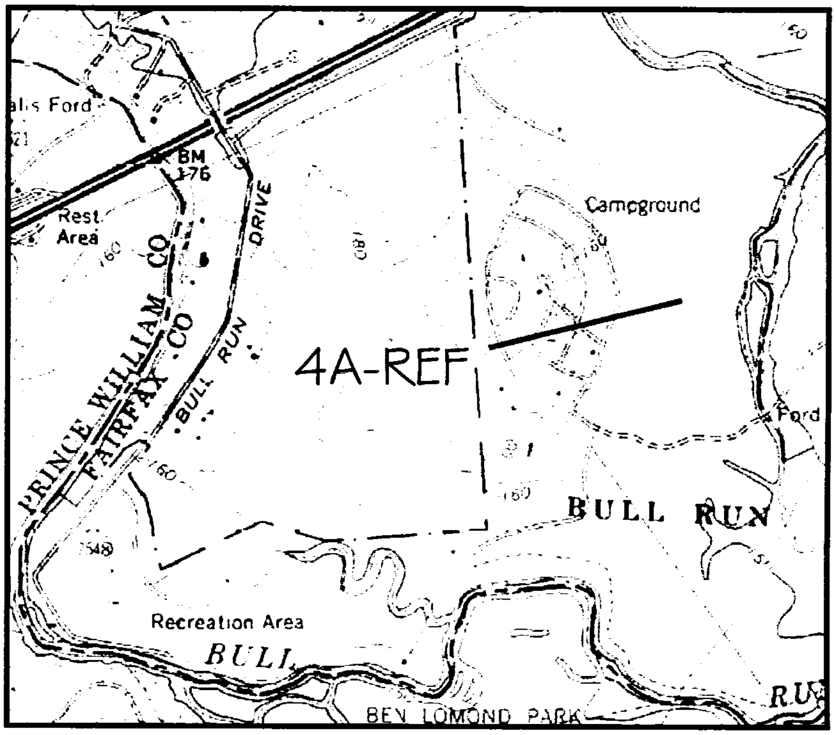

Figure 3-15. Manassas (4A-Manas) reference site location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

3 – Mount Stirling

Year Built: 2001

Age when sampled:

3 years

Size: 8.5 ha

County: Charles City

Quad: Providence

Forge, VA

Reference site age: 37

years

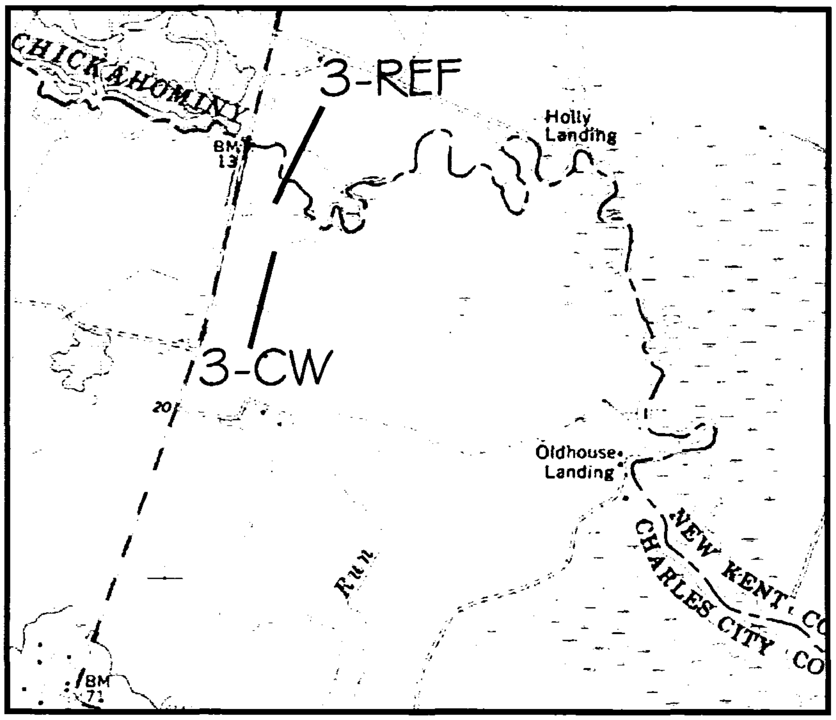

Figure 3-16. Mount Stirling (3-MtStir) location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Mount Stirling mitigation site is located in the Chickahominy River floodplain east of State Route 155 in Charles City County, Virginia (Figure 3-16). The site is access via a VDOT pull-off along Route 155. This setting is similar to the Charles City site described above, but the Chickahominy floodplain contains extensive regions of bottomland hardwood forest overlying silty clay loam soils with accumulated organics shallow in the profile. The surrounding landscape is predominantly forested, with some surface mining activity to the west and agricultural fields to the south. Site hydrology is derived from Chickahominy River floodwaters and surface capture from Collins Run to the west, as well as groundwater discharge from the toe of the primary Chickahominy scarp to the south. The reference wetland is in the forested section of the floodplain immediately to the north, with a deciduous hardwood canopy about 37 years old.

2 – Southwest Suffolk

Year Built: 2002

Age when sampled:

2 years

Size: 5.1 ha

City: Suffolk, VA

Quad: Suffolk, VA

Reference site age:

85 years

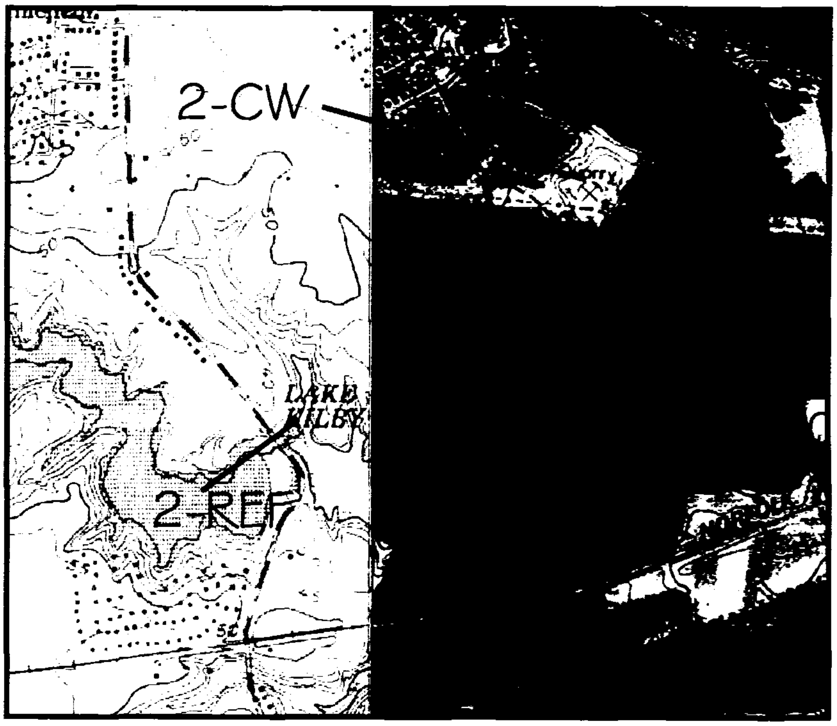

Figure 3-17. Southwest Suffolk (2-SWSfk) location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Southwest Suffolk mitigation site is in an abandoned surface mine located adjacent to Lake Kilby in the City of Suffolk, Virginia (Figure 3-17). Site access is provided from neighborhood roads to the north. This setting is in the southeastern Coastal Plain physiographic province as described in the Bowers Hill site description above. The surrounding landscape includes moderate-density residential communities, some agriculture, and forested land. The primary hydrologic regime is assumed to be surface capture of precipitation and groundwater discharge. The reference wetland is approximately 1.1 km southwest of the mitigation site in an approximately 85 year-old hardwood-cypress floodplain complex just east of Turlington Road in the backwater reaches of Lake Kilby.

1B – Mattaponi

Year Built: 2003

Age when sampled:

1 year

Size: 4.3 ha

County: Caroline, VA

Quad: Woodford, VA

Reference site age:

58 years

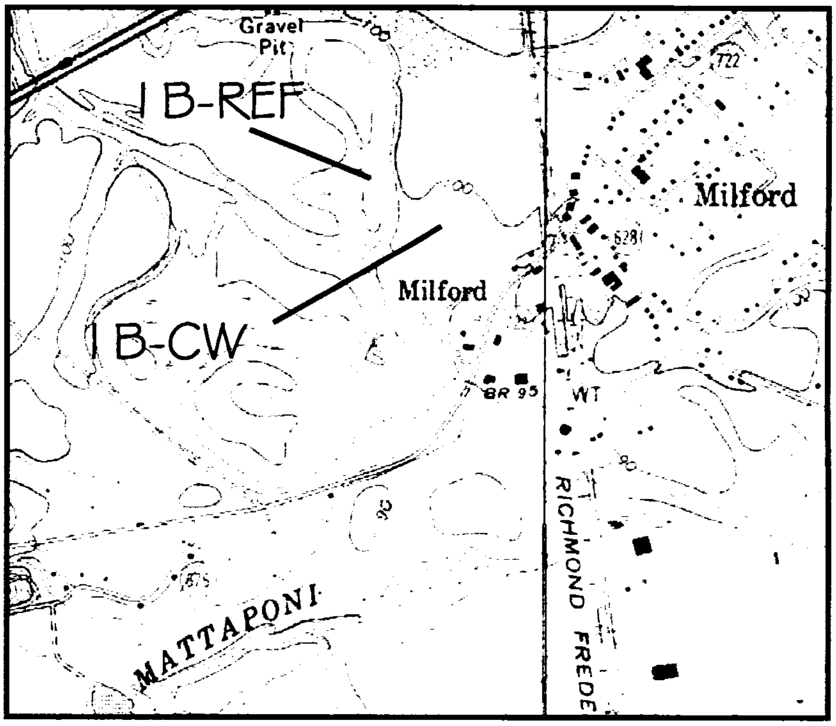

Figure 3-18. Mattaponi (1B-Matta) location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Mattaponi mitigation site is in the Mattaponi River floodplain just southwest of the Town of Milford in Caroline County, Virginia (Figure 3-18). Site access is provided via a VDOT entrance road from the east. This location is in the innermost portion of Coastal Plain. The surrounding landscape includes low-density residential, agriculture, and forested land. The primary hydrologic regime is groundwater discharge, with surface subsidies from Mattaponi River flood stage and direct precipitation capture. The reference wetland is immediately to the northwest in an oxbow of the Mattaponi River, with a hardwood canopy approximately 58 years of age.

1A – Reedy Creek

Year Built: 2003

Age when sampled:

1 year

Size: 7.2 ha

County: Chesterfield

Quad: Mannboro, VA

Reference site age:

71 years

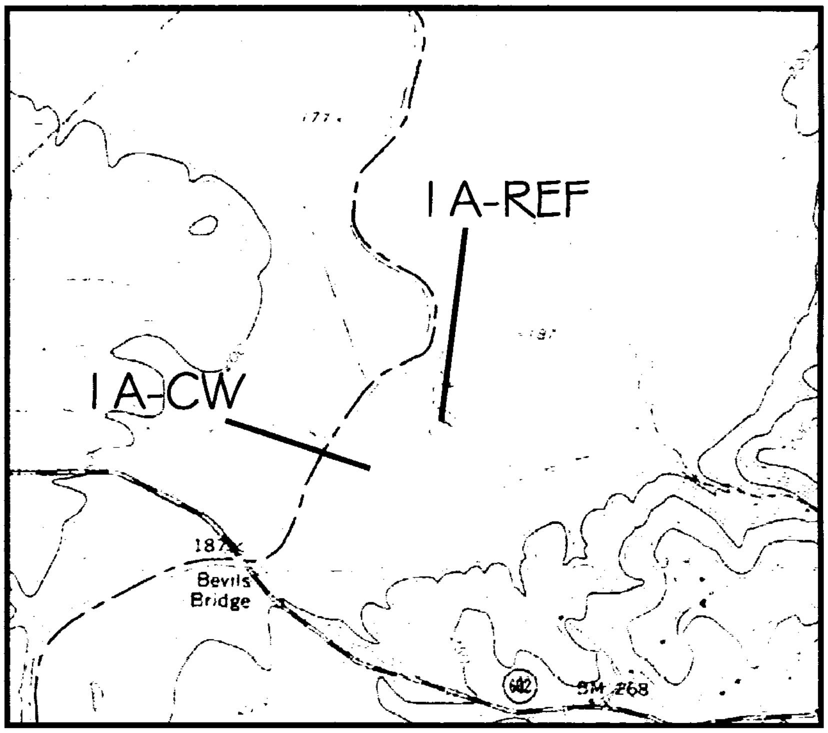

Figure 3-19. Reedy Creek (1A-Reedy) location map (source: Maptech Terrain Navigator, v. 5.0; not to scale).

Description – The Reedy Creek mitigation site is located northeast of the Route 602 bridge at Appomattox River (Bevils Bridge) in Chesterfield County, Virginia (Figure 3-19). Site access is provided from unimproved jeep trails that enter the property from River Road to the east. This setting is in the eastern portion of the Piedmont physiographic province as described for Powhite Creek above. The surrounding landscape is predominantly comprised of forested land, with some low-density residential homes along Route 602 to the east. Source hydrology is derived from surface drainage provided by unnamed tributaries in the Appomattox River watershed. The reference wetland is located in the Appomattox floodplain immediately northeast of the mitigation site, with a deciduous hardwood canopy that is approximately 71 years old.

3.2 VEGETATION SAMPLING

At each wetland site (CW and REF sites), we sampled vegetation within a pre-determined one-hectare segment during late summer site visits (August/September) in 2004 and 2005. The late summer time period represents peak growing season for created wetland sites within the region (DeBerry and Perry 2004). The one-hectare segments were demarcated in areas representing relatively homogeneous stand composition and age (Parsons and Ware 1982, Glascock and Ware 1979). In addition, we prepared a floristic survey of a randomly-chosen subset of sites (n = 5) in which a general site reconnaissance was conducted and a species list generated. The purpose for the floristic survey data set was to test FQI calculation using the "walk-through species list" methods prescribed by the authors of the index (Swink and Wilhelm 1994) against the plot-based methods used throughout the remainder of the study.

For vegetation measurements, we used a stratified-random sampling design (Mueller-Dombois and Ellenberg 1974). At each site, we established a baseline along the wetland perimeter and divided the baseline into segments of approximately 30 m in length each. We then set transects within each segment oriented perpendicular to the baseline and extending into the wetland (Tiner 1999). Each transect point-of-origin along the baseline was randomized by baseline segment using a random numbers table. We then established a single plot on each transect based on a similar random numbers draw, taking the transect length as the domain for the available random numbers set (see Figure 3-20).

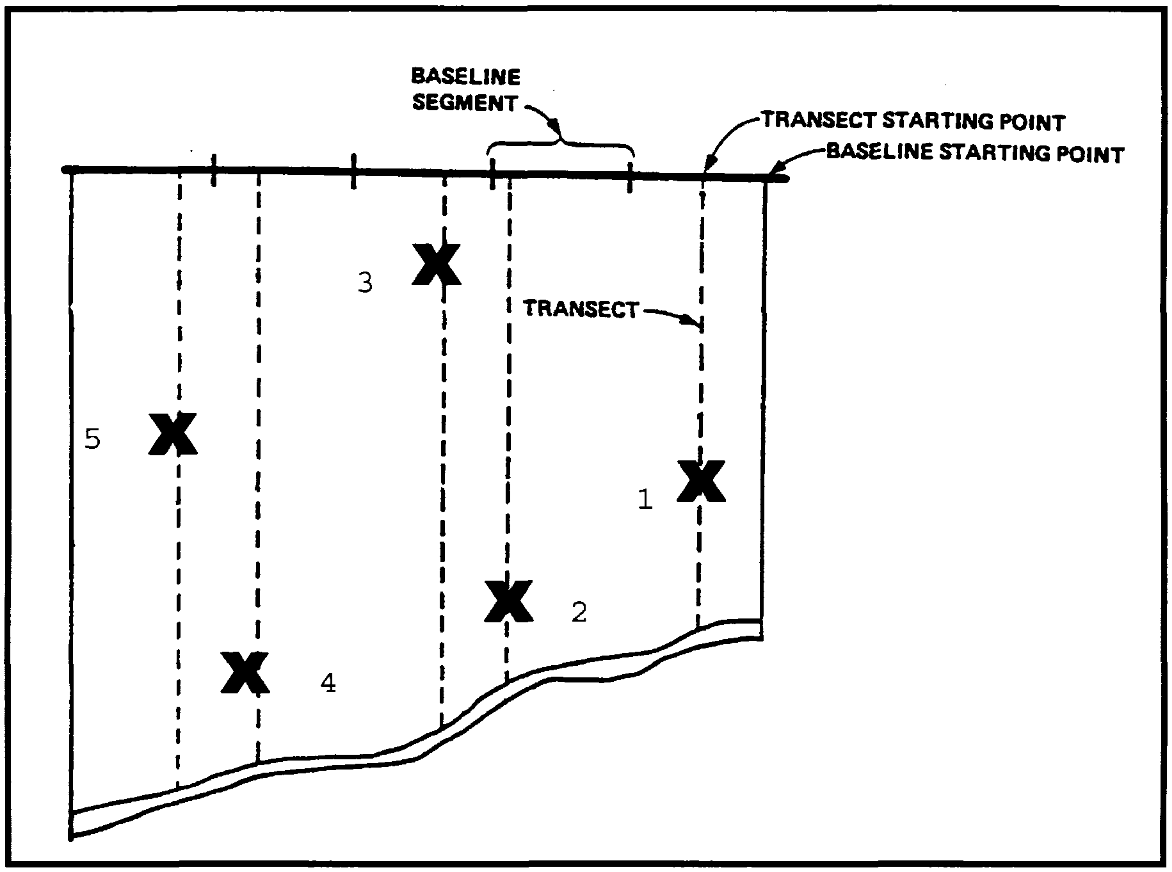

Figure 3-20. Stratified random sampling design (typical). In this sampling strategy, a baseline divided into equal segments is established along the edge of the wetland as shown. Random numbers determine the location of perpendicular transects (dashed lines) within each baseline segment, and the location of plots ("X") along each transect. Adapted from Environmental Laboratory (1987).

Trees, including woody species greater than 10 cm diameter at breast (dbh), were sampled from random 0.04-hectare plots (11.3 m radius; 5 plots per site) (Johnson 2000). Saplings, shrubs, and woody vines greater than 1 m in height but less than 10 cm dbh were sampled from a 5 m radius sub-plot centered on each 0.04-hectare plot (Spencer et al. 2001). Herbaceous vegetation (including woody plants less than 1 m in height) was sampled from three randomly placed 1 m^2 quadrats at each 0.04-hectare plot. The randomization procedure for each 1 m^2 quadrat included two random numbers draws – an azimuth (360 degrees) and a distance from the center point of the plot. All plants were identified to species level according to Fernald (1950), Radford et al. (1968), Wofford (1989), Gleason and Cronquist (1991), Weakley (2002), and the Flora of North America Association (2002), and following the nomenclature of the Flora of North America Association as cited in the USDA, NRCS (2005). Bayer codes taken from this reference were used to abbreviate species names in statistical treatments. Voucher specimens were deposited at the College of William and Mary herbarium (WILLI) and the Virginia Institute of Marine Science teaching herbarium. A checklist of voucher specimens is provided in Appendix B.

Within the 1 m^2 herbaceous quadrats, we recorded areal coverage estimates as a measure of relative dominance for each species using a modified cover class scale (Mueller-Dombois and Ellenberg 1974) and taking the midpoint of the cover class for data analysis. We also determined plant density by species as a direct count of individuals within 0.25 m^2 sub-quadrats randomly selected within a corner of each 1 m^2 quadrat. Plant frequency (presence/absence within quadrats) was determined from cover data. Relative dominance, density, and frequency were then calculated for each species, and the three values were averaged to develop relative Importance Values (IV) by species for each site (Perry and Atkinson 1997). Overall dominant species for each data set (CW and REF) were determined by applying the 50:20 rule to mean IV across all 15 sites. This rule states that dominant species are those that comprise the first 50% of the relative dominance measure when summed in descending order, and any other species that represent 20% of the total dominance measure (Tiner 1999).

Within 0.04-hectare plots, we measured dbh on all trees using a set of Halgof 95 cm tree calipers and/or a Forestry Suppliers 8 m dbh tape. We then calculated basal area (BA) by species (Johnson 2000) using PC-ORD (McCune and Mefford 1999). Density for saplings, shrubs, and woody vines was recorded by direct counts within the nested 5 m-radius sub-plots, and estimates of areal coverage were made using a cover class scale. We then calculated a relative IV for each woody species combining relative dominance (cover or BA) and density. Dominant species were calculated as noted above. [Note: For small sample sizes (i.e., less than fifteen plots per site), frequency (presence/absence) tends to artificially inflate the importance of rare species within the plots, and therefore was not used in calculating IV's for woody species (S. A. Ware pers. comm.).]

The sampling arrangement described above resulted in fifteen 1 m^2 quadrats in each created and reference wetland (450 total), five 5 m-radius shrub-sapling sub-plots in each created and reference wetland (150 total), and five 0.4-hectare tree plots in each reference wetland (75 total). To evaluate sample adequacy, we calculated a running mean on species per sample unit (e.g., plot, sub-plot, or quadrat) (Mueller-Dombois and Ellenberg 1974, Johnson 2000). In all cases, the mean stabilized after the first few sample units; therefore, the sampling effort was determined to be adequate for the objectives of the study.

Reference site age was approximated by dating increment cores taken from representative trees using a 36 cm Suunto increment borer with a 0.5 cm cutting radius, following the coring and dating methods specified in Forestry Suppliers (2004) and Husch et al. (1972). A tree was considered "representative" if it was within the dominant size class within a particular 0.04-hectare plot. Dominant size class was determined as the most prevalent 10 cm dbh class at each plot. The purpose for sampling trees from a dominant size class was to identify the oldest functional tree guild (Lopez et al. 2002, Keddy 2000) that best approximated time since the most recent large-scale disturbance within the history of the stand. In the case of most reference wetlands, this measurement approximated time since the last timber cutting activity at the site. The final site age was calculated as the mean of all cores taken at a given site (n = 5) (Husch et al. 1972).

3.3 SOIL SAMPLING

One soil sample was extracted from the center of each vegetation plot within each wetland using a coring sampler to a depth of 10 cm (Spencer et al. 2001, Sims 2000, Lawson et al. 1999), for a total of five samples from each site. Samples were analyzed by the labs at Virginia Tech Department of Crop and Soil Environmental Sciences for the following physiochemical properties: N, C, C:N ratio, pH, P, K, Ca, Mg, CEC, and particle size analysis (percent sand, silt, and clay) (Sims 2000, Campbell et al. 2002). Soil N and C values were determined via combustion using a macro-elemental analyzer, and particle size analyses were conducted using the pipette method (J. Burger pers comm.). Analysis of the remaining soil elements was completed with an inductively coupled plasma spectrometer (Donohue and Heckendorn 1996). We calculated the mean value of each physiochemical variable at each site for data analysis ($n = 5$).

3.4 INDEX CALCULATIONS

3.4.1 Floristic Quality Index (FQI)

For each site, a species list was generated from plot data, and species were assigned C-values based on Virginia Department of Environmental Quality (2004). FQI was then calculated at each site using the following formula:

$$\text{(3.1)} \quad FQI = C' (\sqrt{N})$$

where C' represents the average coefficient of conservatism for native species, and N is native species richness in the wetland (Swink and Wilhelm 1979, 1994). Equation 3.1 was used to produce an overall index for each site (FQI), as well as an index for each vegetation layer present within each site. For example, FQI_h represents the index calculated for just the herbaceous layer within a site as $FQI_h = C'_h (\sqrt{N_h})$, where C'_h is the average C-value for the herbaceous layer species and N_h is the native herbaceous species richness. A similar equation was generated for the shrub-sapling layer (FQI_s) and the tree layer (FQI_t).

In addition, we calculated a modified version of the index based on all species sampled at a site as:

$$(3.2) \quad FQI_{all} = C'_{all} (\sqrt{S})$$

where C'_{all} is the average coefficient of conservatism for all species at a site and S is the total species richness (including non-native species). Layer-specific versions of Equation 3.2 were also calculated for each site as noted above.

The layer-specific variations of Equations 3.1 and 3.2 were then used to create abundance-weighted versions of the index as follows:

$$(3.3) \quad FQI_{mod} = [\Sigma\ C_i (IV_i/100)]\ (\sqrt{N})$$

where C_i is the C-value for the i^{th} species ($i = 1,\ldots,n$) and IV_i is the importance value for the i^{th} species. Using this calculation, the individual C-value for a species was weighted by the relative abundance of that species at a given site, and the new weighted C-values were then summed across all species present within a given vegetation layer at a given site. This produced an abundance-weighted average of C-values, which was then multiplied by the square root of the number of native species present in the layer. Equation 3.3 was used to calculate a modified index for each individual layer at each site using both the "natives only" version of the index and the "all species" version (including non-native species).

3.4.2 Intrinsic Floristic Quality Parameters (IFQP)

We calculated four additional community indices from the plot-based data, as follows:

1. *Species Richness* – the total number of species (S) present at a given site (Magurran 1988). S was defined across all layers, representing the total species richness at a given site. For layer-specific analyses, richness was calculated as the total number of species present within a given layer at a given site, yielding S_h for the herbaceous layer, S_s for the shrub-sapling layer, and S_t for the tree layer.

2. *Shannon's Diversity Index* – a measure of species diversity (H′) based on the proportion of an entire sample represented by each species. Shannon's Diversity Index is given by:

   $$(3.4) \quad H' = -\Sigma\, p_i \ln p_i$$

   where p_i is the proportion of individuals from the overall population found in the i^{th} species (i = 1,...,s) (Pielou 1975). This index, derived from information theory, varies with species richness, as well as the relative evenness of the species present. For a given sample, H′ is maximized when all species present are equally abundant within the sample (H'_{max}).

Because the index is dependent on abundance data, H′ was calculated for individual layers within a given site.

3. *Shannon's Evenness Index* – a measure of the "equitability" (E) of species present within a given sample. Shannon's Evenness Index is given by:

$$E = H' / \ln S \tag{3.5}$$

where lnS is the natural logarithm of S, which corresponds to H'_{max} (Magurran 1988). This measure of evenness ranges from 0 to 1, where E = 1 represents a sample in which all species are equally abundant (Krebs 1999). Like diversity, evenness is dependent on abundance data and was therefore calculated as a layer-specific index.

4. *Percent Native Species* – the proportion species richness (S) represented by native species (N). Percent native species is given by:

$$\%N = N / S \tag{3.6}$$

As with species richness, an overall %N was calculated across layers, and a layer-specific %N was calculated for each vegetative layer.

3.5 STATISTICAL ANALYSES

We evaluated data sets using Cochran's test for homogeneity of variance (Fried 1976, Cochran 1941) and found that the homoscedasticity assumption of parametric statistical tests was violated in most cases. Further, because of the type of community data collected, the probability distribution of species at each site is attended by a large number of zeros (i.e., plots in which species are not represented), which produces a positively skewed distribution and violates the assumption of normality (McCune and Grace 2002, Lopez and Fennessey 2002, Taft et al. 1997). Therefore, non-parametric methods were used to test for significant statistical relationships at the 95% confidence limit ($\alpha = 0.05$).

Since FQI is typically calculated from a species list (not plot-based data), we used the Mann-Whitney U statistic (Sheskin 1999) to test a subset of CW sites (n=5) using the "classic" FQI calculation (i.e., from a species list generated by a "walk-through" on the sites) against the same index derived from plot-based data. The Mann-Whitney U statistic, which is the non-parametric analog to the Student's t-test, is used to evaluate statistically significant differences between population medians.

From the calculation of the various community indices and environmental data described above, we generated two data matrices – one for the CW site pool and one for the REF site pool – including all relevant parameters (site age, FQIs, IFQPs, and soil physiochemical parameters). A Spearman's rank-order correlation coefficient matrix was then calculated for both data sets (CW and REF) to test for significant correlations among the site variables (Sheskin 1999). Spearman's coefficient measures the degree of monotonicity between variables, and therefore is an appropriate non-parametric test for this purpose. The original data matrices were composed of *n* sites by *p* variables, and the correlation matrix presented a p x p arrangement of correlation coefficients, with an accompanying matrix of p-values. Both the Mann-Whitney U and Spearman correlation statistics were computed using MatLab Version 7.1 (MathWorks 2005).

Finally, we used the Canonical Correspondence Analysis (CCA) community ordination procedure to evaluate FQI correlation with the arrangement of sites ordinated in species space (i.e., ordination axes) (ter Braak 1986). We used the CCA algorithm included in PC-ORD (McCune and Mefford 1999), which tests significance of eigenvalue computations using Monte Carlo permutations (n=500) of the existing data set. The null hypothesis of this test is that there is no linear relationship between the two matrices, and the reported p-value represents the probability of type I error for the null hypothesis (α = 0.05) (McCune and Grace 2002). FQI was then plotted against CCA site scores [i.e., the LC or linear combination scores *sensu* McCune and Grace (2002)] to evaluate relationships between the two column vectors (Steele and Torrie 1980, Neter et al. 1990). This procedure was applied separately to all vegetation layers in the CW and REF sites, and to a composite data set combining CW and REF data in both the herbaceous and shrub-sapling layers.

The environmental matrix for the first run of each layer-specific ordination was constructed from site age and all 12 soil physiochemical variables (soil N, C, C:N, pH, P, K, Ca, Mg, CEC, %sand, %silt, and %clay). The biplot overlay on each ordination graph shows the strongest environmental variables explaining the variance in the community matrix. If the eigenvalues in the first ordination run were statistically non-significant ($p>0.05$), the environmental matrix was reduced by one parameter and the ordination was repeated. The decision of which parameter to remove was based on inspection of the biplot overlay. This environmental matrix reduction procedure was repeated until statistically significant eigenvalue computations were achieved for at least one of the first two ordination axes (McCune and Grace 2002).

In analyzing FQI correspondence with CCA output, we used the layer-based modified indices ($FQI_{h\text{-}mod}$, $FQI_{s\text{-}mod}$, and $FQI_{t\text{-}mod}$) because, like CCA, these versions of the index incorporate species abundance data. Although relationships from the non-weighted indices (FQI_h, FQI_s, and FQI_t) could have been derived, such analyses are not advisable because the structure of the two column vectors (CCA site scores and FQI) would be composed of fundamentally different community parameters. In other words, because CCA ordinates sites relative to species abundance data (as constrained by environmental parameters), the non-weighted FQI, which uses only native species richness, reflects a fundamentally different property of the community relative to the CCA ordination (species abundance). Thus, any correlation observed between non-weighted FQI values and CCA site scores would be by chance alone and interpretation of such results would be limited.

4.0 RESULTS

4.1 FLORISTICS

4.1.1 Created Wetlands

We sampled 152 species from the herbaceous layer and 27 species from the shrub-sapling layer across the 15 CW sites (Appendix C). There were nine overall dominants in the herbaceous layer, as follows (overall relative IV in parentheses): *Juncus effusus* (10.4), *Scirpus cyperinus* (7.6), *Ludwigia palustris* (6.4), *Eleocharis obtusa* (5.3), *Polygonum hydropiperoides* (4.9), *Murdannia keisak* (4.1), *Microstegium vimineum* (4.0), *Galium tinctorium* (3.8), and *Panicum dichotomiflorum* (3.6). In addition, there were four overall dominant species in the shrub-sapling layer: *Salix nigra* (23.2), *Acer rubrum* (13.2), *Liquidambar styraciflua* (13.0), and *Betula nigra* (10.4). C-values for all species sampled on the CW sites are provided in Appendix C.

We checked state distributions (Virginia Botanical Associates 2005) against our species lists and found 10 county records from the CW samples, including two Virginia state records, *Cuphea carthagenensis* and *Ludwigia bonariensis* (both from the Southwest Suffolk site, 2-SWSfk) (Appendix B). In addition, we found a new population of *Aeschynomene indica* in Southampton County (Franklin Bypass, 10A-Fkln), previously reported as a state record in 1998 on a nearby site (Perry et al. 1998). This new location is significant because the previous site, a portion of the Franklin Bypass mitigation area north of U.S. Route 58, has recently been impacted by beaver activity, and therefore the population reported in 1998 has most likely been extirpated due to excessive flooding (J. E. Perry pers. comm.).

4.1.2 Reference Wetlands

We sampled 150 herbaceous species, 58 species from the shrub-sapling layer, and 34 tree species across the 15 REF sites (Appendix C). We calculated 13 dominant species in the REF herbaceous layer: *Saururus cernuus* (7.7), *Murdannia keisak* (6.5), *Woodwardia areolata* (6.2), *Cinna arundinacea* (4.1), *Carex projecta* (3.7), *Arundinaria gigantea* (3.6), *Smilax rotundifolia* (3.6), *Boehmeria cylindrica* (3.3), *Leersia virginica* (2.8), *Impatiens capensis* (2.8), *Lysimachia nummularia* (2.7), *Microstegium vimineum* (2.4), and *Pilea pumila* (2.3). There were five overall dominants in the REF shrub-sapling layer: *Acer rubrum* (21.0), *Smilax rotundifolia* (12.0), *Fraxinus pennsylvanica* (8.1), *Arundinaria gigantea* (7.4), and *Lindera benzoin* (5.8). Finally, we calculated four overall dominants in the REF tree layer, including *Acer rubrum* (27.3), *Liquidambar styraciflua* (12.9), *Nyssa biflora* (9.7), and *Quercus phellos* (7.9). C-values for REF species are given in Appendix C. There were six county records in the REF species lists (Virginia Botanical Associates 2005) (Appendix B).

4.2 FQI CALCULATION FROM PLOT-BASED DATA

Results from the Mann-Whitney U test of FQI values derived from a subset of CW sites (n=5) and REF sites (n=5) using the "classic" FQI calculation (i.e., from a species list generated by a "walk-through" on the sites) against the same index derived from plot-based data showed no significant statistical difference between indices (CW p=0.69; REF p=0.84). Therefore, at least for this comparison, calculation of FQI using plot-based data did not compromise the precision of the index (Table 4-1).

Table 4-1. FQI values calculated from a subset of 5 sites in the CW and REF wetlands using the "classic" FQI species list method (e.g., a species list generated by a walk-through reconnaissance of the site) vs. a plot-based species list. S = species richness.

CW Sites

p = 0.69	"Walk-through" Data		Plot Data	
Sites	FQI	S	FQI	S
Sleeter Lake	23.2	52	22.5	42
Proctor's Creek	16.5	26	18.1	24
Fort Lee	18.8	29	20.9	34
Mattaponi	19.2	22	12.1	21
Reedy Creek	18.0	24	24.6	53

REF Sites

p = 0.84	"Walk-through" Data		Plot Data	
Sites	FQI	S	FQI	S
Sleeter Lake	26.6	37	31.0	43
Proctor's Creek	30.2	44	28.4	39
Fort Lee	26.3	32	31.6	50
Mattaponi	30.3	35	25.5	27
Reedy Creek	29.4	44	29.1	38

4.3 DATA MATRICES

The data matrices, including all calculated indices and environmental parameters for the CW and REF data sets, are presented in Appendix D. Note that CW shrub-sapling values for Mattaponi (1A-Matta) are not included because this site had not been planted at the time the site was sampled; therefore, no woody species meeting the shrub-sapling size threshold (greater than 1 m in height) were present in sample plots.

4.4 SPEARMAN'S RANK-ORDER CORRELATION COEFFICIENT MATRICES

Results of the Spearman's rank-order correlation analyses are presented in Appendix E. Two pairs of matrices were calculated, the first providing correlation coefficients (rho), and the second p-values. For brevity, the matrices do not show correlations among soil physiochemical variables. This is consistent with study objectives, since the relationships between soil variables and other site parameters (site age and vegetation indices) were of more interest than the correlations among soil variables *per se*. Results of the correlation analyses are discussed in the following subsections.

4.4.1 FQI from Native Species Richness (N) vs. Species Richness (S)

Based on the correlation matrices, FQI_{all}, which is calculated from species richness (S), did not increase the number of statistically significant correlations with site

IFQPs as compared with the "classic" version of the index, FQI, which is calculated from native species richness (N). In most cases, the $\mathrm{FQI}_{\mathrm{all}}$ correlation coefficients decreased when compared with FQI (Table 4-2). Recall that the C-value for non-native species is "0"; thus, the "zeros-in" method used to calculate $\mathrm{FQI}_{\mathrm{all}}$ did not improve index performance as interpreted from statistically significant correlations with IFQPs. For this reason, the "natives-only" or "zeros-out" versions of the index (FQI and variants) were retained for the remainder of the analyses discussed in subsequent sections.

Table 4-2. Comparison of Spearman coefficients between FQI and $\mathrm{FQI}_{\mathrm{all}}$ for both data sets (CW and REF). Notice that the "all species" versions of the index did not improve correlations with IFQPs (species richness, diversity, evenness, and % native species). Statistically significant correlations are shown in red. The indices for the REF tree layer are not shown because all trees sampled are native species; thus, N = S for the tree layer and $\mathrm{FQI}_{\mathrm{t}} = \mathrm{FQI}_{\mathrm{t(all)}}$.

	CW						**REF**					
	FQI	**$\mathrm{FQI}_{\mathrm{all}}$**	**$\mathrm{FQI}_{\mathrm{h}}$**	**$\mathrm{FQI}_{\mathrm{h(all)}}$**	**$\mathrm{FQI}_{\mathrm{s}}$**	**$\mathrm{FQI}_{\mathrm{s(all)}}$**	**FQI**	**$\mathrm{FQI}_{\mathrm{all}}$**	**$\mathrm{FQI}_{\mathrm{h}}$**	**$\mathrm{FQI}_{\mathrm{h(all)}}$**	**$\mathrm{FQI}_{\mathrm{s}}$**	**$\mathrm{FQI}_{\mathrm{s(all)}}$**
S	**0.913**	**0.852**	-	-	-	-	**0.882**	**0.830**	-	-	-	-
%N	0.237	0.376	-	-	-	-	-0.209	-0.116	-	-	-	-
S_{h}	-	-	**0.870**	**0.815**	-	-	-	-	**0.940**	**0.897**	-	-
$\mathrm{H'}_{\mathrm{h}}$	-	-	**0.765**	**0.754**	-	-	-	-	**0.857**	**0.829**	-	-
E_{h}	-	-	0.404	0.421	-	-	-	-	0.432	0.404	-	-
$\%\mathrm{N}_{\mathrm{h}}$	-	-	0.233	0.341	-	-	-	-	-0.209	-0.007	-	-
S_{s}	-	-	-	-	**0.878**	**0.878**	-	-	-	-	**0.922**	**0.915**
$\mathrm{H'}_{\mathrm{s}}$	-	-	-	-	**0.824**	**0.820**	-	-	-	-	**0.808**	**0.769**
E_{s}	-	-	-	-	0.331	0.327	-	-	-	-	0.046	-0.011
$\%\mathrm{N}_{\mathrm{s}}$	-	-	-	-	**0.663**	**0.699**	-	-	-	-	-0.331	-0.214

4.4.2 Overall FQI Correlations

The overall FQI (i.e., the index calculated from all native species onsite irrespective of vegetative layer) for both CW and REF sites showed a statistically significant positive correlation with species richness (S) ($p<0.001$). FQI in the CW data set was also significantly and negatively correlated with soil phosphorus ($p<0.001$). However, neither index (CW or REF) was correlated with site age, % native species, or soil physiochemical variables (with the exception of the FQI-phosphorus relationship mentioned above) (Table 4-3).

Table 4-3. Spearman correlation coefficients for the overall FQIs from both the CW and REF data sets. Statistically significant correlations are shown in red.

	CW FQI	**REF FQI**
Age	0.337	0.132
S	**0.913**	**0.882**
%N	0.237	-0.209
N	0.220	-0.129
C	0.282	-0.093
C:N	0.161	0.007
pH	0.196	0.425
P	**-0.757**	-0.194
K	0.289	-0.061
Ca	0.036	0.057
Mg	-0.100	0.061
CEC	-0.150	-0.086
%Sand	-0.336	0.136
%Silt	0.432	0.029
%Clay	0.079	-0.054

4.4.3 FQI by Vegetation Layer

As noted in the correlation matrices (Appendix E), the layer-based FQIs showed statistically significant positive correlations with species richness and diversity ($p<0.05$), excluding the REF values $FQI_{h\text{-mod}}$, FQI_t, and $FQI_{t\text{-mod}}$. Over both data sets (CW and REF), only $FQI_{t\text{-mod}}$ (the modified tree layer index) was significantly correlated with site age ($p=0.005$). Finally, FQI correlations with soil physiochemical properties were inconsistent; however, soil phosphorus was negatively correlated with FQI in the CW herbaceous data ($p<0.01$), and soil carbon and nitrogen values were positively correlated with FQI in the REF shrub-sapling data set ($p<0.05$). A summary of layer-based correlation coefficients is provided in Table 4-4.

An important observation from Table 4-4 is that, in most cases, the modified index did not degrade the correlation with site variables (i.e., it "performed" as well as the overall FQI). This relationship held for all layers analyzed except the REF herbaceous layer (REF $FQI_{h\text{-mod}}$), although Spearman's rho was still fairly high (0.493; $p=0.062$). Perhaps more importantly, **the modified index (i.e., the abundance-weighted index) actually *improved* FQI correlation with IFQPs in the case of CW herbaceous data** (i.e., the CW $FQI_{h\text{-mod}}$ was significantly and positively correlated with richness, diversity, *and* evenness). In this respect, the modified index appeared to perform *better* than the traditional index when calculated over the CW herbaceous data set, in that the modified index was able to predict more intrinsic floristic quality parameters (IFQP).

Table 4-4. Spearman correlation coefficients for layer-based FQI calculations from both the CW and REF data sets. Statistically significant correlations are shown in red.

	CW				**REF**					
	FQI_h	**$FQI_{h\text{-}mod}$**	**FQI_s**	**$FQI_{s\text{-}mod}$**	**FQI_h**	**$FQI_{h\text{-}mod}$**	**FQI_s**	**$FQI_{s\text{-}mod}$**	**FQI_t**	**$FQI_{t\text{-}mod}$**
S_h	**0.870**	**0.567**	-	-	**0.940**	**0.559**	-	-	-	-
H'_h	**0.765**	**0.779**	-	-	**0.857**	0.493	-	-	-	-
E_h	0.404	**0.704**	-	-	0.432	0.164	-	-	-	-
$\%N_h$	0.233	0.437	-	-	-0.209	-0.002	-	-	-	-
S_s	-	-	**0.878**	**0.611**	-	-	**0.922**	**0.803**	-	-
H'_s	-	-	**0.824**	**0.679**	-	-	**0.808**	**0.643**	-	-
E_s	-	-	0.331	0.289	-	-	0.046	0.029	-	-
$\%N_s$	-	-	**0.663**	**0.698**	-	-	-0.331	-0.117	-	-
S_t	-	-	-	-	-	-	-	-	**0.827**	**0.545**
H'_t	-	-	-	-	-	-	-	-	0.478	0.447
E_t	-	-	-	-	-	-	-	-	0.077	0.250
N	0.320	0.046	-0.136	-0.236	-0.114	0.071	**0.574**	**0.571**	0.422	0.361
C	0.289	0.232	-0.091	-0.146	-0.061	0.250	**0.554**	**0.625**	0.298	0.236
C:N	0.043	0.475	0.052	0.021	-0.075	0.100	0.302	0.407	-0.013	-0.218
pH	0.318	-0.064	-0.397	-0.429	0.318	0.432	-0.032	0.096	0.164	-0.139
P	**-0.699**	**-0.667**	-0.409	-0.132	-0.172	-0.093	-0.328	-0.397	-0.204	-0.097
K	0.314	0.196	-0.143	-0.179	0.021	0.346	0.256	0.361	-0.046	0.018
Ca	0.129	-0.254	-0.399	-0.271	0.014	0.436	0.043	0.107	0.213	0.029
Mg	0.014	-0.325	**-0.518**	-0.432	0.079	0.471	0.025	0.004	0.132	0.143
CEC	-0.079	-0.379	-0.343	-0.236	-0.122	0.406	0.243	0.182	0.054	0.109
%Sand	-0.475	-0.132	0.334	0.271	-0.064	0.107	0.382	0.489	0.257	-0.300
%Silt	**0.543**	0.043	-0.316	-0.346	0.225	-0.082	-0.347	-0.432	-0.222	0.343
%Clay	0.196	0.254	-0.206	-0.082	0.046	0.146	0.080	0.004	-0.002	0.114
Age	0.308	0.246	0.165	0.109	0.054	0.454	0.504	0.382	0.438	**0.679**

4.4.4 Other Observations from the Correlations Matrices

Statistically significant relationships between soil physiochemical variables and other site parameters were found in the Spearman correlation coefficient matrices. From the CW data set, soil phosphorus was negatively correlated with overall species richness (S) ($p=0.011$), and soil calcium, magnesium, and CEC were negatively correlated with overall percent native species (%N) ($p<0.05$). Further, soil nitrogen, carbon, pH, and potassium were positively correlated with herbaceous species richness (S_h) ($p<0.05$), phosphorus was negatively correlated with herbaceous species diversity and evenness (H'_h and E_h) ($p<0.05$), and CEC was negatively correlated with herbaceous percent native species ($\%N_h$) ($p<0.01$). Finally, soil magnesium and CEC were negatively correlated with shrub-sapling species richness (S_s) ($p<0.05$), and percent sand (%sand) was positively correlated with S_s.

From the REF data set, soil nitrogen, carbon, and CEC were positively correlated with site age ($p<0.05$), carbon:nitrogen ratio (C:N) was positively correlated with overall percent native species (%N) ($p<0.05$), and phosphorus was negatively correlated with shrub-sapling percent native species ($\%N_s$) ($p<0.05$). Soil physiochemical correlations are summarized in Table 4-5.

Table 4-5. Spearman correlation coefficients for select soil physiochemical variables and site parameters from the CW and REF data sets. Statistically significant correlations are shown in red.

	CW							**REF**		
	S	**%N**	**S_h**	**H'_h**	**E_h**	**%N_h**	**S_s**	**Age**	**%N**	**%N_s**
N	0.365	-0.499	**0.536**	0.315	0.155	-0.497	-0.203	**0.521**	0.245	-0.110
C	0.403	-0.384	**0.558**	0.388	0.204	-0.373	-0.101	**0.554**	0.365	0.096
C:N	0.127	0.057	0.125	0.315	0.261	0.079	0.096	0.132	**0.525**	0.464
pH	0.442	-0.452	**0.590**	0.214	-0.229	-0.366	-0.361	-0.014	-0.357	-0.370
P	**-0.635**	-0.300	-0.444	**-0.620**	**-0.594**	-0.373	-0.383	0.047	-0.319	**-0.526**
K	0.453	-0.487	**0.567**	0.504	0.264	-0.434	-0.248	0.318	0.018	0.034
Ca	0.261	**-0.516**	0.441	0.107	-0.279	-0.441	-0.507	0.239	-0.282	-0.321
Mg	0.136	**-0.552**	0.306	-0.052	-0.432	-0.477	**-0.563**	0.296	-0.284	-0.259
CEC	-0.018	**-0.674**	0.188	-0.052	-0.257	**-0.663**	**-0.567**	**0.615**	0.084	-0.232
%Sand	-0.299	0.111	-0.420	-0.290	0.029	0.014	**0.549**	-0.150	0.327	0.353

4.5 CANONICAL CORRESPONDENCE ANALYSIS (CCA)

The following sections summarize the results of the community ordinations for each layer in the CW and REF data sets. Summary statistics, site scores, and Monte Carlo permutation results for each CCA run are reported in Appendix F.

4.5.1 CCA and CW Herbaceous Data

CCA results for the herbaceous data from the CW sites are summarized as follows. The first matrix (species IV) was ordinated with a second matrix composed of site age and 12 soil physiochemical parameters (soil N, C, C:N, pH, P, K, Ca, Mg, CEC, % sand, % silt, and % clay). The ordination output graphically represented some clear "clusters" of sites. As Figure 4-1 indicates, these clusters roughly corresponded to ranges of $FQI_{h\text{-mod}}$ values. In addition, when $FQI_{h\text{-mod}}$ scores were plotted against site scores in the ordination, a very clear polynomial relationship was observed in which the ordinated clusters were conserved (Figure 4-2).

CCA CW herbaceous

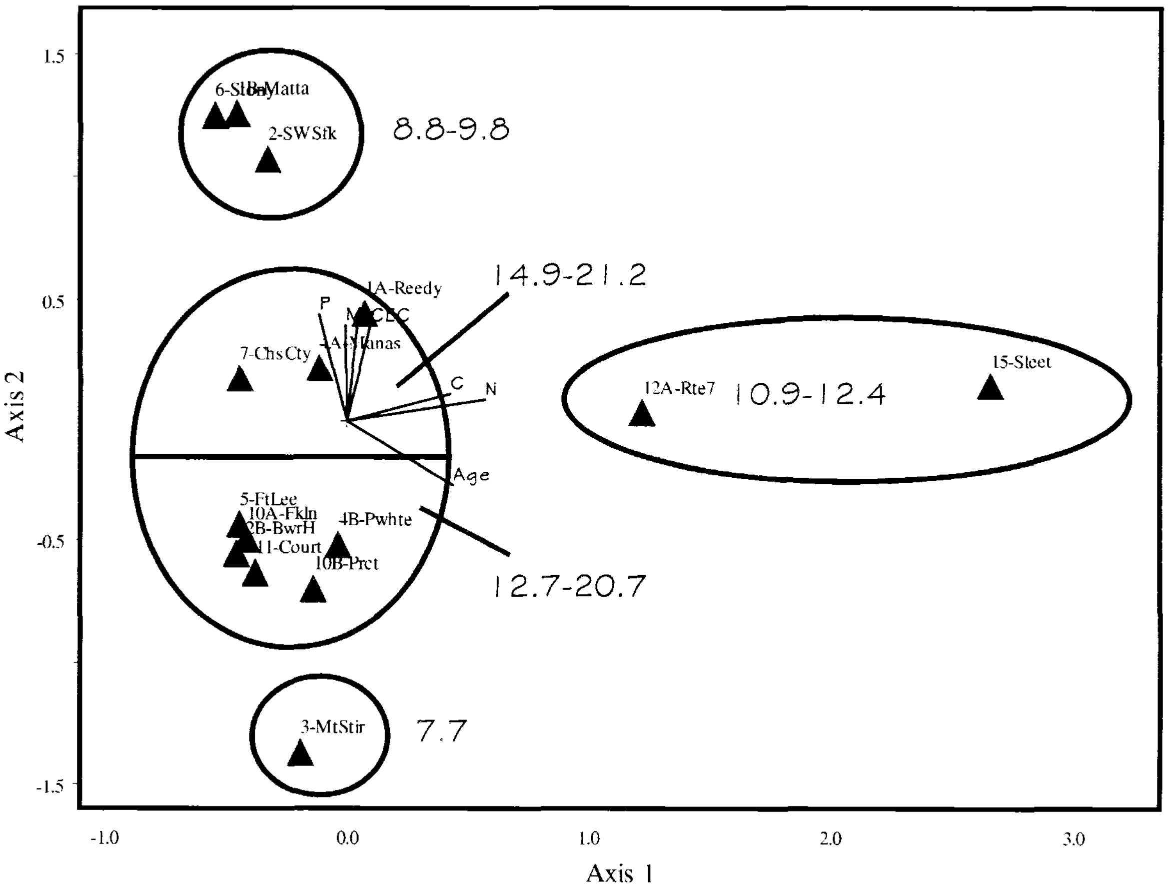

Figure 4-1. CCA ordination graph for CW herbaceous data. The arrangement of sites in species space, as constrained by environmental parameters, corresponds to ranges of $FQI_{h\text{-}mod}$ values superimposed on the graph. Biplots of environmental parameters show that soil P, Mg, K, and CEC best explain the scatter of sites along Axis 2.

Notice that the ranges of $FQI_{h\text{-}mod}$ scores provided within each of the apparent groupings are unique and non-overlapping (with the exception of the large group in the left-central region of the graph, which may be comprised of two subgroups representing the higher end of the $FQI_{h\text{-}mod}$ range) (Figure 4-1). Biplots of environmental variables indicate that soil P, Mg, K, and CEC best explain the arrangement of sites along Axis 2, the one axis with a statistically significant eigenvalue computation based on Monte Carlo simulations (i.e., the proportion of randomized runs with eigenvalues greater than those based on the observed values is <0.05) (Appendix F). Of note is the nearly inverse relationship between soil P and site age. Plotting $FQI_{h\text{-mod}}$ values against Axis 2 site scores, the observed groupings are conserved, and a polynomial least squares fit shows that the relationship is statistically significant ($r^2=0.50$, $p=0.015$) (Figure 4-2).

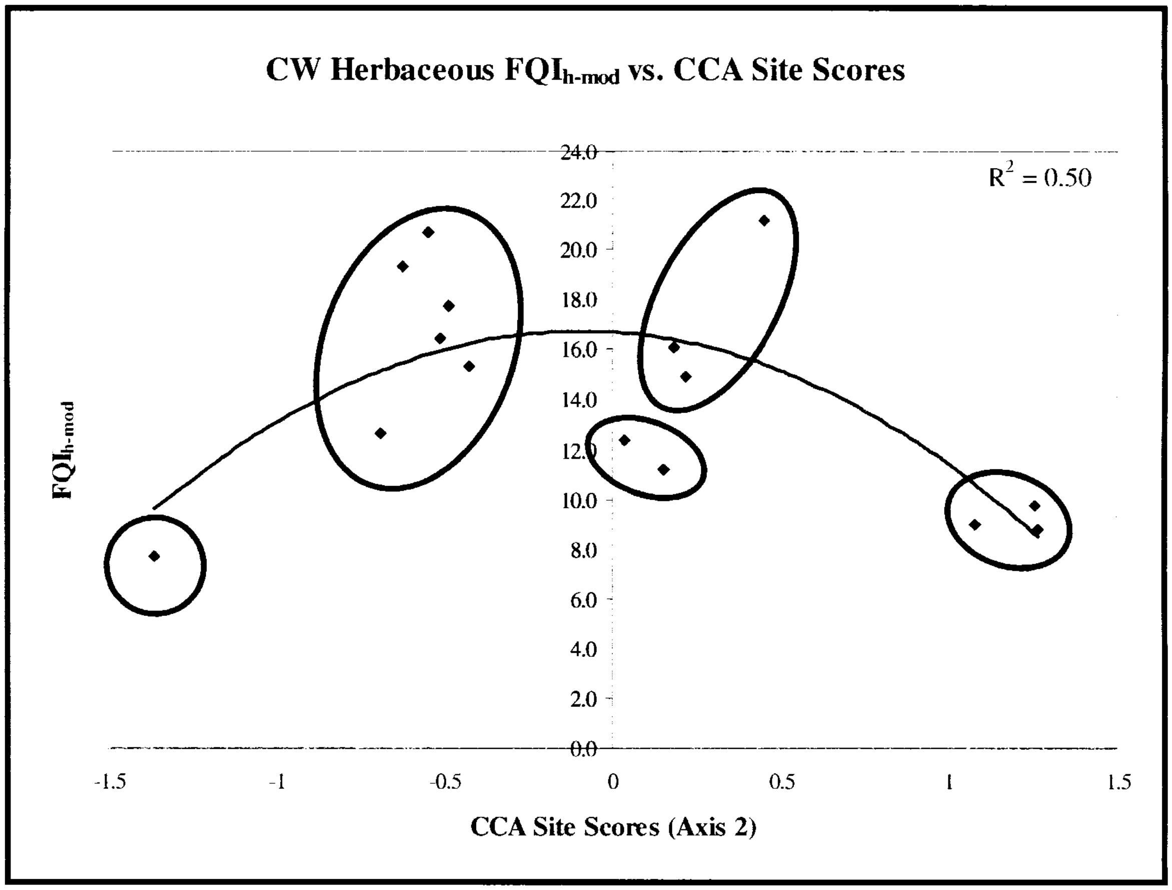

Figure 4-2. CW $FQI_{h\text{-mod}}$ values plotted against CCA site scores (Axis 2). This arrangement produces a very clear polynomial least squares fit ($r^2 = 0.50$) in which the original $FQI_{h\text{-mod}}$ groupings are conserved.

4.5.2 CCA and CW Shrub-sapling Data

In the CW shrub-sapling CCA run, all 14 sites containing abundance data were ordinated, and the environmental matrix was composed of site age and ten soil physiochemical parameters (soil N, C, C:N, P, K, Ca, Mg, CEC, % sand, and % silt). Procedures for parameter reduction in the environmental matrix are explained in Section 3-5. The resultant CCA ordination graph showed a strong outlier (Mattaponi, 1B-Matta) (Figure 4-3). We removed the outlier and re-ran the analysis, but could not generate a statistically significant eigenvalue for any axis based on Monte Carlo permutations; therefore, the original ordination output represented by Figure 4-3 was retained for interpretation.

Unlike the CW herbaceous ordination, $FQI_{s\text{-}mod}$ ranges did not correspond to the final arrangement of sites based on CCA site scores (r^2=0.03, p=0.197) (Figure 4-4). Biplots of environmental variables on Figure 4-3 indicate that site age and soil P are important factors explaining the variance along Axis 2, the only axis for which eigenvalue computations were statistically significant (p=0.05). As with the CW herbaceous ordination, soil P and site age appear to be inversely related in the biplot configuration. The strong cluster of sites in the upper portion of the graph is comprised of mostly older sites; seven of the 11 sites in this cluster were age seven or older, and all were dominated by low C-value species such as *Salix nigra* (C=3), *Acer rubrum* (C=2), and *Liquidambar styraciflua* (C=3) (Appendix C). By contrast, the three disjunct sites in the lower portion of the graph were generally younger [Mattaponi (1B-Matta), Southwest

Suffolk (2-SWSfk), and Stony Creek (6-Stony)], and were dominated by high C-value species such as *Taxodium distichum* (C=8), *Quercus michauxii* (C=7), and *Fraxinus pennsylvanica* (C=6) (Appendix C).

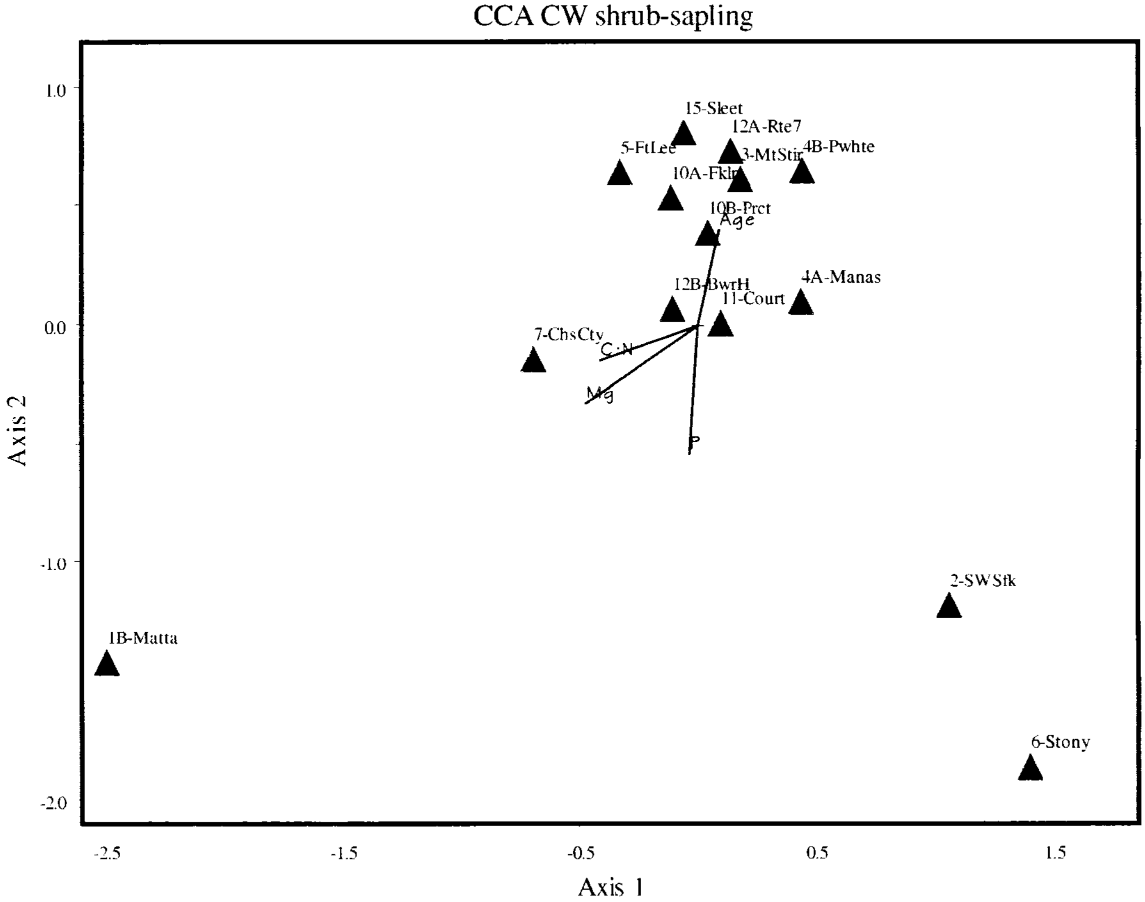

Figure 4-3. CCA ordination graph for CW shrub-sapling data. Biplots of environmental variables indicate that site age and soil P best explain site variance along Axis 2, which was the only statistically significant axis based on Monte Carlo permutations of the eigenvalue calculations. Unlike the CW herbaceous CCA analysis, this arrangement does not correspond to distinct ranges in $FQI_{s\text{-}mod}$ values.

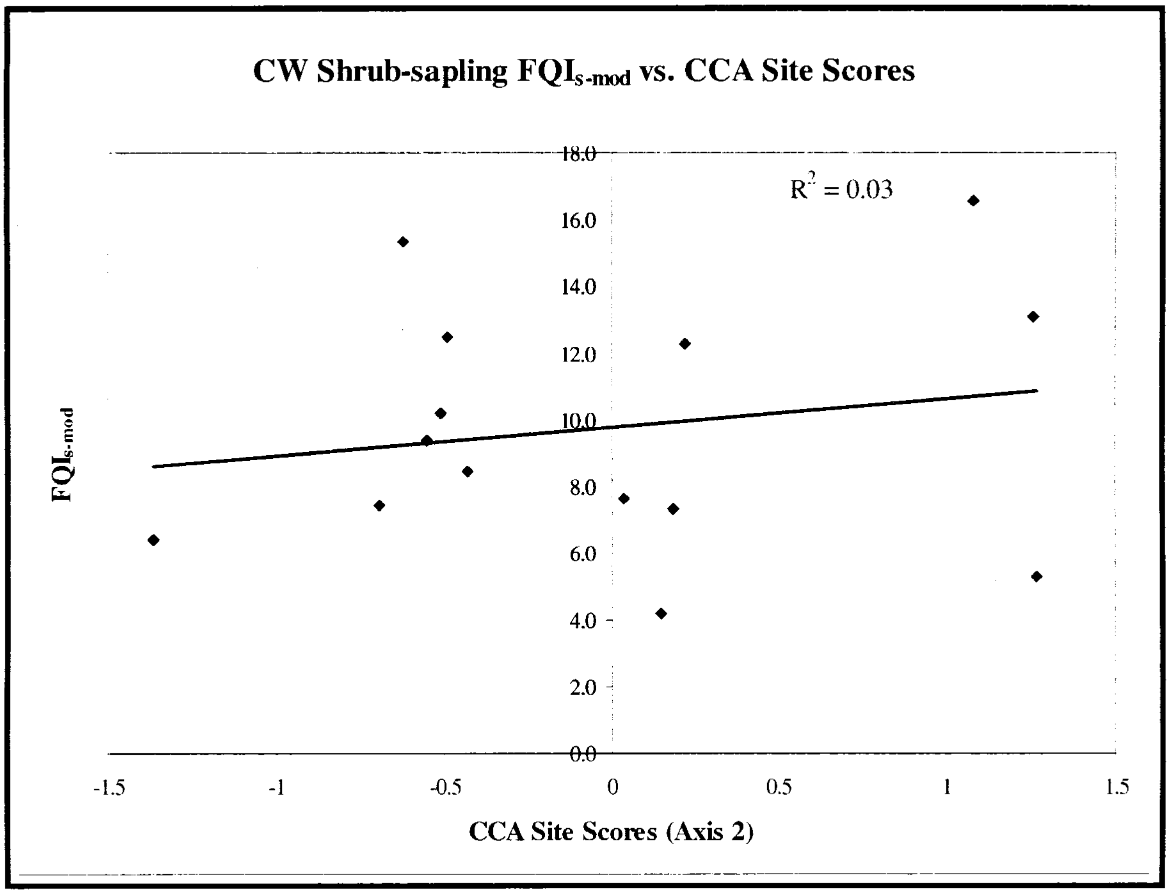

Figure 4-4. CW $FQI_{s\text{-mod}}$ values plotted against CCA site scores (Axis 2) from the CW shrub-sapling data analysis. The relationship between $FQI_{s\text{-mod}}$ and CCA site scores is not as distinct as that for the CW herbaceous ordination.

4.5.3 CCA and REF Herbaceous Data

In the REF herbaceous layer CCA analysis, the environmental matrix was created with nine soil physiochemical variables (soil N, C, C:N, pH, K, Ca, Mg, %sand, and %silt). The ordination output produced fairly indistinct site separation (Figure 4-5), with most variation along Axis 1 (eigenvalue computation $p<0.05$) corresponding to soil C, N, and C:N ratio, and texture (% sand and % silt), and along Axis 2 (eigenvalue computation

$p<0.05$) to soil K, pH, Mg, and Ca. Plotting $FQI_{h\text{-mod}}$ against CCA Axis 2 site scores showed a statistically significant linear relationship ($r^2=0.37$, $p=0.017$) (Figure 4-6).

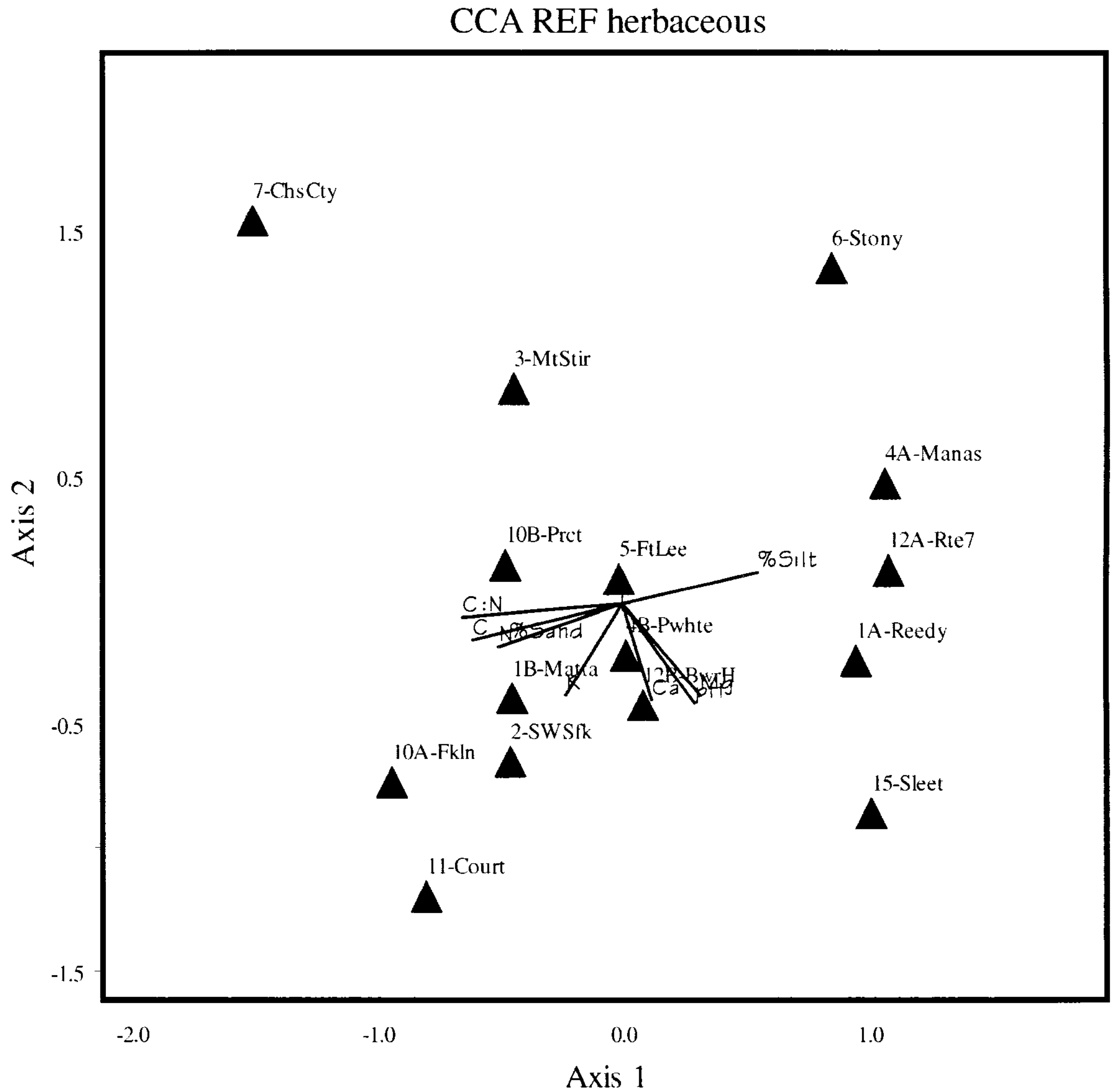

Figure 4-5. CCA ordination graph for REF herbaceous data. Biplots of environmental variables indicate that soil C, N, and C:N ratio, and texture (%sand and %silt) best explained site variance along Axis 1, and soil K, pH, Mg, and Ca generally corresponded to the spread of sites along Axis 2.

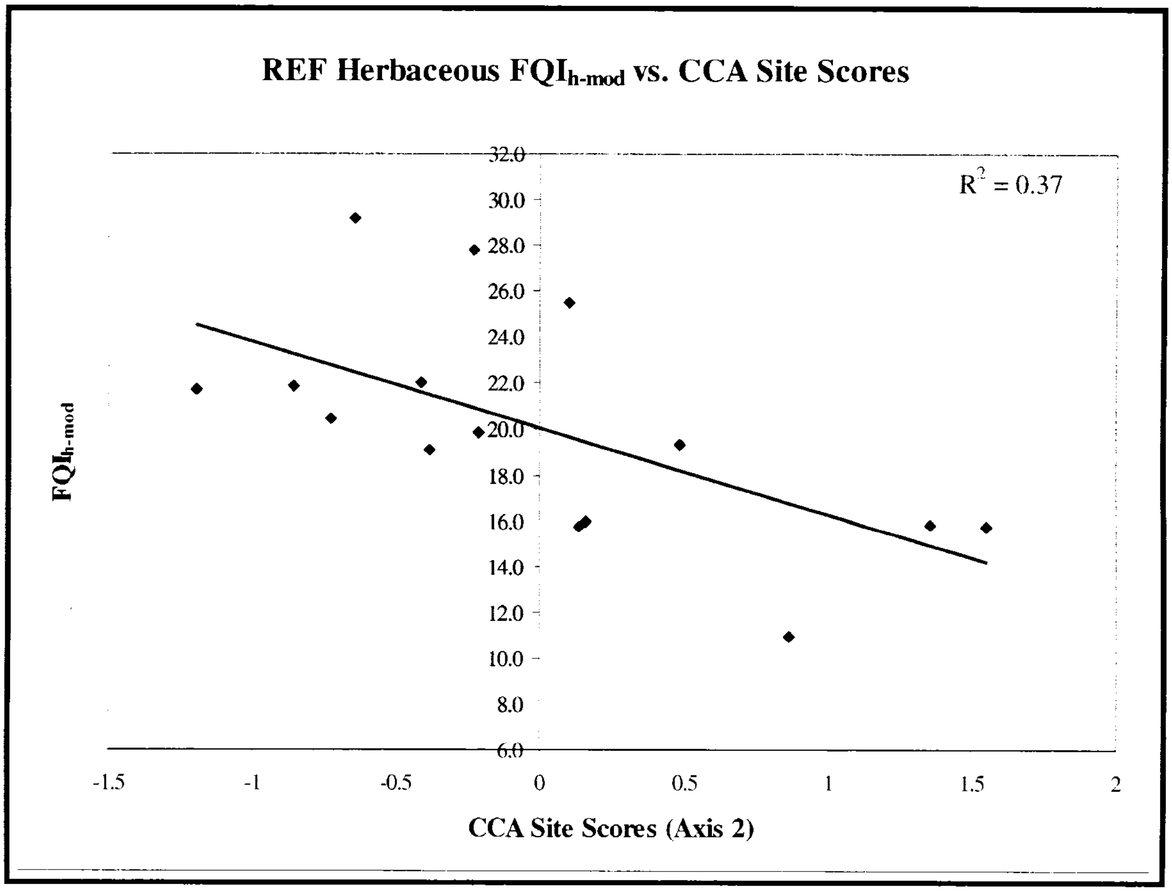

Figure 4-6. REF FQI$_{h\text{-}mod}$ values plotted against CCA site scores (Axis 2), showing a significant linear relationship.

4.5.4 CCA and REF Shrub-sapling Data

The first REF shrub-sapling CCA run included abundance data from all 15 sites, and an environmental matrix composed of site age and six soil physiochemical parameters (C, N, C:N ratio, K, CEC, and % silt). The resultant CCA ordination graph showed Powhite Parkway (4B-Pwhte) as a strong outlier (Figure 4-7). Although this site had the highest shrub-sapling species richness (S=21), it was inordinately dominated by *Carpinus caroliniana* (IV=40.9), and was one of the few sites for which *Acer rubrum* was not dominant (IV=2.7). Because of these distinct differences in composition and dominance, site 4B-Pwhte was removed and the ordination was re-calculated.

Removing the outlier from the abundance matrix and re-running the analysis produced better site separation, with most of the species variance accounted for along Axis 1 (Figure 4-8). Three distinct regions of site separation were noted, corresponding to moderate soil K, C, N, C:N, and % silt gradients along Axis 1. Plotting $FQI_{s\text{-}mod}$ against CCA Axis 1 site scores showed a statistically significant linear relationship (r^2=0.39, p=0.017) (Figure 4-9).

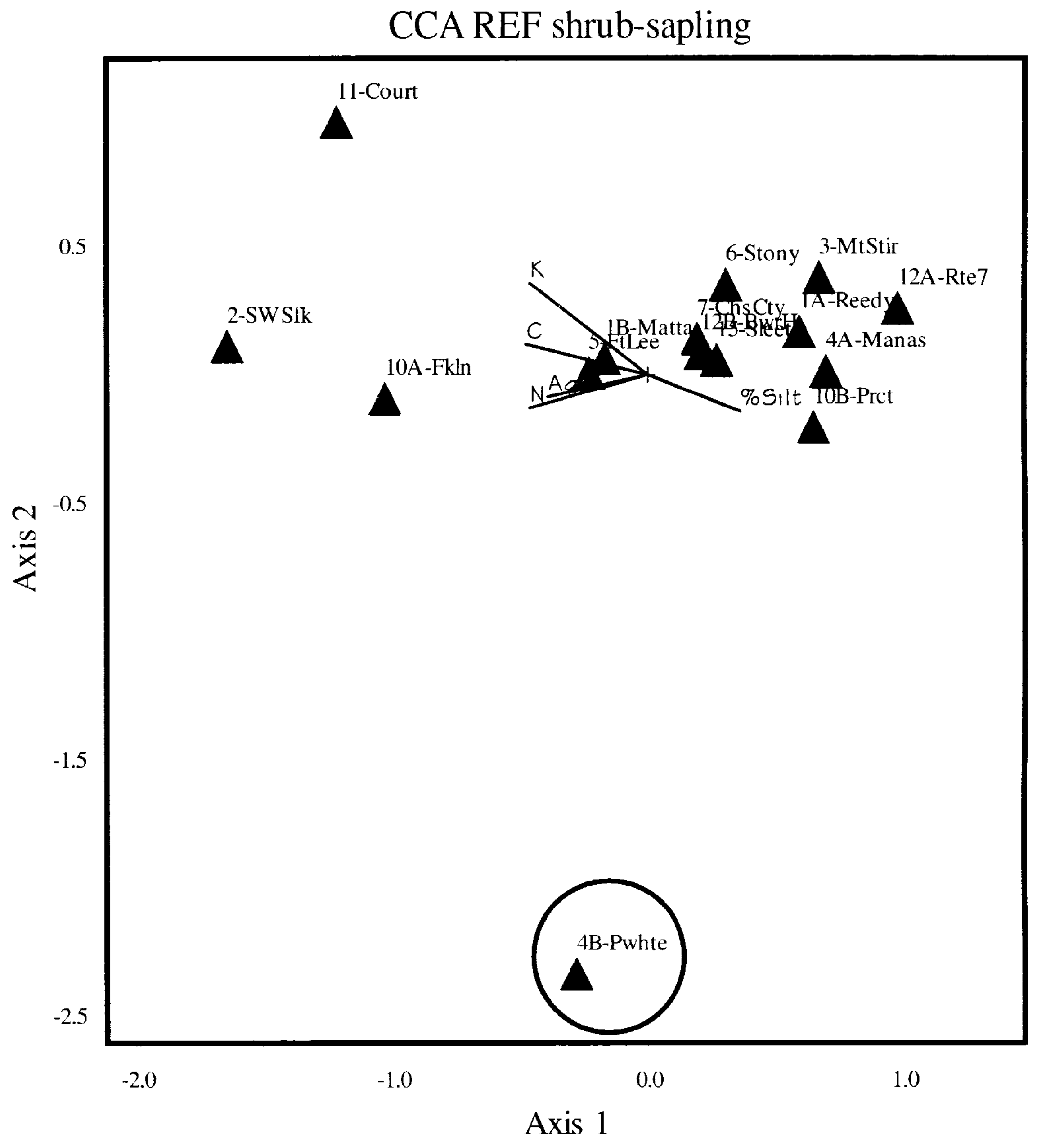

Figure 4-7. CCA first-run ordination graph for REF shrub-sapling data. This ordination shows a strong outlier (Powhite Parkway, 4B-Pwhte).

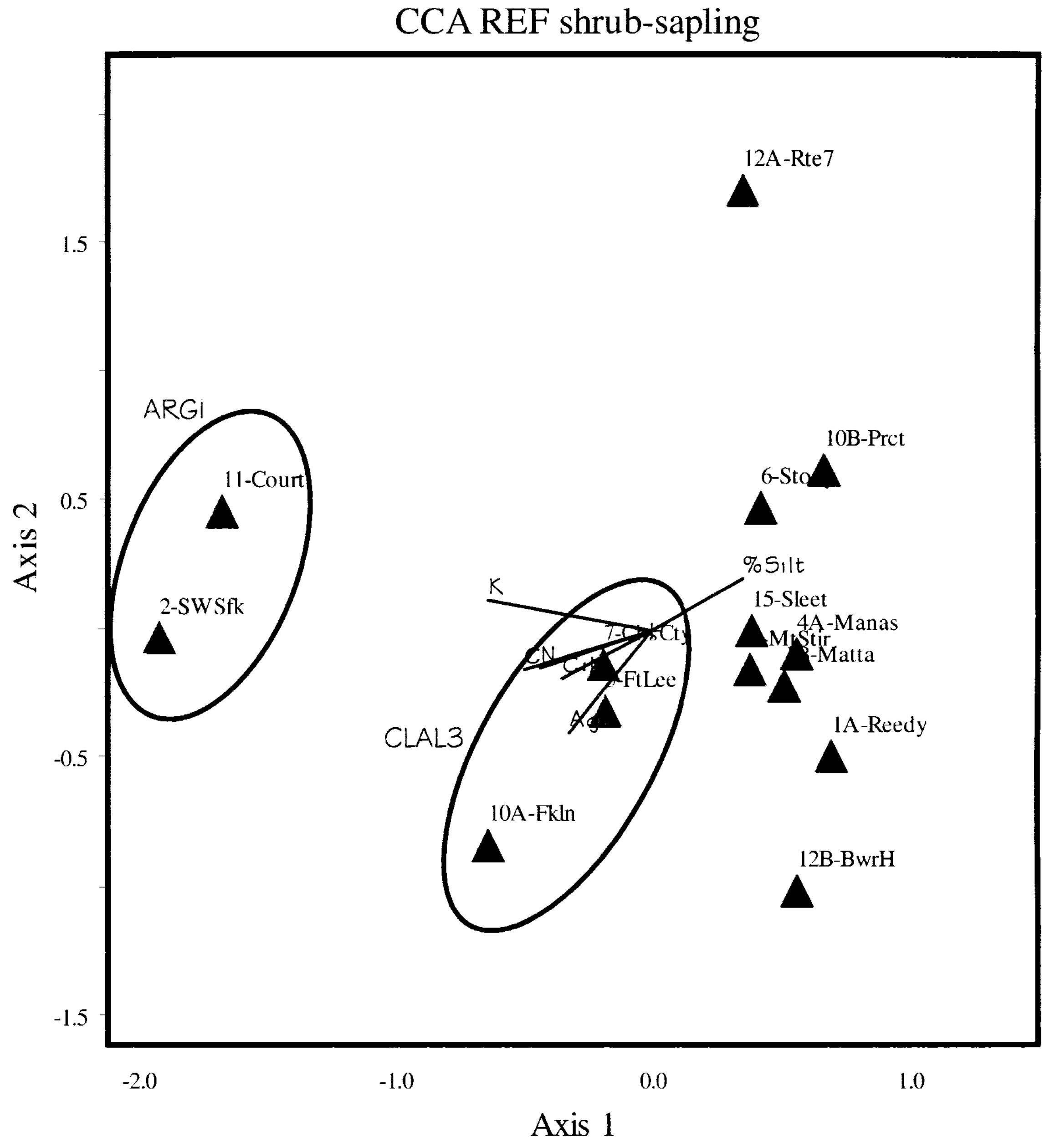

Figure 4-8. CCA final-run ordination graph for REF shrub-sapling data with outlier removed (Powhite Parkway, 4B-Pwhte).

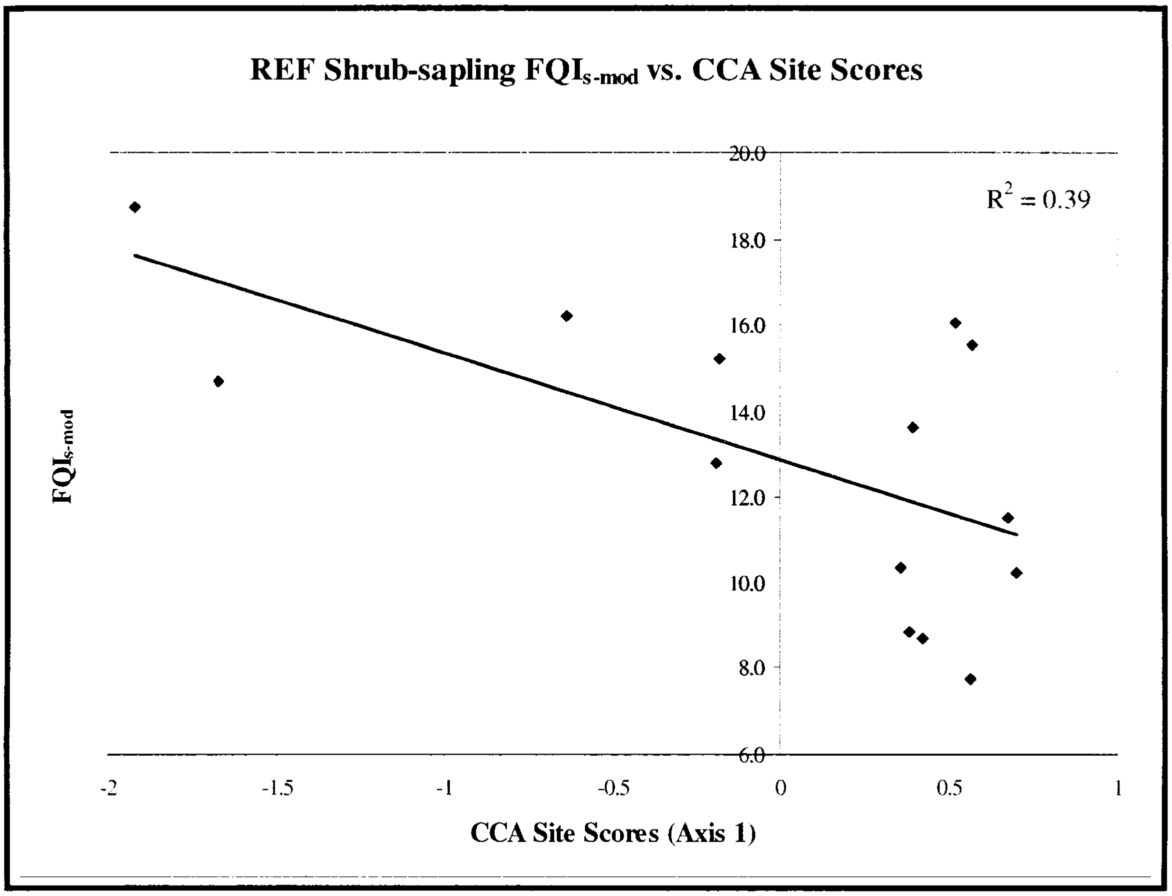

Figure 4-9. REF $FQI_{s\text{-mod}}$ values plotted against CCA site scores (Axis 1) from the REF shrub-sapling data analysis.

In the final REF shrub-sapling ordination (Figure 4-8), two site clusters appear to correspond to dominant species (Appendix C). The two sites comprising the small cluster to the left (2-SWSfk and 11-Court) were the only sites dominated by *Arundinaria gigantea* (ARGI) (IV=56.7 and 52.1, respectively), and the three in the center of the graph (5-FtLee, 7-ChCty, 10A-Fkln) were the only sites in which *Clethra alnifolia* (CLAL3) was a dominant (IV=20.7, 18.0, and 16.8, respectively). The remaining sites aligned to the right are generally dominated by *Acer rubrum*.

4.5.5 CCA and REF Tree Data

In the REF tree layer CCA analysis, the environmental matrix was created with site age and twelve soil physiochemical variables (soil N, C, C:N, pH, P, K, Ca, Mg, CEC, % sand, % silt, and % clay). The ordination output produced four general groups corresponding to dominants or unique associations in the IV matrix (Appendix C), as follows: *Nyssa biflora* association (NYBI); *Taxodium distichum-Nyssa biflora* association (TADI2-NYBI); *Liquidambar styraciflua-Quercus phellos* association (LIST2-QUPH); and, *Acer rubrum* association (ACRU) (Figure 4-10). Biplots indicated that most of the variation corresponded to soil K and site age along Axis 1, and C:N ratio, texture (%sand, %silt), and soil P and Mg along Axis 2. As Figure 4-11 shows, the relationship between $FQI_{t\text{-}mod}$ and CCA site scores was statistically non-significant (r^2=0.24, p=0.067).

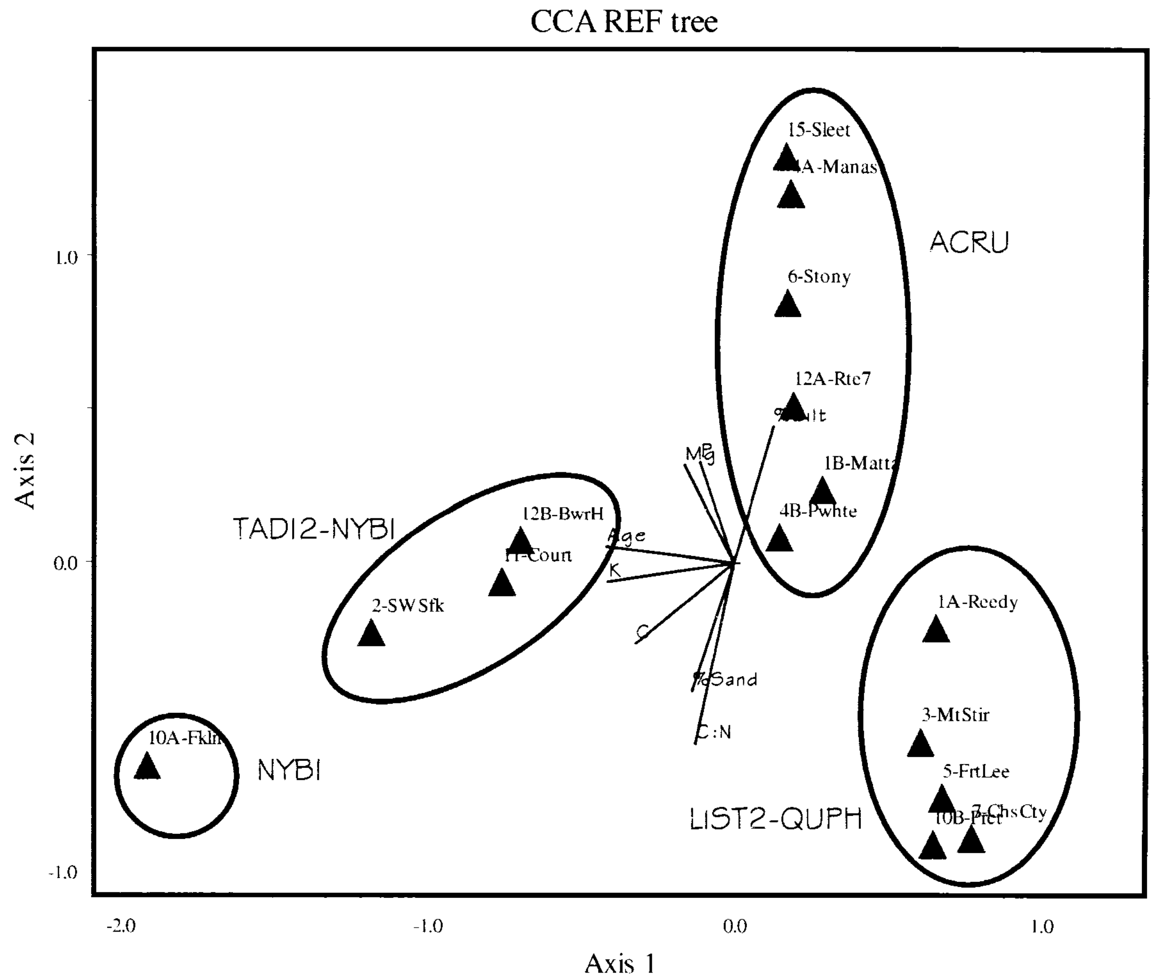

Figure 4-10. CCA ordination graph for REF tree data. Soil C:N and texture (%sand, %silt) are strongly correlated with Axis 2, and site age and soil K best explain the arrangement of sites along Axis 2. The four general clusters of sites corresponded to strong dominance or unique associations as interpreted from the IV matrix: *Nyssa biflora* (NYBI); *Taxodium distichum-Nyssa biflora* (TADI2-NYBI); *Liquidambar styraciflua-Quercus phellos* (LIST2-QUPH); *Acer rubrum* (ACRU).

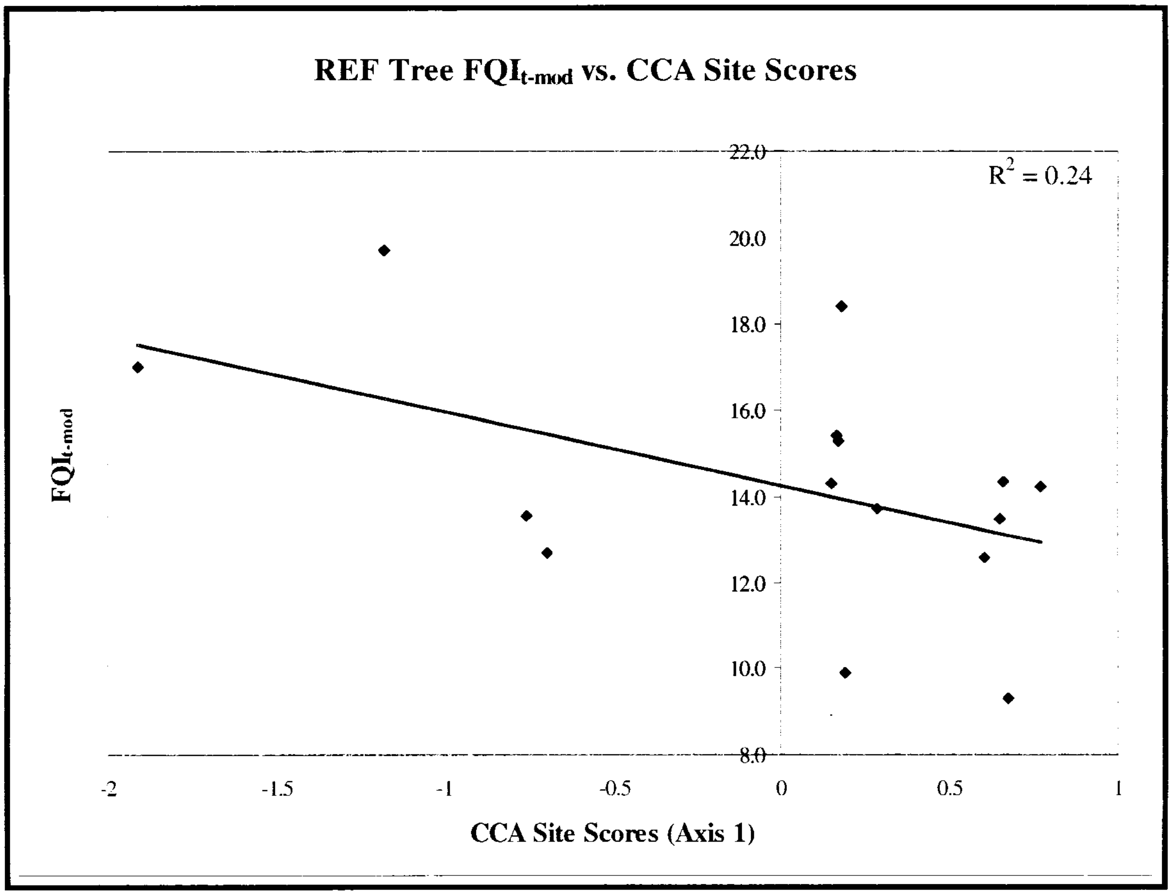

Figure 4-11. REF $FQI_{t\text{-}mod}$ values plotted against CCA site scores (Axis 2) from the REF tree data analysis, showing a weak negative correlation between $FQI_{t\text{-}mod}$ with CCA site scores.

4.5.6 CCA and CW-REF Combined Herbaceous Data

The CCA ordination for combined CW and REF herbaceous data was run with 12 soil physiochemical parameters (soil N, C, C:N, pH, P, K, Ca, Mg, CEC, % sand, % silt, and % clay). Site age was excluded in the environmental matrix due to the inordinate effect that the disparity in age between the REF group and the CW group would have on the final position of sites in species space. The site abbreviations were annotated with

"C" or "R" in front of the site number to distinguish between CW and REF sites, respectively. The resultant CCA ordination graph showed the Charles City REF site (R-7) as a strong outlier (Figure 4-12). This site had a very low herbaceous species richness value (13) in comparison with the rest of the data set, and was the only site dominated by *Carex joorii*, *Clethra alnifolia*, and *Smilax rotundifolia* in the herbaceous layer. Due to these apparent differences, the Charles City REF site was removed from the data set and the ordination re-calculated.

The final ordination graph showed strong segregation between CW and REF sites, with the former occupying the left side of the graph, and the latter to the right (Figure 4-13). Biplots of environmental variables indicate that soil N and C best explain the arrangement of sites along Axis 1. As described in Section 4.4.4, both C and N were significantly and positively correlated with site age in the REF data set (see Table 4-5). Further, as Figure 4-1 shows, both C and N were important in explaining CW site distribution along Axis 1 in the CW herbaceous ordination, which appeared to separate older sites (likely to have more organic carbon buildup) from younger sites. Presumably, the small overlap in older CW sites with REF sites is related to this C and N gradient. Plotting $FQI_{h\text{-}mod}$ against CCA Axis 1 site scores showed a statistically significant linear relationship ($r^2=0.34$, $p<0.001$) (Figure 4-14).

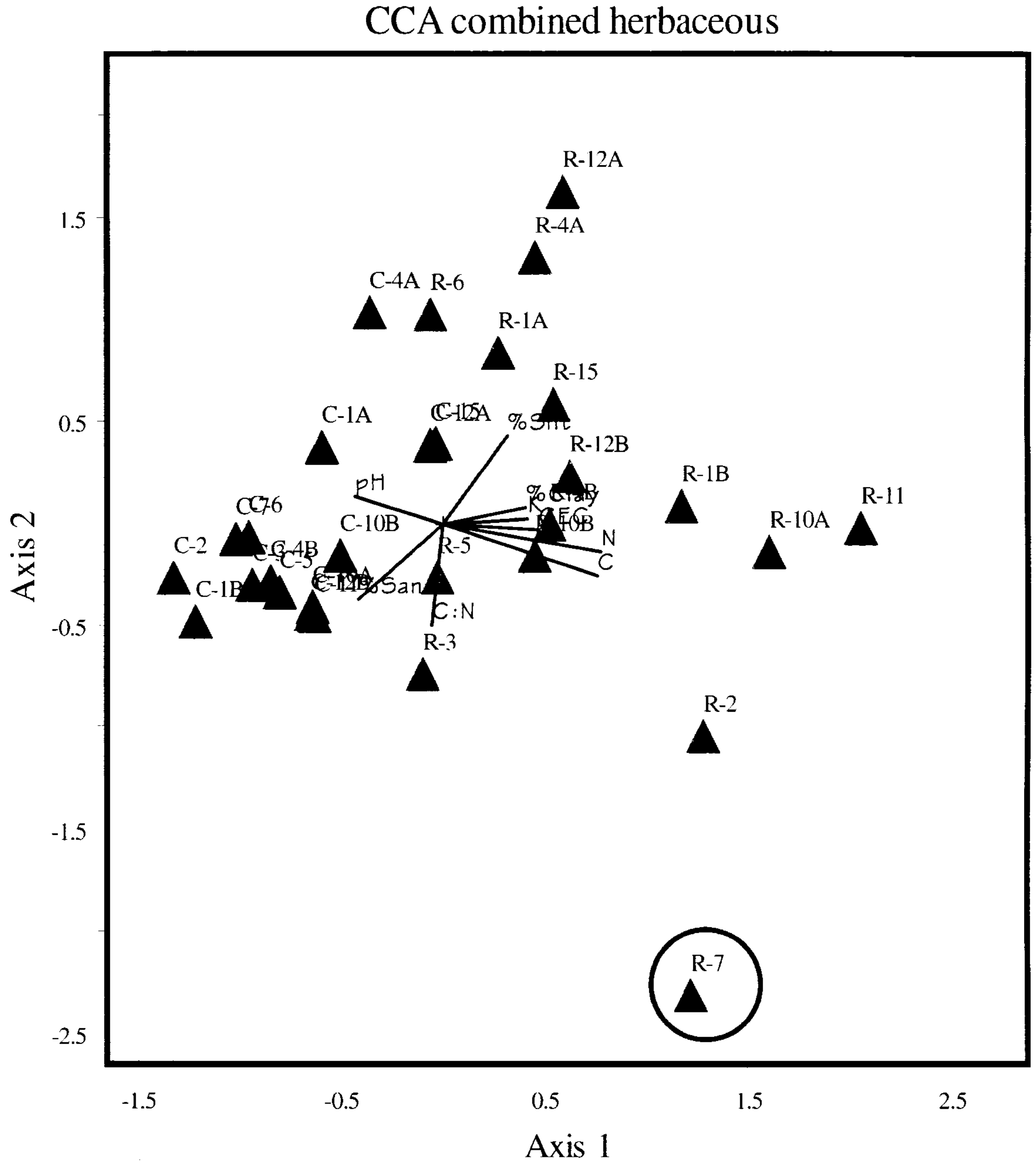

Figure 4-12. CCA first-run ordination graph for CW-REF combined herbaceous data. This ordination shows a strong outlier (REF Charles City, R-7).

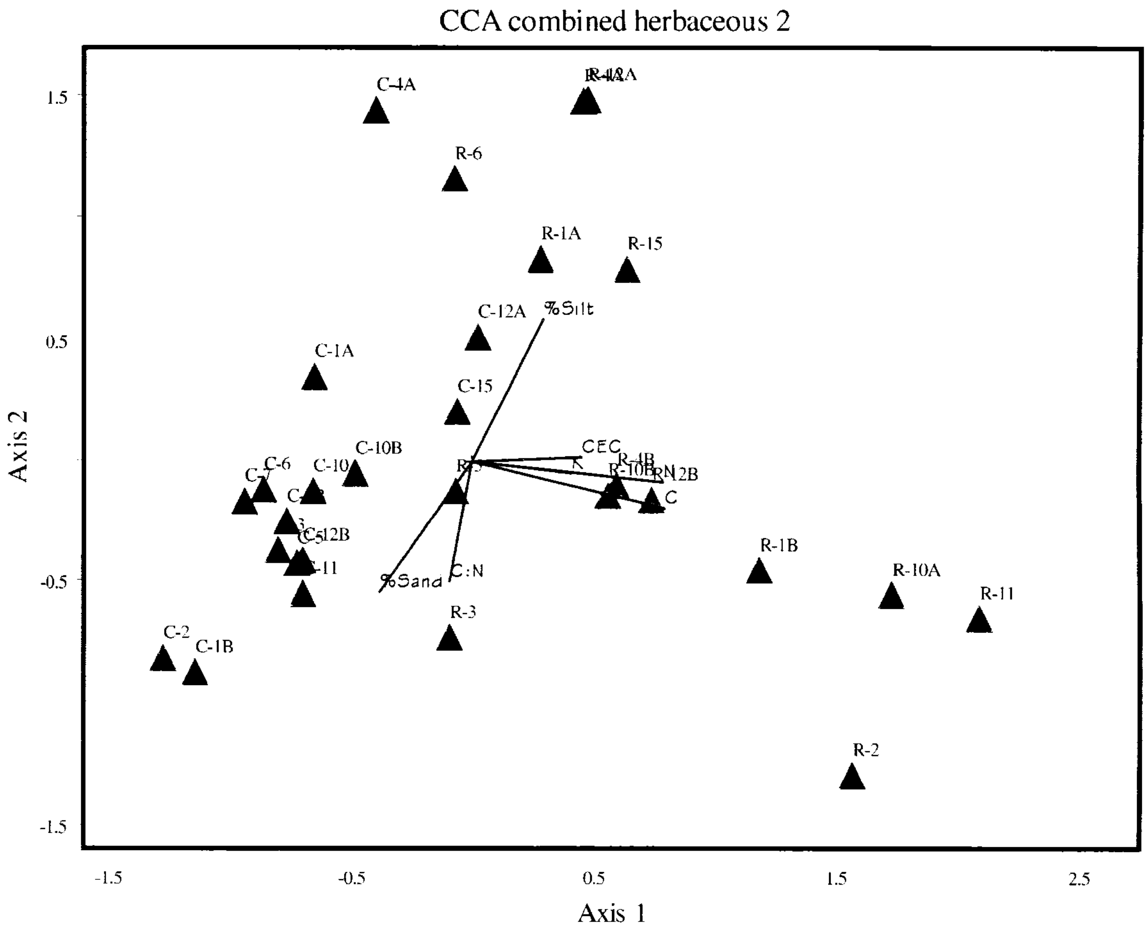

Figure 4-13. CCA final-run ordination graph for CW-REF combined herbaceous data. Nearly all REF sites are positioned on the right side of the graph, with CW sites positioned to the left.

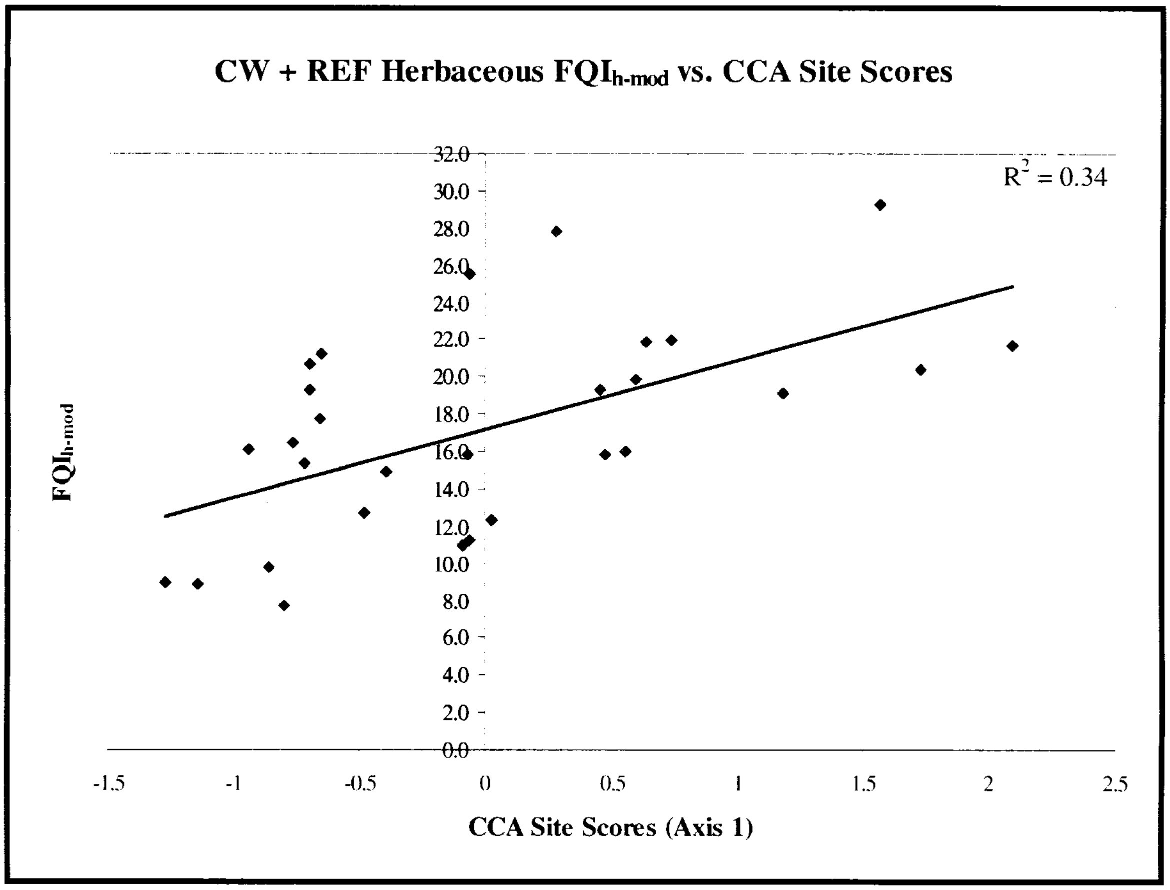

Figure 4-14. Combined $FQI_{h\text{-}mod}$ values plotted against CCA site scores (Axis 1) from the CW-REF combined herbaceous data analysis.

4.5.7 CCA and CW-REF Combined Shrub-sapling Data

The CCA ordination for combined CW and REF shrub-sapling data was calculated with 12 soil physiochemical parameters (soil N, C, C:N, pH, P, K, Ca, Mg, CEC, % sand, % silt, and % clay). Site age was excluded in the environmental matrix as described in Section 4.5.6 above. The CCA ordination graph showed the Mattaponi CW site (C-1B) as a strong outlier (Figure 4-15). This site contained only three shrub-sapling species, and was the only site in the data set dominated by *Alnus incana* ssp. *rugosa* and

Quercus michauxii, both of which were planted. Therefore, the Mattaponi CW site was removed from the data set and the ordination re-calculated.

Results from the final ordination were very similar to those reported in Section 4.5.6 above. CW and REF sites occupied distinct regions of the graph (Figure 4-16), with CW sites to the left and REF to the right. Also, soil N and C appear to be related to the spread of sites along Axis 1. Plotting $FQI_{s\text{-}mod}$ against CCA Axis 1 site scores showed a statistically significant linear relationship ($p<0.01$), but generally low coefficient of determination ($r^2=0.28$) (Figure 4-17).

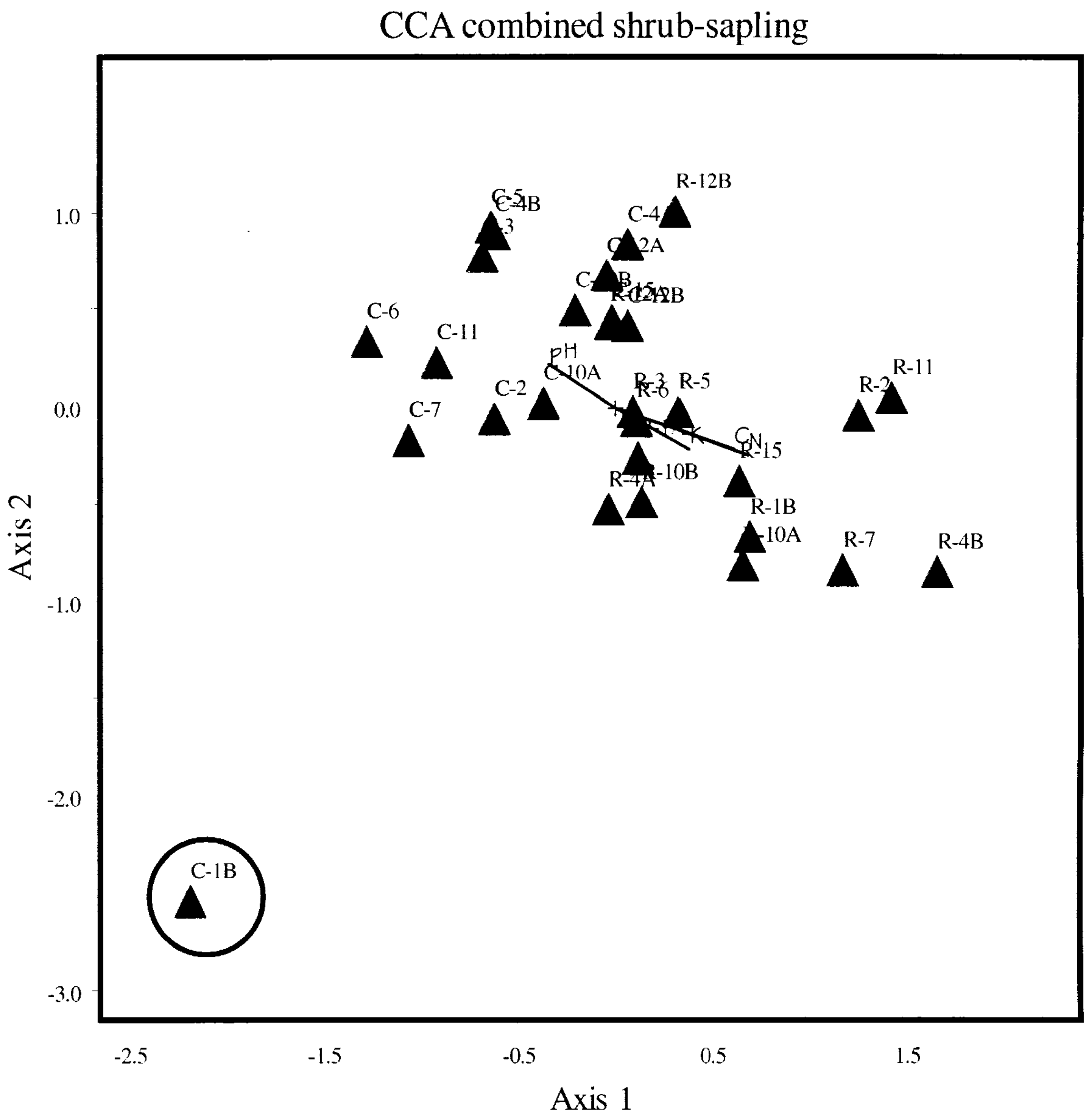

Figure 4-15. CCA first-run ordination graph for CW-REF combined shrub-sapling data. This ordination shows a strong outlier (CW Mattaponi, C-1B).

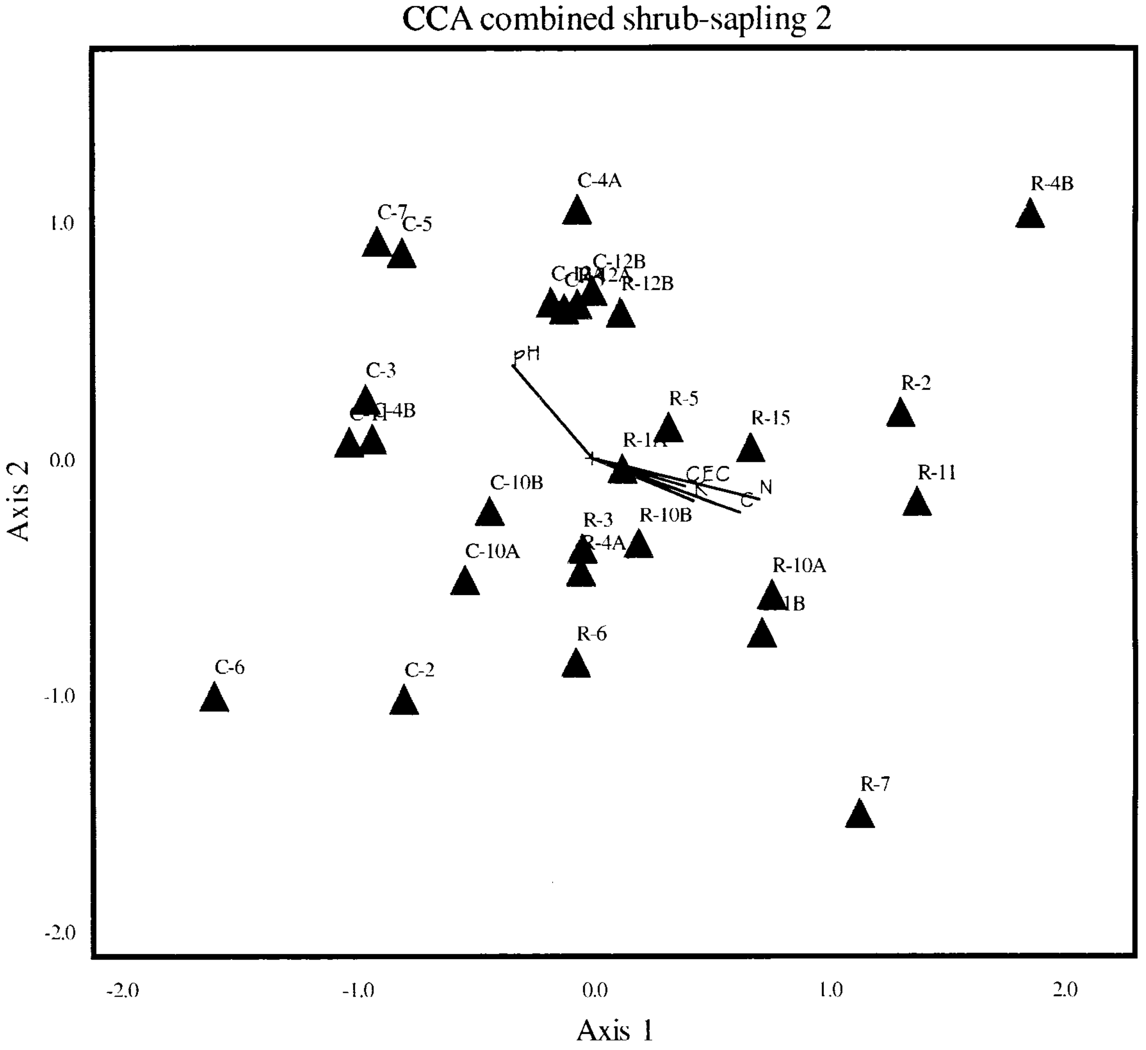

Figure 4-16. CCA final-run ordination graph for CW-REF combined shrub-sapling data. CW sites are almost exclusively segregated to the left, with REF sites to the right.

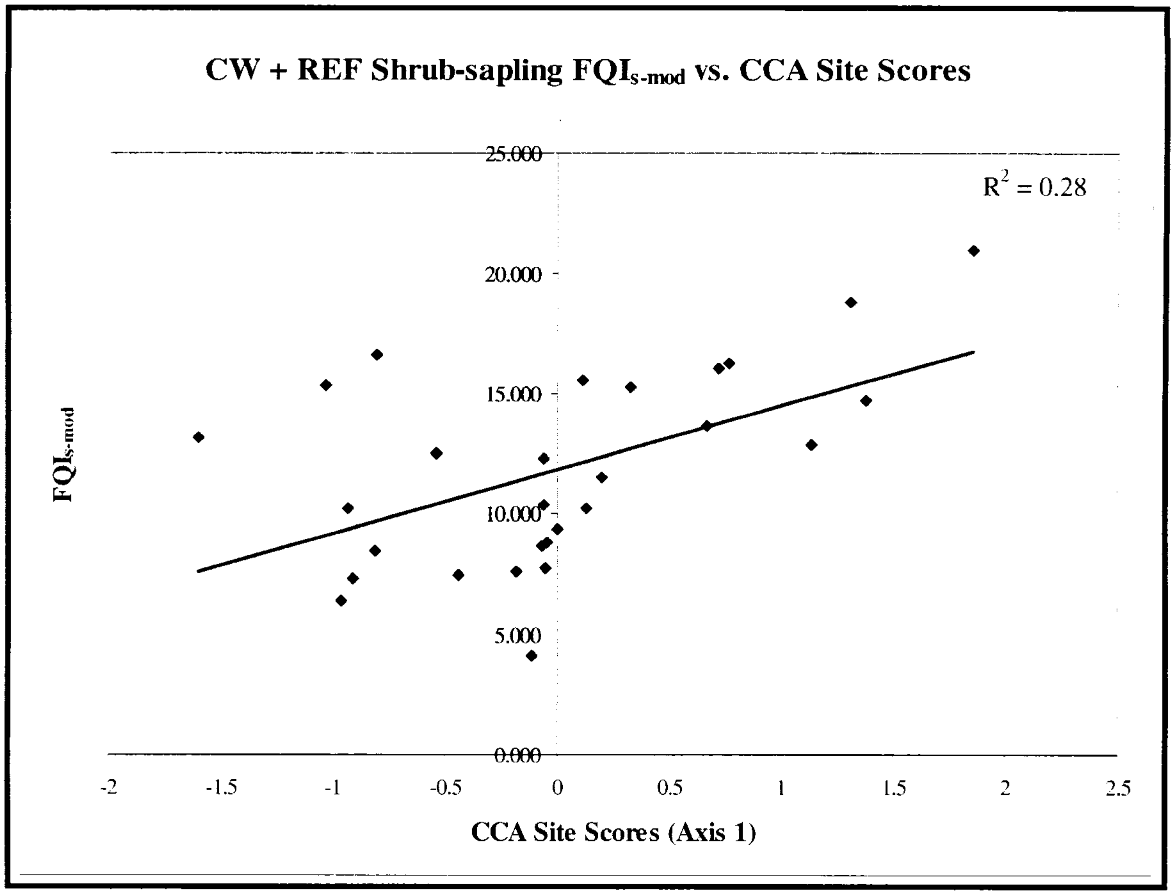

Figure 4-17. Combined $FQI_{s\text{-}mod}$ values plotted against CCA site scores (Axis 1) from the CW-REF combined shrub-sapling data analysis.

5.0 DISCUSSION

From the results of the correlation and community ordination analyses we observed that different versions of the index discriminated the array of site and vegetation attributes differently for CW and REF wetlands. The relative "performance" of overall vs. vegetation layer-based indices could be differentiated based on significant correlations with intrinsic floristic quality parameters (IFQP) (i.e., species richness, diversity, evenness, and percent native species). In evaluating FQI as an assessment method in wetlands, we address the following questions: 1) What is the most appropriate form (i.e., method of calculation) of FQI when applied to CW sites and/or REF sites in Virginia? 2) Can FQI be used to infer ecological differences among sites? And finally, 3) Does FQI provide a potentially useful tool for floristic quality assessment of CW sites in Virginia, and can it be used to compare CW sites to their respective REF wetlands in a meaningful sense?

5.1 AN APPROPRIATE FQI FOR WETLANDS IN VIRGINIA

5.1.1 FQI from Native vs. Non-native Species

The authors of the FQI concept reject the notion of including non-native species in the calculation of the index, stating: "Because the ecological contexts of native and introduced plants are so inherently disparate in character, introduced plants are necessarily and explicitly excluded from the floristic assessment" (Swink and Wilhelm 1994, p. 13). Further, they maintain that if non-native species are occupying an area to a "deleterious extent, or their presence is a reflection of habitat alteration, their occurrence will be measured indirectly by diminishment in conservative species." By contrast, others have suggested that inclusion of non-native species may provide a more realistic estimate of floristic quality (Bowles and Jones 2005, Cohen et al. 2004). The presence of alien species is often linked to anthropogenic disturbance (Hobbs and Huenneke 1992), and in this respect could be useful in assessing floristic quality in the context of species conservatism. However, because the C-value assigned to all non-native wetland species in Virginia is zero, there is a subtle problem imposed by including a potentially significant number of zeros in the calculation – the "zero truncation problem" (Beals 1984).

Non-native species represent a significant portion of the regional wetland flora. Roughly 14% of the 1,131 species included on the Virginia C-value wetland plant list are non-native, yet each of these takes a C-value of zero regardless of differences in tolerance to anthropogenic disturbance (Virginia Department of Environmental Quality 2004). This creates a problem in the calculation of the index when several non-native species are present, because the C-value for these species has been assigned based on nativity and not on degree of fidelity to natural areas *per se*. This is analogous to the zero truncation problem in ecological studies, where the mere absence of a species gives no information about how unfavorable the environment is for that species (Beals 1984, McCune and

Grace 2002). Just as no negative abundance values are possible in a sample, there is no negative C-value scale to account for the relative differences in ecological tolerances of non-native species, and the scale is “truncated” at zero. In this respect, the C-value of non-native species (zero), and the C-value of native species (one through ten), represent two fundamentally different classifications that are perhaps incompatible in the structure of the index. In our study, the “zeros-in” or “all” versions of the index did not improve the correlations with site variables, and in most cases, the correlation coefficient decreased when compared with the “classic” method (i.e., “zeros-out” or natives only). Therefore, we conclude that an all-inclusive index with non-native species in the calculation is not appropriate for this type of application in Virginia given the current zero C-value assignment for non-native species.

However, it is possible to rank non-native species in accordance with relative impact on natural areas (i.e., potential for invasion). This has been done by Oldham et al. (1995) in assigning “weediness scores” to exotic plants in Ontario, and applied as an index (“mean weediness score”) by Francis et al. (2000). Development of an exotic plant index in this manner is a potentially useful concept that, if undertaken, could be beneficially incorporated into floristic quality assessment in Virginia.

5.1.2 Overall vs. Vegetation Layer-based FQI

The overall FQI values in this study, as in most applications from the literature, were calculated across all layers. In this manner, a single species could be present in two or three layers (e.g., *Acer rubrum* could be present in the tree, shrub-sapling, and herbaceous layers), yet its C-value would be equally weighted with a rare species represented by a single individual in one layer, and vice-versa. Wilhelm and Ladd (1988) justify this approach by defining the operative premises for the method in terms of the mere presence of a plant and its C-value. This is done without regard for physiognomic or structural attributes such as stratification. As such, FQI can only be used to infer the degree to which a site represents "natural area", as defined by the site's affinity to an assumed vegetational assemblage that would have occurred prior to human alteration (Wilhelm and Ladd 1988, Swink and Wilhelm 1994). This is, in a sense, an assessment of the "natural heritage" attributes of a system that accounts for unique or sensitive elements, the mere presence of such elements giving importance to an area on a relative scale (Wilson and Tuberville 2003).

However, in forested systems, different functional groups or plant guilds (e.g., structural or life-history groups) have been shown to express different responses to anthropogenic disturbance (Keddy et al. 1993, Lopez et al. 2002). For example, woody species exhibit a property termed "ecological inertia", characterized by slower growth and a life history strategy allocating photosynthate to structural tissue for long-term survival (Chapin 1991, Lopez et al. 2002). By contrast, herbaceous species allocate resources to maximize reproduction, a life history strategy that results in short-term survival (Grime 1977). In this respect, herbaceous species are more likely to show the effects of short-term disturbance relative to woody species, the latter exhibiting ecological inertia due to longer disturbance response times predicated by a longer life history strategy (Lopez et al. 2002). Therefore, individuals within different layers should be expected to express different responses to disturbance due to inherent differences in autecological tolerances, and as such, deriving a single index across all vegetation layers may reduce the sensitivity of FQI in distinguishing floristic quality among sites.

In a recent study, Nichols et al. (in press) applied vegetation layer-specific FQIs to forested wetlands in Virginia and found that a layer-based approach was more appropriate in differentiating floristic quality relative to disturbance gradient than an overall FQI calculated across layers. Their findings were consistent with our results, in that the overall FQI showed a general lack of statistically significant correlations with most site variables in both the created and reference sites, but layer-specific FQIs increased the number of statistically significant correlations, particularly with respect to IFQPs. Therefore, given the inherent disparity in response to disturbance expected from different structural plant guilds across different layers, we found that FQI should be calculated on a layer-specific basis in Virginia wetlands. This approach tended to increase the sensitivity of the index to relative differences in floristic quality between sites.

5.1.3 The Modified (Abundance-weighted) FQI

In defining the scope and application of FQI, Swink and Wilhelm (1994, pg. 13) note that "[t]he density, apparent dominance, or frequency of individual plant species are not relevant factors when considering the qualitative value of a site." We maintain, however, that qualitative value is only part of the objective of assessing wetland vegetation communities and plant guilds. An assessment strategy should combine some measure of floristic quality (i.e., such as diversity) with a reasonably reliable indicator of successional development within the system (National Research Council 1992). This latter consideration was justification alone for testing a modified, abundance-weighted FQI. Abundance weighting gives more information about quantitative aspects of the community without which successional development cannot be inferred (Bazzaz 1996). This type of information is desirable for those wishing to gain insight into the system beyond simply a summary of its "natural heritage" attributes.

As our results indicated, in most cases the modified (i.e., abundance-weighted) index did not reduce the number of significant correlations with IFQPs, and in the case of the CW herbaceous layer, the modified index actually *increased* the number of significant correlations. In this respect, the modified index appeared to perform *better* than the non-weighted index, in that the former was able to predict more IFQPs, which were calculated directly from the array of species present on the site. A modified index may be desirable for two reasons: 1) the abundance-weighted approach preserves the "heritage" aspect of the FQI concept since the relative ranks between sites are not significantly different between FQI and FQI_{mod}; and, 2) the modified index also provides information about the ecology of the system as inferred from quantitative measures of the species present. In other words, since the modified index is weighted by abundance, it gives more information about the community without losing any information derived simply from the conservatism (C-values) of the species present. Therefore, a modified, abundance-weighted version of the index shows promise as an indicator of wetland vegetation condition for the given type of study.

5.2 ECOLOGICAL IMPLICATIONS

The general lack of correlation between FQI and environmental attributes (site age and soil parameters) could be due to several factors: 1) although the arrangement of CW sites is a chronosequence based on site age, the actual history of the site (i.e., how it was created, soil amendments, plantings, etc.) is probably more important to the recruitment of species than age alone; 2) the distribution of species relative to site variables may not be linear – if the response is, for instance, unimodal (i.e., hump-shaped), a simple correlation coefficient will not capture this relationship; and, 3) because of these factors, age alone does not give a "full-picture" view of the ecological and synergistic relationships that may exist between soil physiochemical attributes, site age, and species conservatism. In other words, although FQI values do not correlate with site age, they may nonetheless represent the general sequence (i.e., rank) of sites based on substrate quality.

5.2.1 $FQI_{h\text{-}mod}$ and the CW Herbaceous Layer

Results from the CCA ordination indicated that the $FQI_{h\text{-}mod}$ responded to the arrangement of CW sites in herbaceous species space as defined (constrained) by the environmental variables included in this study. The relationship was made more apparent by the unique, non-overlapping distribution of $FQI_{h\text{-}mod}$ value ranges relative to CCA ordination site groupings (Figures 4-1 and 4-2). In this respect, using the floristic quality concept to index species conservatism *and* abundance reflected underlying ecological differences interpreted by the specific environmental variables treated in this analysis (i.e., soil physiochemical variables and site age). This suggests that the modified index, applied to the CW herbaceous layer, was robust in its ability to differentiate site "quality" in the absence of a clear linear relationship with site age.

5.2.2 $FQI_{s\text{-}mod}$ and the CW Shrub-sapling Layer

Unlike the CW herbaceous results, $FQI_{s\text{-}mod}$ did not predict ecological differences in the CW shrub-sapling ordination (Figure 4-4). One possible reason for this is the management of sites relative to planting and maintenance of tree species. We believe that the data are heavily influenced by planted saplings observed on younger sites, particularly less than six years old. Because a high percentage of oaks and other conservative trees [e.g., *Taxodium distichum* (C=8), *Quercus michauxii* (C=7), and *Fraxinus pennsylvanica* (C=6)] is often a planting requirement imposed by regulatory agencies responsible for specifying performance standards for created wetlands, some of the highest $FQI_{s\text{-}mod}$ values were calculated from the younger sites. If these sites were left to regenerate without planting, one might expect a better correlation with site age or substrate quality due to natural successional processes (Noon 1996, Spencer et al. 2001). Therefore, it is likely that $FQI_{s\text{-}mod}$ corresponded poorly with site scores from the CCA ordination due to C-value "inflation" on the younger sites from planting. We conclude, then, that $FQI_{s\text{-}mod}$ has limited potential for assessing shrub-sapling layers on created wetland sites, and any attempt to use the index in this manner should be interpreted with caution. Although FQI in general may be useful from a "heritage" perspective when assessing CW shrub-sapling data (i.e., correlations observed with IFQPs), it should not be used to infer successional development or ecological differences between CW sites. This was not the case for shrub-sapling analysis in the REF data set.

5.2.3 FQI_{mod} and REF Wetlands

The significant relationships between REF CCA site scores and FQI_{mod} in both the herbaceous and shrub-sapling layers show that modified indices for these layers corresponded to site arrangement in the REF species-environment ordination space (Figures 4-6 and 4-9). As such, these indices reflected ecological differences among sites relative to the environmental parameters used in this study. This suggests that REF $FQI_{h\text{-}mod}$ and $FQI_{s\text{-}mod}$ scores have the potential to differentiate natural wetland sites in the absence of linear correlations with site substrate characteristics and/or site age. This result underscores the potential sensitivity of the index when applied to the understory in forested wetland systems (e.g., herbaceous and shrub-sapling layers), and is consistent with other research conducted on FQI applications in Virginia (Nichols et al. in press).

Based on the lack of correlation between $FQI_{t\text{-}mod}$ and CCA site scores from the REF tree layer, one might infer that $FQI_{t\text{-}mod}$ has limited application to floristic quality assessment in the tree layer. This is reasonable in the context of ecological inertia (see discussion in Section 5.1.2 above) in that the tree layer typically contains the oldest individuals in the community and, as such, is more likely to reflect historic rather than recent disturbance conditions (Lopez et al. 2002). However, by the same argument, the distribution of individuals in the tree layer is less likely to be directly related to gradients in substrate condition caused by recent soil disturbance regimes or nutrient stress (Marks and Bormann 1972, Huston and Smith 1987). In this respect, the CCA ordination approach applied in this study may not be as instructive a model for trees relative to other layers.

This is likely due to temporal effects associated with natural successional processes that determine the relative abundance of trees in forested wetland sites (King and Allen 1996, Mitsch and Gosselink 2000). In our study, $FQI_{t\text{-}mod}$ was shown to have a statistically significant correlation with REF site age. One possible reason is that the inclusion of abundance data in the calculation of the index renders the final value more sensitive to differences in species composition related to successional development, a time-dependent phenomenon (Pickett 1976, Smith 1990). In this respect, younger sites (ca. 35-50 years) and older sites alike may be populated with lower C-value species such as *Acer rubrum* and *Liquidambar styraciflua*, but the relative abundance of such species would be expected to be higher in the younger age group (Rheinhardt and Rheinhardt 2000). Likewise, higher C-value species (e.g., *Taxodium distichum*, *Quercus* spp., and *Fraxinus pennsylvanica*) may be present in both age classes, but should be more abundant on older sites. This was a consistent observation among REF sites in our study.

The implication of our results is that a non-weighted tree FQI will not account for relative differences in species abundance, and will tend to score sites similarly irrespective of successional development and, by analogy, floristic quality. This was an obvious distinction between FQI and $\text{FQI}_{\text{t-mod}}$ in our data, and was also observed in a similar study using FQI in forested wetland sites in Virginia (Nichols et al. in press). As we observed from the correlation matrix (Appendix E), FQI alone could not differentiate sites with different community composition. In fact, FQI ranged from 16.1 to 18.5 on 11 of 15 sites, a 2.4-point range over 73% of the data set (Appendix D). By contrast, $\text{FQI}_{\text{t-mod}}$ gave a range from 9.3 to 19.7 and produced a more representative spread of index values consistent with the relative abundance of conservative and non-conservative species among sites (Appendix C and D). Therefore, we conclude that although $\text{FQI}_{\text{t-mod}}$ may not reflect the ecological condition of reference sites as inferred from the specific suite of environmental parameters tested in this study, the index may yet be useful in differentiating sites related to species composition and successional development. In any case, if researchers are intent on assessing floristic quality for tree data from forested wetland sites, $\text{FQI}_{\text{t-mod}}$ appears to be superior to FQI for this purpose, in that $\text{FQI}_{\text{t-mod}}$ is more sensitive to differences in community composition and conservatism predicated by site maturity and ecological succession.

5.2.4 FQI_{mod} and CW-REF Combined Data Sets

The benefit of the composite treatments (i.e., combining both CW and REF data into one abundance matrix) was that it allowed us to observe the potential for site "overlap" in the CCA graphical output. In other words, if any CW sites occurred on the "REF side" of the ordination, it could be assumed that these sites exhibited characteristics more reflective of the identified REF condition than other CW sites. However, as shown on Figures 4-13 and 4-16, there was little, if any, overlap in either ordination (herbaceous or shrub-sapling). When we plotted FQI_{mod} against CCA site scores, both treatments showed a statistically significant linear relationship (see Figures 4-14 and 4-17). However, based on the low coefficients of determination in both cases, and the scatter of points on the right-hand (CW) side of either graph, the predictive power of FQI_{mod} as a tool for relating CW site condition to established REF conditions appears limited.

For example, on Figure 4-13, two sites (Sleeter Lake and Route 7) appear closer to the "REF side" than any other CW sites, showing some overlap with REF sites along Axis 1. However, these two sites are near the lower-middle portion of the CW $FQI_{h\text{-}mod}$ range (11.8 and 12.4, respectively). If higher floristic quality can be assumed to indicate successional "progress" toward the ecological endpoint (i.e., the reference condition, or the projected community, which in this case is a forested wetland), then our observations do not support that assumption. The fact that these are two of the oldest sites in the study is interesting, because it suggests that, in time, site conditions are approaching the reference state, particularly with respect to the soil C and N gradient. This observation seems to support the use of reference sites to compare soil development in created wetlands, a practice that has been used extensively by researchers in created and restored wetland studies (Gilliam et al. 1999, Vepraskas et al. 1999, Stolt et al. 2000, Hunter and Faulkner 2001, Hogan et al. 2004, D'Angelo et al. 2005). However, this phenomenon does not appear to be reflected in the floristic composition of the site – the lack of site clustering on the graph in both treatments (herbaceous and shrub-sapling) confirms that the CW and REF data sets are compositionally very different, even on the oldest CW sites. Therefore, we conclude that FQI is perhaps not appropriate for CW-to-REF site comparisons, particularly if mature forested wetland communities are used as REF sites.

5.2.5 Soil Nutrient Content and Community Correlations

Soil phosphorus showed statistically significant negative correlations with $FQI_{h\text{-}mod}$, species richness, and herbaceous species diversity and evenness among the CW sites. Auclair et al. (1976) reported similar negative correlations between P and species diversity measures in a freshwater marsh. One explanation may be the effect that soil P has on primary productivity, and the attendant relationship between richness and productivity. Increases in soil P levels have been shown to result in significant increases in productivity and standing crop biomass in freshwater wetlands (Chiang et al. 2000, Keddy 2000, Chapin et al. 2004). Standing crop biomass, in turn, has been found to be negatively correlated with species richness in several studies (Auclair et al. 1976, Huston 1979, Moore and Keddy 1989, Wisheu and Keddy 1989, Keddy 2000). The implication of these interactions in young wetlands is that P may be a limiting nutrient in early soil development, favoring higher species richness in a low-productivity environment.

The biogeochemical mechanism for such a P-limitation may be related to the degree of soil anaerobiosis in some young wetlands. Although soil redox potential does not directly affect phosphorus transformations, an indirect effect may occur in the presence of ferric (oxidized) iron, which immobilizes otherwise bioavailable phosphate by precipitation (Ponnamperuma 1972, Mohanty and Dash 1982). As anoxia proceeds in saturated soils, iron-bound phosphorus may be released as bioavailable phosphate when ferric iron is reduced to ferrous iron by anaerobic microbial respiration (Stauffer and Brooks 1997, Mitsch and Gosselink 2000, Hogan et al. 2004). In this manner, chemical reduction in created wetland soils can reverse a P-limiting condition in the soil medium.

If this process were occurring in our CW sites, the lack of a statistically significant correlation between P and site age would suggest that the phenomenon may not be completely time-dependent. Therefore, this process could also be related to other factors such as degree of soil wetness and soil organic matter content, the latter of which provides the primary source of electrons used for the reduction reactions characteristic of anaerobic soils (Vepraskas and Faulkner 2001, Megonigal et al. 2004). At the outset, wetland hydrology was a controlled variable in this study through the site selection process – each site was required to have met the federal definition of wetland hydrology. Presumably, this meant that soil wetness was sufficient to create reducing conditions in the shallow soil profile at each site (Environmental Laboratory 1987). If true, then soil organic matter may have been the most important link in mediating P transformations among our sites. It is in fact the case that soil carbon was positively correlated with soil P. Although the correlation was statistically non-significant (Spearman's rho = 0.177, p=0.528), soil carbon was one of only a few parameters with which P was *positively* correlated. However, neither C nor P were significantly correlated with site age, a result that conflicts with other studies in created wetlands (Noon 1996, Nair et al. 2001, Campbell et al. 2002, Johns et al. 2004). This suggests that differences in biogeochemical processes on our sites may have been related to differences in site construction methods such as amount and type of organic soil amendments, which are likely to have been more common practices on younger sites due to advancements in wetland creation technology (S. Russell, VDOT, pers. comm.; Bischel-Machung et al. 1996). Further, since exposure of subsurface mineral soils increases the availability of P-sorption sites on, for instance, iron and aluminum complexes (Hogan et al. 2004), the use of organic amendments during construction to encourage water holding capacity and surface soil reduction may be very important in regulating P availability in created wetlands. This relationship is conceptualized in Figure 5-1.

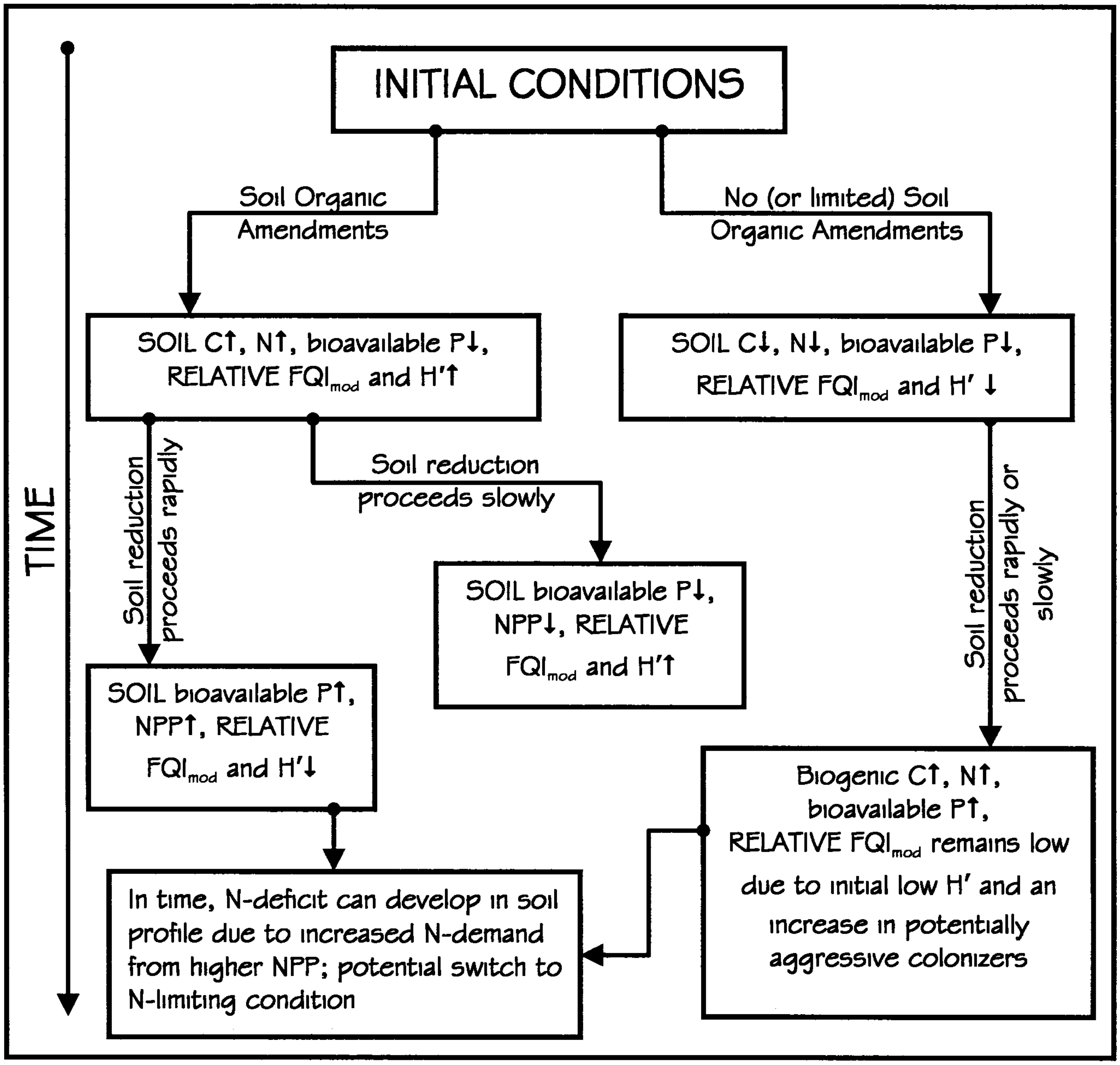

Figure 5-1. Conceptual model for CW herbaceous vegetation development expressed in terms of initial site conditions, soil chemistry, species diversity, and floristic quality. Arrows (↑↓) indicate *relative* increases or decreases in variables expected from the different biogeochemical and management scenarios. FQI$_{mod}$ = modified floristic quality index; C = organic carbon; P = bioavailable phosphorus; NPP = net primary productivity; H′ = species diversity.

5.2.6 "Initial Conditions" Model for Vegetation Development in Created Wetlands

From the observations generated in this study, we propose a conceptual model of vegetation development in created wetlands – the "Initial Conditions" model – as depicted in Figure 5-1. As the model indicates, organic amendments may create a favorable initial condition for higher species diversity at the outset, a relationship that has been observed in other studies (Reinhartz and Warne 1993, Noon 1996, Stauffer and Brooks 1997). However, on wetter sites, soil reduction will proceed more rapidly, resulting in an increase in bioavailable P with a potential decrease in species diversity and FQI_{mod}. This is often seen in sites that are inundated for long periods of time during the growing season, where species such as *Typha latifolia* and *Scirpus cyperinus* aggressively colonize and preempt other species by occupying space and monopolizing resources (Mitsch et al. 1995, Campbell et al. 2002, Atkinson et al. 2005). When this occurs, aggressive species have the capacity to rapidly translocate available nutrients to aboveground biomass, increasing growth and, therefore, competitive vigor for aboveground resources such as light (Davis 1991, Chiang et al. 2000). In our study, potentially aggressive species such as *Murdannia keisak*, *Juncus effusus*, and *Scirpus cyperinus* appeared to play this role on younger sites with lower diversity and higher P. Over time, the increase in aboveground biomass (facilitated by increased P-availability) could result in an N-deficit due to increased N-demand from high net primary productivity (NPP) (Bedford et al. 1997). In our study, N and C always occurred along parallel gradients, yet N and P gradients were generally antagonistic with one another across the chronosequence. This suggests a P-to-N limitation shift in created wetland sites that is mediated by initial conditions, organic amendments, and site hydrology.

The implication is that if species diversity and floristic quality are objectives for a particular wetland creation site, some amount of control over the hydrologic regime may be needed during the early years of vegetation development (Hammer 1996, Noon 1996). However, if degree of soil wetness is the primary management objective (as it is in most wetland creation projects; Bedford 1996), then a reduction in species diversity and FQI_{mod} should be *expected.* Over longer timeframes, the assumption is that once woody species begin to colonize a site and grow, there will be an associated increase in structural complexity and resource partitioning, and diversity and floristic quality will increase accordingly.

5.3 MANAGEMENT IMPLICATIONS

5.3.1 Practical Considerations

The abundance-weighted approach to FQI calculation applied in this study could be affected by time of year in which the community was sampled. As Swink and Wilhelm (1994) note, abundance is often an artifact of the season, particularly in the herbaceous layer where values may fluctuate in accordance with seasonal shifts in species dominance. However, most wetland permits require that vegetation compliance monitoring occur during peak growing season (e.g., late summer) on created wetland sites; therefore seasonality, and its effect on abundance measures, is perhaps not as significant a concern in monitoring CW sites since monitoring presumably will occur most often during the same timeframe among years.

Another consideration is the time required to generate importance values such as those used in this study. Since most CW sites are dominated by high-density graminoids (i.e., grasses and grass-like species), density counts can be time-consuming. Importance values provide the most complete representation of abundance within the community (Mueller-Dombois and Ellenberg 1974); however, any relative abundance measure could presumably be used to weight FQI in the manner applied in this study (McCune and Grace 2002). Most mitigation monitoring standards require some calculation of abundance (typically cover estimates) (USACE 2004, Spieles 2005), so we expect that abundance data would be available for many wetland creation sites that have been authorized by a wetland permit. The effect of alternative abundance-weighting metrics, such as relative cover, in calculating the modified FQI on CW sites is unknown. For wetland managers seeking a more rapid method of data collection and analysis in applying FQI to CW sites, further research in this area may be warranted.

Finally, FQI is limited to some extent by the field experience of the wetland scientists and botanists collecting the data (U.S. EPA 2002b). The accurate identification of several wetland plant taxa, such as grasses and sedges, requires a high level of field botany skill that is often not consistently represented across the population of scientists and wetland managers monitoring created sites (U.S. EPA 2002a). This presents the problem of consistency – if many conservative species are "overlooked" due to difficulty of identification, then FQI values can be artificially lowered by sampling bias irrespective of the actual conservatism of the community being sampled, and *vice versa.* We recommend that assessment teams be comprised of competent field botanists, and that quality assurance measures (e.g., voucher submittals to herbaria) be developed to ensure sampling consistency among studies.

5.3.2 Reference Wetlands and Created Wetland Floristic Quality Assessment

We noted several instances in which a younger CW site expressed a higher modified index relative to an older CW site. For example, in the 1-year old Reedy Creek site (1A-Reedy) we calculated $FQI_{h\text{-mod}}$ at 23.2, yet the 10-year old Proctor's Creek site (10B-Prct) had an $FQI_{h\text{-mod}}$ value of 14.8. It is unclear whether such CW-to-CW comparisons can be used to infer that the former is progressing toward an ecological endpoint (i.e., forested wetland) at an accelerated successional rate relative to the latter, particularly in the context of differences in substrate condition and nutrient dynamics discussed above.

Reference wetlands have been used extensively to evaluate soil conditions in created or restored wetlands (Gilliam et al. 1999, Vepraskas et al. 1999, Stolt et al. 2000, Hunter and Faulkner 2001, Hogan et al. 2004, D'Angelo et al. 2005), but have had limited application in comparative studies involving vegetation (Campbell et al. 2002, Balcombe et al. 2005a). In our study, the use of REF sites to address floristic quality in the CWs would have required some method of relating the *relative* differences between paired CW and REF FQI scores. In other words, to test whether one CW was "closer" to its REF site (i.e., ecological endpoint) than other CW-REF pairings, we would have needed an idealized REF wetland with the exact same attributes and FQI scores at each location. However, this arrangement is unrealistic in nature given the natural variability among wetlands (Keddy 2000, Mitsch and Gosselink 2000). Also, an idealized REF wetland is an unrealizable goal in such studies given the prevalence of anthropogenic disturbance in natural systems (USEPA 2002a). Although the concept of "minimally impaired" condition was applied in REF site selection, the range in site variables and FQIs among REF sites indicates the lack of uniformity across the REF data set.

The use of natural forested wetlands as reference sites for vegetation development in created wetland projects remains a dubious process that is perhaps too reliant on the subjectivity of the researchers involved in site selection. Floristic quality assessment avoids some of the difficulties associated with attempting to make direct comparisons between CW and REF sites by indexing site quality relative to species conservatism. However, due to the inherent discrepancies in species composition, abundance, and species conservatism between similar layers in CW and REF settings, direct CW-to-REF comparisons are perhaps inappropriate under the floristic quality approach. A more productive application of the FQI concept would be to identify a subset of *created wetlands* with high floristic quality and maximum ecological function for the type of wetlands attempting to be created, and use these as "reference wetlands" for comparative evaluations. The difficulty in this approach is that there are few wetland creation projects old enough to demonstrate that a functioning forested wetland system is an attainable goal. However, as our results indicate, $FQI_{h\text{-}mod}$ appears to reflect both floristic quality and ecological function, and may therefore provide a useful scale upon which to measure the success of CW sites in the context of ecological succession and management objectives.

5.3.3 FQI as a Component of Biotic Integrity

In this study, we have demonstrated that the FQI concept has strengths and limitations within the contexts of created wetland assessment and potential use in natural wetland systems. The FQI approach, in and of itself, is a reasonably reliable diagnostic tool in certain vegetation layers. However, if used as a component of a larger assessment strategy such as Index of Biotic Integrity (IBI), FQI could be profitably integrated into a more comprehensive evaluative approach. The biotic integrity concept is based on the premise that healthy ecosystems support and maintain a balanced, adaptive community of organisms with species diversity, composition, and functional organization comparable to that of natural habitats within a given region (Karr and Dudley 1981). The emphasis on natural habitats makes FQI a likely candidate for inclusion in a wetland IBI.

IBIs in freshwater wetlands are typically developed around one or a few taxonomic groups of organisms, including plants. Although specific metrics for vegetation assessment are often difficult to identify, plants are particularly compatible with this application because sampling protocols are well known, and because plants are ubiquitous in wetland environments (Cronk and Fenessey 2001, U.S. EPA 2002b). The biotic integrity concept is developed around the premise that ecosystems are affected by human alteration, and that the biological components within the system will display observable reactions to environmental stressors. Thus, the goal of wetland biological assessment is to evaluate wetland condition by inspection of the inhabiting organisms against the background of a human disturbance gradient anchored by reference conditions. Typically, each metric is plotted against site disturbance rank on a "dose-response" curve, and metrics showing significant relationships with the disturbance gradient are retained for the final IBI.

There are several benefits to this type of approach: 1) it considers a broad range of human disturbance factors across the spectrum of wetland sites being considered; 2) it is not limited to the concept of least and most impaired condition; and, 3) a disturbance index can be determined for each wetland using a rapid assessment approach (Gernes and Helgen 2002, U.S. EPA 2002a). Further, FQI is increasingly being used in different states as a component of wetland IBI programs in the U.S. (Mack et al. 2000, Gernes and Helgen 2002, Wilcox et al. 2002, Minc 2004). Examples of other vegetation metrics include: species richness, exotic species, native species, diversity, evenness, *Carex* species, invasive species, wetland taxa, sensitive species, number of plant guilds, perennial to annual species ratio, wetness index, etc. (U.S. EPA 2002b). Given the results of our study, one could also envision including soil nutrient content into a wetland IBI based on vegetation properties.

Although the biotic integrity concept has only recently gained acceptance as a theoretical approach to wetland assessment, the collective work of federal and state agencies and other stakeholders and professionals has produced a growing body of knowledge and literature on this subject (Adamus et al. 2001). While it is clear that no single environmental indicator (e.g., FQI) can provide all solutions to the problems of consistency and universal applicability in wetland assessment, it appears that the IBI approach has much to contribute. In this manner, a single technique such as FQI, used in association with other proven assessment metrics across a disturbance gradient, could provide a more holistic understanding of wetland condition that integrates not only floristic quality, but also ecosystem function. The challenge in created wetlands will be to establish a disturbance gradient across created wetland sites that is meaningful in the context of the wholesale disturbance regime that nearly all sites experience when created. Although time-since-disturbance should provide a surrogate measure of disturbance gradient, as we have seen in our study, age is not always equivalent to relative site condition. Perhaps the IBI concept would benefit from an understanding of initial conditions established when the site was constructed. If so, then a metric based on soil condition, as well as FQI, would be an appropriate component of a created wetland IBI in Virginia.

6.0 CONCLUSIONS

We collected vegetation data across a chronosequence of created wetland sites in Virginia and calculated Floristic Quality Index (FQI) for each site. This approach was also applied to a selection of forested reference wetlands. FQI was computed using several different versions of the core equation [$FQI = C' (\sqrt{N})$], and each version was tested for correlation with a suite of vegetation community indices and environmental variables. Based on our results, the following conclusions may be drawn regarding the structure and application of FQI in Virginia wetlands:

1. FQI should be calculated from native species richness and native species C-values. Use of non-native species introduces problems associated with using a C-value of zero for all non-native plants included on the Virginia C-value wetland plant list, irrespective of differences in tolerance to anthropogenic disturbance among non-native species. Creation of a separate exotic plant index has proven useful in other geographic areas and may be a beneficial undertaking in Virginia.

2. FQI should be calculated by vegetation layer. Compared with overall FQI calculated across layers, a vegetation layer-specific index is more likely to increase sensitivity to relative differences in floristic quality between sites.

3. A modified, abundance-weighted FQI shows promise as an indicator of wetland vegetation condition for the types of wetlands considered in this study. The abundance weight confers additional information about the community without losing relative site ranks based on conservatism alone, and appears to reflect ecological differences among created wetland sites in the herbaceous layer, and among natural forested wetland sites in the herbaceous and shrub-sapling layers, based on interpretation of community ordination results.

4. FQI should not be used to assess floristic differences in the shrub-sapling layer of created wetland sites. Planting of highly conservative species (i.e., with high C-values) on younger sites tends to inflate the final FQI calculation relative to older sites, giving limited information about the successional development of vegetation in this layer.

5. Due to ecological inertia, FQI may not be an appropriate assessment method to evaluate floristic quality in the tree layer. However, if FQI is to be used in this manner, the modified, abundance-weighted version increases sensitivity to differences in community composition and conservatism relative to the non-weighted index.

6. The unique correlation of modified FQI values with soil variables and site scores from the community ordination suggests a model of vegetation

development on created wetland sites that links initial site conditions, soil amendment practices, soil nutrient content, species diversity measures, and FQI.

The results of this study suggest that FQI holds promise as a tool for wetland vegetation assessment in Virginia. This may be particularly important in evaluating created wetland vegetation, a process that has historically been characterized by lack of consistency in methods used to compare sites. Our results also indicate that a modified, abundance-weighted FQI may provide more information about floristic quality and ecological succession than a non-weighted index. However, further research on the application of abundance weights in FQI calculation is warranted.

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APPENDIX A

Representative Site Photographs

SLEETER LAKE

Sleeter Lake (15-Sleet): Created wetland site (8-6-04).

Sleeter Lake reference wetland (72 years) (8-6-04).

BOWERS HILL

Bowers Hill (12B-Bwrh) created wetland site (7-8-04).

Bowers Hill reference wetland site (78 years) (9-24-04).

ROUTE 7

Route 7 (12A-Rte7) created wetland site (8-3-04).

Route 7 reference wetland site (39 years) (9-8-05). (Author pictured).

COURTLAND BYPASS

Courtland Bypass (11-Court) created wetland site (5-28-04).

Courtland Bypass reference wetland site (65 years) (9-16-04).

PROCTOR'S CREEK

Proctor's Creek (10B-Prct) created wetland site (9-7-04).

Proctor's Creek reference wetland site (43 years) (6-11-04).

FRANKLIN BYPASS

Franklin Bypass (10A-Fkln) created wetland site (7-8-04).

Franklin Bypass reference wetland site (87 years) (7-8-04).

CHARLES CITY

Charles City (7-ChsCty) created wetland site (9-2-04).

Charles City reference wetland site (82 years) (9-2-04).

STONY CREEK

Stony Creek (6-Stony) created wetland site (8-24-05).

Stony Creek reference wetland site (57 years) (8-24-05).

FORT LEE

Fort Lee (5-FtLee) created wetland site (9-7-04).

Fort Lee reference wetland site (56 years) (9-7-04).

POWHITE PARKWAY

Powhite Parkway (4B-Pwhte) created wetland site (9-29-04).

Powhite Parkway reference wetland site (69 years) (9-8-05).

MANASSAS

Manassas (4A-Manas) created wetland site (8-2-04).

Manassas reference wetland site (79 years) (8-18-04).

MOUNT STIRLING

Mount Stirling (3-MtStir) created wetland site (8-30-04).

Mount Stirling reference wetland site (37 years) (8-26-04).

SOUTHWEST SUFFOLK

Southwest Suffolk (2-SWSfk) created wetland site (9-17-04).

Southwest Suffolk reference wetland site (85 years) (9-27-05).

MATTAPONI

Mattaponi (1B-Matta) created wetland site (8-13-04).

Mattaponi reference wetland site (58 years) (8-20-04).

REEDY CREEK

Reedy Creek (1A-Reedy) created wetland site (8-23-04).

Reedy Creek reference wetland site (71 years) (8-23-04).

APPENDIX B

Herbarium Voucher Species Checklist

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Acalypha rhomboidea Raf.	Chesterfield	Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	813	Euphorbiaceae
Acer rubrum L.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	9/8/2005	D. A. DeBerry	696	Aceraceae
Acer saccharinum L.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	9/8/2005	D. A. DeBerry	695	Aceraceae
Aeschynomene indica L.	Southampton	Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin; approximately 250 feet south of Route 58 Bypass just west of Blackwater River floodplain.	10/12/2005	D. A. DeBerry	838	Fabaceae
Agalinis purpurea (L.) Pennell	Prince George	Fort Lee VDOT wetland creation site; approximately 1 mile north of Interstate 295 and Route 36 intersection west of Hopewell; approximately 300 feet due east of Interstate 295.	9/12/2005	D. A. DeBerry	722	Scrophulariaceae
Agrostis perennans (Walt.) Tuckerman	Chesterfield	Forested wetlands in Powhite Park 0.3 miles east-northeast of Chippenham Parkway/Powhite Parkway intersection in floodplain of Powhite Creek; south side of floodplain.	9/8/2005	D. A. DeBerry	710	Poaceae
Alisma subcordatum Raf.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	7/14/2005	D. A. DeBerry	662	Alismataceae
Alnus serrulata (Ait.) Willd.	Southampton	Forested wetlands in Nottoway River floodplain north of Courtland Bypass VDOT wetland creation site; 1.6 miles south of Courtland on the north side of Route 58 Bypass, west of Nottoway River.	10/11/2005	D. A. DeBerry	783	Betulaceae
Alnus serrulata (Ait.) Willd.	Southampton	Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin; approximately 250 feet south of Route 58 Bypass just west of Blackwater River floodplain.	10/12/2005	D. A. DeBerry	828	Betulaceae
Ambrosia artemisiifolia L.	Chesapeake	Bowers Hill VDOT wetland creation site; west line of Interstate 664 and 0.25 miles north of Joliff Road.	9/13/2005	D. A. DeBerry	735	Asteraceae
Amelanchier arborea (Michx. f.) Fern.	Southampton	Forested wetlands east of Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin, approximately 250 feet south of Route 58 Bypass along western flank of Blackwater River floodplain.	10/12/2005	D. A. DeBerry	830	Rosaceae
Andropogon virginicus L.	Chesapeake	Bowers Hill VDOT wetland creation site; west line of Interstate 664 and 0.25 miles north of Joliff Road.	9/13/2005	D. A. DeBerry	734	Poaceae
Apios americana Medik.	Southampton	Forested wetlands in Nottoway River floodplain north of Courtland Bypass VDOT wetland creation site; 1.6 miles south of Courtland on the north side of Route 58 Bypass, west of Nottoway River.	10/11/2005	D. A. DeBerry	778	Fabaceae

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Arisaema triphyllum (L.) Schott	Chesapeake	Forested wetlands along west line of Branchview Way northwest of Bowers Hill, due west of Interstate 664/Route 58 intersection.	9/27/2005	D. A. DeBerry	758	Araceae
Arthraxon hispidus (Thunb.) Makino	Fairfax	Route 7 VDOT wetland creation site; north line of Route 7 approximately 0.2 miles east of Loudoun/Fairfax County line.	9/10/2005	D. A. DeBerry	822	Poaceae
Arundinaria gigantea (Walt.) Muhl.	Chesapeake	Forested wetlands along west line of Branchview Way northwest of Bowers Hill, due west of Interstate 664/Route 58 intersection.	9/27/2005	D. A. DeBerry	749	Poaceae
Asclepias incarnata L.	Chesterfield	Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection on north side of Proctor's Creek floodplain.	8/23/2005	D. A. DeBerry	676	Asclepiadaceae
Asimina triloba (L.) Dunal	Charles City	Forested wetlands immediately south of Charles City VDOT wetland creation site; 0.2 miles west-southwest of Route 623/Route 621 intersection	10/14/2005	D. A. DeBerry	841	Annonaceae
Athyrium filix-femina (L.) Roth	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/15/2005	D. A. DeBerry	775	Dryopteridaceae
Baccharis halimifolia L.	Suffolk	Southwest Suffolk VDOT wetland creation site; 1 mile southeast of U.S. 58 and Route 688 intersection.	10/12/2005	D. A. DeBerry	824	Asteraceae
Betula nigra L.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	9/8/2005	D. A. DeBerry	708	Betulaceae
Bidens aristosa (Michx.) Britt.	Southampton	Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin; approximately 250 feet south of Route 58 Bypass just west of Blackwater River floodplain.	9/12/2005	D. A. DeBerry	723	Asteraceae
Bidens discoidea (Torr. & Gray) Britt.	**Charles City**	**Charles City VDOT wetland creation site; 0.2 miles west of Route 623/Route 621 intersection along eastern perimeter of wetland creation site.**	**10/12/2005**	**D. A. DeBerry**	**823**	**Asteraceae**
Bidens tripartita L.	**Chesterfield**	**Forested wetlands in Powhite Park 0.3 miles east-northeast of Chippenham Parkway/Powhite Parkway intersection in floodplain of Powhite Creek; south side of floodplain.**	**9/8/2005**	**D. A. DeBerry**	**712**	**Asteraceae**
Bignonia capreolata L.	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	9/27/2005	D. A. DeBerry	755	Bignoniaceae
Boehmeria cylindrica (L.) Sw.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	7/14/2005	D. A. DeBerry	656	Urticaceae
Campsis radicans (L.) Seem. ex Bureau	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	795	Bignoniaceae

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Carex amphibola Steud.	Caroline	Forested wetlands west of Mattaponi VDOT wetland creation site; 0.2 miles west of Town of Milford along eastern flank of Mattaponi River floodplain.	5/19/2004	D. A. DeBerry	635	Cyperaceae
Carex atlantica Bailey	Caroline	Forested wetlands west of Mattaponi VDOT wetland creation site; 0.2 miles west of Town of Milford along eastern flank of Mattaponi River floodplain.	5/19/2004	D. A. DeBerry	634	Cyperaceae
Carex crinita Lam.	Southampton	Forested wetlands in Nottoway River floodplain north of Courtland Bypass VDOT wetland creation site; 1.6 miles south of Courtland on the north side of Route 58 Bypass, west of Nottoway River.	10/11/2005	D. A. DeBerry	777	Cyperaceae
Carex folliculata L.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	5/19/2004	D. A. DeBerry	631	Cyperaceae
Carex joorii Bailey	Southampton	Forested wetlands east of Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin, approximately 250 feet south of Route 58 Bypass along western flank of Blackwater River floodplain.	10/12/2005	D. A. DeBerry	836	Cyperaceae
Carex lupulina Muhl. ex Willd.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	7/14/2005	D. A. DeBerry	658	Cyperaceae
Carex lupulina Muhl. ex Willd.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	9/8/2005	D. A. DeBerry	703	Cyperaceae
Carex lurida Wahlenb.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	7/14/2005	D. A. DeBerry	659	Cyperaceae
Carex lurida Wahlenb.	Chesterfield	Forested wetlands in Powhite Park 0.3 miles east-northeast of Chippenham Parkway/Powhite Parkway intersection in floodplain of Powhite Creek; south side of floodplain.	9/8/2005	D. A. DeBerry	711	Cyperaceae
Carex projecta Mackenzie	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	7/14/2005	D. A. DeBerry	654	Cyperaceae
Carex seorsa Howe	Charles City	Forested wetlands immediately south of Charles City VDOT wetland creation site; 0.2 miles west-southwest of Route 623/Route 621 intersection	5/17/2005	D. A. DeBerry	641	Cyperaceae
Carex stipata Muhl. ex Willd.	Caroline	Forested wetlands west of Mattaponi VDOT wetland creation site; 0.2 miles west of Town of Milford along eastern flank of Mattaponi River floodplain.	5/19/2004	D. A. DeBerry	633	Cyperaceae

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Carex typhina Michx.	Caroline	Forested wetlands west of Mattaponi VDOT wetland creation site; 0.2 miles west of Town of Milford along eastern flank of Mattaponi River floodplain.	5/19/2004	D. A. DeBerry	632	Cyperaceae
Carpinus caroliniana Walt.	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	9/27/2005	D. A. DeBerry	760	Betulaceae
Carya aquatica (Michx. f.) Nutt.	Charles City	Forested wetlands north of Mount Stirling VDOT wetland creation site; just inside treeline on southern perimeter of Chickahominy River east of Route 155.	10/14/2005	D. A. DeBerry	844	Juglandaceae
Carya ovata (P. Mill.) K. Koch	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	803	Juglandaceae
Cephalanthus occidentalis L.	Chesterfield	Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection on north side of Proctor's Creek floodplain.	8/23/2005	D. A. DeBerry	679	Rubiaceae
Chasmanthium latifolium (Michx.) Yates	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	7/14/2005	D. A. DeBerry	655	Poaceae
Chasmanthium laxum (L.) Yates	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	9/27/2005	D. A. DeBerry	754	Poaceae
Cicuta maculata L.	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	9/27/2005	D. A. DeBerry	747	Apiaceae
Cinna arundinacea L.	Chesterfield	Forested wetlands in Proctor's Creek floodplain south of Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection.	8/23/2005	D. A. DeBerry	668	Poaceae
Cinna arundinacea L.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	9/8/2005	D. A. DeBerry	698	Poaceae
Clethra alnifolia L.	Chesterfield	Forested wetlands in Proctor's Creek floodplain south of Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection.	8/23/2005	D. A. DeBerry	666	Clethraceae
Commelina virginica L.	Chesapeake	Forested wetlands along west line of Branchview Way northwest of Bowers Hill, due west of Interstate 664/Route 58 intersection.	9/24/2004	D. A. DeBerry	643	Commelinaceae
Cornus amomum P. Mill.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	9/8/2005	D. A. DeBerry	700	Cornaceae
Cornus foemina P. Mill.	Southampton	Forested wetlands in Nottoway River floodplain north of Courtland Bypass VDOT wetland creation site; 1.6 miles south of Courtland on the north side of Route 58 Bypass, west of Nottoway River.	10/11/2005	D. A. DeBerry	781	Cornaceae

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Crataegus phaenopyrum (L. f.) Medik.	Southampton	Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin; approximately 250 feet south of Route 58 Bypass just west of Blackwater River floodplain.	10/12/2005	D. A. DeBerry	837	Rosaceae
Cuphea carthagenensis (Jacq.) J.F. MacBr.	**Suffolk**	**Southwest Suffolk VDOT wetland creation site; 1 mile southeast of U.S. 58 and Route 688 intersection.**	**9/17/2004**	**D. A. DeBerry**	**638**	**Lythraceae**
Cyperus erythrorhizos Muhl.	Sussex	Stony Creek VDOT wetland creation site; north line of Route 40 approximately 1.5 miles east of Town of Stony Creek in Nottoway River floodplain.	8/24/2005	D. A. DeBerry	690	Cyperaceae
Cyperus pseudovegetus Steud.	Charles City	Charles City VDOT wetland creation site; 0.2 miles west of Route 623/Route 621 intersection along eastern perimeter of wetland creation site.	9/12/2005	D. A. DeBerry	720	Cyperaceae
Cyperus strigosus L.	Charles City	Charles City VDOT wetland creation site; 0.2 miles west of Route 623/Route 621 intersection along eastern perimeter of wetland creation site.	9/21/2005	D. A. DeBerry	739	Cyperaceae
Decumaria barbara L.	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	9/27/2005	D. A. DeBerry	753	Hydrangeaceae
Dichanthelium clandestinum (L.) Gould	Chesterfield	Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection on north side of Proctor's Creek floodplain.	10/11/2005	D. A. DeBerry	768	Poaceae
Dichanthelium dichotomum (L.) Gould	Chesterfield	Forested wetlands in Proctor's Creek floodplain south of Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection.	10/11/2005	D. A. DeBerry	769	Poaceae
Dichanthelium scoparium (Lam.) Gould	Southampton	Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin; approximately 250 feet south of Route 58 Bypass just west of Blackwater River floodplain.	9/12/2005	D. A. DeBerry	725	Poaceae
Digitaria ischaemum (Schreb.) Schreb. ex Muhl.	**Chesterfield**	**Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.**	**10/11/2005**	**D. A. DeBerry**	**810**	**Poaceae**
Digitaria sanguinalis (L.) Scop.	Suffolk	Southwest Suffolk VDOT wetland creation site; 1 mile southeast of U.S. 58 and Route 688 intersection.	9/12/2005	D. A. DeBerry	730	Poaceae
Diodia virginiana L.	Chesterfield	Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	807	Rubiaceae
Dioscorea villosa L.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	800	Dioscoreaceae
Diospyros virginiana L.	Sussex	Forested wetlands in Nottoway River floodplain north of Stony Creek VDOT wetland creation site; 1.5 miles east of Town of Stony Creek on the north side of Route 40.	9/10/2005	D. A. DeBerry	785	Ebenaceae
Echinochloa muricata (Beauv.) Fern.	**Chesterfield**	**Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection on north side of Proctor's Creek floodplain.**	**8/23/2005**	**D. A. DeBerry**	**677**	**Poaceae**

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Eclipta prostrata (L.) L.	Chesterfield	Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	805	Asteraceae
Eleocharis obtusa (Willd.) J.A. Schultes	Chesterfield	Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection on north side of Proctor's Creek floodplain.	8/23/2005	D. A. DeBerry	678	Cyperaceae
Elymus virginicus L.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	9/8/2005	D. A. DeBerry	715	Poaceae
Erechtites hieraciifolia (L.) Raf. ex DC.	Sussex	Forested wetlands in Nottoway River floodplain north of Stony Creek VDOT wetland creation site; 1.5 miles east of Town of Stony Creek on the north side of Route 40.	9/12/2005	D. A. DeBerry	726	Asteraceae
Euonymus americana L.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	788	Celastraceae
Eupatorium capillifolium (Lam.) Small	Sussex	Forested wetlands in Nottoway River floodplain north of Stony Creek VDOT wetland creation site; 1.5 miles east of Town of Stony Creek on the north side of Route 40.	9/13/2005	D. A. DeBerry	731	Asteraceae
Eupatorium dubium Willd. ex Poir.	Chesapeake	Forested wetlands along west line of Branchview Way northwest of Bowers Hill, due west of Interstate 664/Route 58 intersection.	9/24/2004	D. A. DeBerry	642	Asteraceae
Eupatorium dubium Willd. ex Poir.	**Chesterfield**	**Forested wetlands in Proctor's Creek floodplain south of Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection.**	**9/27/2005**	**D. A. DeBerry**	**763**	**Asteraceae**
Euthamia graminifolia (L.) Nutt.	Charles City	Charles City VDOT wetland creation site; 0.2 miles west of Route 623/Route 621 intersection along eastern perimeter of wetland creation site.	9/12/2005	D. A. DeBerry	718	Asteraceae
Fagus grandifolia Ehrh.	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	9/27/2005	D. A. DeBerry	752	Fagaceae
Fraxinus pennsylvanica Marsh.	**Chesterfield**	**Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.**	**9/8/2005**	**D. A. DeBerry**	**697**	**Oleaceae**
Fuirena squarrosa Michx.	Suffolk	Southwest Suffolk VDOT wetland creation site; 1 mile southeast of U.S. 58 and Route 688 intersection.	9/17/2004	D. A. DeBerry	637	Cyperaceae
Galium tinctorium L.	**Chesterfield**	**Powhite Parkway VDOT wetland creation site; 450 feet south of Piney Lane in Powhite Creek floodplain.**	**10/12/2005**	**D. A. DeBerry**	**821**	**Rubiaceae**
Geum canadense Jacq.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	9/8/2005	D. A. DeBerry	707	Rosaceae
Glyceria striata (Lam.) A.S. Hitchc.	Sussex	Forested wetlands in Nottoway River floodplain north of Stony Creek VDOT wetland creation site; 1.5 miles east of Town of Stony Creek on the north side of Route 40.	9/21/2005	D. A. DeBerry	740	Poaceae

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Hibiscus moscheutos L.	Chesterfield	Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	808	Malvaceae
Hydrocotyle ranunculoides L. f.	Chesterfield	Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection on north side of Proctor's Creek floodplain.	8/23/2005	D. A. DeBerry	672	Apiaceae
Hydrocotyle umbellata L.	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	9/27/2005	D. A. DeBerry	762	Apiaceae
Hydrolea quadrivalvis Walt.	Sussex	Stony Creek VDOT wetland creation site; north line of Route 40 approximately 1.5 miles east of Town of Stony Creek in Nottoway River floodplain.	8/24/2005	D. A. DeBerry	682	Hydrophyllaceae
Hypericum mutilum L.	Southampton	Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin; approximately 250 feet south of Route 58 Bypass just west of Blackwater River floodplain.	10/12/2005	D. A. DeBerry	835	Clusiaceae
Ilex decidua Walt.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	7/14/2005	D. A. DeBerry	663	Aquifoliaceae
Ilex decidua Walt.	Charles City	Forested wetlands north of Mount Stirling VDOT wetland creation site; just inside treeline on southern perimeter of Chickahominy River east of Route 155.	10/14/2005	D. A. DeBerry	842	Aquifoliaceae
Ilex opaca Ait.	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	9/27/2005	D. A. DeBerry	757	Aquifoliaceae
Ilex verticillata (L.) Gray	Chesterfield	Forested wetlands in Proctor's Creek floodplain south of Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection.	8/23/2005	D. A. DeBerry	669	Aquifoliaceae
Impatiens capensis Meerb.	Loudoun	Sleeter Lake VDOT wetland creation site; south line of Route 7 Bypass in Catoctin Creek floodplain approximately 1 mile northwest of Purcellville.	7/13/2005	D. A. DeBerry	647	Balsaminaceae
Impatiens capensis Meerb.	Chesterfield	Forested wetlands in Powhite Park 0.3 miles east-northeast of Chippenham Parkway/Powhite Parkway intersection in floodplain of Powhite Creek; south side of floodplain.	9/8/2005	D. A. DeBerry	714	Balsaminaceae
Iris virginica L.	Southampton	Forested wetlands east of Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin, approximately 250 feet south of Route 58 Bypass along western flank of Blackwater River floodplain.	10/12/2005	D. A. DeBerry	833	Iridaceae
Itea virginica L.	Southampton	Forested wetlands in Nottoway River floodplain north of Courtland Bypass VDOT wetland creation site; 1.6 miles south of Courtland on the north side of Route 58 Bypass, west of Nottoway River.	10/11/2005	D. A. DeBerry	779	Grossulariaceae

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Juncus acuminatus Michx.	Charles City	Charles City VDOT wetland creation site; 0.2 miles west of Route 623/Route 621 intersection along eastern perimeter of wetland creation site.	9/12/2005	D. A. DeBerry	721	Juncaceae
Juncus effusus L.	Loudoun	Sleeter Lake VDOT wetland creation site; south line of Route 7 Bypass in Catoctin Creek floodplain approximately 1 mile northwest of Purcellville.	7/13/2005	D. A. DeBerry	649	Juncaceae
Juncus tenuis Willd.	Loudoun	Sleeter Lake VDOT wetland creation site; south line of Route 7 Bypass in Catoctin Creek floodplain approximately 1 mile northwest of Purcellville.	7/13/2005	D. A. DeBerry	651	Juncaceae
Kummerowia striata (Thunb.) Schindl.	Chesapeake	Bowers Hill VDOT wetland creation site; west line of Interstate 664 and 0.25 miles north of Joliff Road.	9/13/2005	D. A. DeBerry	736	Fabaceae
Leersia lenticularis Michx.	Sussex	Forested wetlands in Nottoway River floodplain north of Stony Creek VDOT wetland creation site; 1.5 miles east of Town of Stony Creek on the north side of Route 40.	8/24/2005	D. A. DeBerry	691	Poaceae
Leersia oryzoides (L.) Sw.	Charles City	Mount Stirling VDOT wetland creation site; southern perimeter of Chickahominy River floodplain approximately 350 feet east of Route 155.	9/12/2005	D. A. DeBerry	716	Poaceae
Leersia virginica Willd.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	9/8/2005	D. A. DeBerry	704	Poaceae
Lespedeza cuneata (Dum.-Cours.) G. Don	Chesapeake	Bowers Hill VDOT wetland creation site; west line of Interstate 664 and 0.25 miles north of Joliff Road.	9/13/2005	D. A. DeBerry	733	Fabaceae
Lespedeza virginica (L.) Britt.	Chesterfield	Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	815	Fabaceae
Leucothoe racemosa (L.) Gray	Southampton	Forested wetlands in Nottoway River floodplain north of Courtland Bypass VDOT wetland creation site; 1.6 miles south of Courtland on the north side of Route 58 Bypass, west of Nottoway River.	10/11/2005	D. A. DeBerry	782	Ericaceae
Leucothoe racemosa (L.) Gray	Southampton	Forested wetlands east of Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin, approximately 250 feet south of Route 58 Bypass along western flank of Blackwater River floodplain.	10/12/2005	D. A. DeBerry	829	Ericaceae
Ligustrum sinense Lour.	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	10/12/2005	D. A. DeBerry	827	Oleaceae
Lindera benzoin (L.) Blume	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	9/10/2005	D. A. DeBerry	793	Lauraceae
Lindernia dubia (L.) Pennell	Sussex	Forested wetlands in Nottoway River floodplain north of Stony Creek VDOT wetland creation site; 1.5 miles east of Town of Stony Creek on the north side of Route 40.	8/24/2005	D. A. DeBerry	688	Scrophulariaceae

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Liquidambar styraciflua L.	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	9/27/2005	D. A. DeBerry	750	Hamamelidaceae
Liriodendron tulipifera L.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	787	Magnoliaceae
Lobelia cardinalis L.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	8/4/2005	D. A. DeBerry	665	Campanulaceae
Lonicera japonica Thunb.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	801	Caprifoliaceae
Ludwigia alternifolia L.	Chesterfield	Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection on north side of Proctor's Creek floodplain.	8/23/2005	D. A. DeBerry	673	Onagraceae
Ludwigia bonariensis (M. Micheli) Hara	**Suffolk**	**Southwest Suffolk VDOT wetland creation site; 1 mile southeast of U.S. 58 and Route 688 intersection.**	**9/21/2004**	**D. A. DeBerry**	**639**	**Onagraceae**
Ludwigia decurrens Walt.	Sussex	Stony Creek VDOT wetland creation site; north line of Route 40 approximately 1.5 miles east of Town of Stony Creek in Nottoway River floodplain.	8/24/2005	D. A. DeBerry	683	Onagraceae
Ludwigia glandulosa Walt.	Sussex	Stony Creek VDOT wetland creation site; north line of Route 40 approximately 1.5 miles east of Town of Stony Creek in Nottoway River floodplain.	8/24/2005	D. A. DeBerry	689	Onagraceae
Ludwigia leptocarpa (Nutt.) Hara	**Sussex**	**Forested wetlands in Nottoway River floodplain north of Stony Creek VDOT wetland creation site; 1.5 miles east of Town of *Stony Creek on the north side of Route 40.***	**9/29/2004**	**D. A. DeBerry**	**644**	**Onagraceae**
Ludwigia leptocarpa (Nutt.) Hara	Sussex	Forested wetlands in Nottoway River floodplain north of Stony Creek VDOT wetland creation site; 1.5 miles east of Town of Stony Creek on the north side of Route 40.	9/11/2005	D. A. DeBerry	818	Onagraceae
Ludwigia palustris (L.) Ell.	Chesterfield	Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection on north side of Proctor's Creek floodplain.	8/23/2005	D. A. DeBerry	671	Onagraceae
Lycopus americanus Muhl. ex W. Bart.	Chesterfield	Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	812	Lamiaceae
Lycopus rubellus Moench	Southampton	Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin; approximately 250 feet south of Route 58 Bypass just west of Blackwater River floodplain.	10/12/2005	D. A. DeBerry	834	Lamiaceae
Lycopus virginicus L.	Chesterfield	Forested wetlands in Powhite Park 0.3 miles east-northeast of Chippenham Parkway/Powhite Parkway intersection in floodplain of Powhite Creek; south side of floodplain.	9/8/2005	D. A. DeBerry	713	Lamiaceae

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Lysimachia nummularia L.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	9/8/2005	D. A. DeBerry	706	Primulaceae
Microstegium vimineum (Trin.) A. Camus	Loudoun	Sleeter Lake VDOT wetland creation site; south line of Route 7 Bypass in Catoctin Creek floodplain approximately 1 mile northwest of Purcellville.	7/13/2005	D. A. DeBerry	646	Poaceae
Mikania scandens (L.) Willd.	Chesterfield	Forested wetlands in Proctor's Creek floodplain south of Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection.	8/23/2005	D. A. DeBerry	670	Asteraceae
Mimulus alatus Ait.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	8/4/2005	D. A. DeBerry	664	Scrophulariaceae
Morella cerifera (L.) Small	Southampton	Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin; approximately 250 feet south of Route 58 Bypass just west of Blackwater River floodplain.	9/10/2005	D. A. DeBerry	839	Myricaceae
Murdannia keisak (Hassk.) Hand.-Maz.	Chesterfield	Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection on north side of Proctor's Creek floodplain.	8/23/2005	D. A. DeBerry	674	Commelinaceae
Nyssa biflora Walt.	**Southampton**	**Forested wetlands in Nottoway River floodplain north of Courtland Bypass VDOT wetland creation site; 1.6 miles south of Courtland on the north side of Route 58 Bypass, west of Nottoway River.**	**10/11/2005**	**D. A. DeBerry**	**780**	**Nyssaceae**
Nyssa sylvatica Marsh.	Chesterfield	Forested wetlands in Proctor's Creek floodplain south of Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection.	10/11/2005	D. A. DeBerry	766	Nyssaceae
Onoclea sensibilis L.	Southampton	Forested wetlands in Nottoway River floodplain north of Courtland Bypass VDOT wetland creation site; 1.6 miles south of Courtland on the north side of Route 58 Bypass, west of Nottoway River.	10/12/2005	D. A. DeBerry	817	Dryopteridaceae
Oxalis stricta L.	Chesterfield	Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	809	Oxalidaceae
Panicum dichotomiflorum Michx.	Sussex	Stony Creek VDOT wetland creation site; north line of Route 40 approximately 1.5 miles east of Town of Stony Creek in Nottoway River floodplain.	9/12/2005	D. A. DeBerry	729	Poaceae
Panicum rigidulum Bosc ex Nees	Chesterfield	Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	806	Poaceae
Panicum rigidulum Bosc ex Nees *var. elongatum* (Pursh) Lelong	**Charles City**	**Mount Stirling VDOT wetland creation site; southern perimeter of Chickahominy River floodplain approximately 350 feet east of Route 155.**	**9/12/2005**	**D. A. DeBerry**	**717**	**Poaceae**

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Panicum verrucosum Muhl.	Southampton	Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin; approximately 250 feet south of Route 58 Bypass just west of Blackwater River floodplain.	9/12/2005	D. A. DeBerry	724	Poaceae
Panicum virgatum L.	Charles City	Charles City VDOT wetland creation site; 0.2 miles west of Route 623/Route 621 intersection along eastern perimeter of wetland creation site.	9/21/2005	D. A. DeBerry	738	Poaceae
Parthenocissus quinquefolia (L.) Planch.	Chesterfield	Forested wetlands in Proctor's Creek floodplain south of Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection.	10/11/2005	D. A. DeBerry	770	Vitaceae
Paspalum laeve Michx.	Prince William	Manassas VDOT wetland creation site; 0.6 miles east of Manassas Municipal Airport on east side of Broad Run, south-central region of wetland creation site.	10/12/2005	D. A. DeBerry	840	Poaceae
Peltandra virginica (L.) Schott	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	7/14/2005	D. A. DeBerry	660	Araceae
Penthorum sedoides L.	Chesterfield	Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	7/14/2005	D. A. DeBerry	657	Crassulaceae
Photinia pyrifolia (Lam.) Robertson & Phipps	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	799	Rosaceae
Pilea pumila (L.) Gray	Chesterfield	Forested wetlands in Powhite Park 0.3 miles east-northeast of Chippenham Parkway/Powhite Parkway intersection in floodplain of Powhite Creek; south side of floodplain.	9/27/2005	D. A. DeBerry	743	Urticaceae
Pinus taeda L.	Chesterfield	Forested wetlands in Proctor's Creek floodplain south of Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection.	10/11/2005	D. A. DeBerry	786	Pinaceae
Platanus occidentalis L.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	9/8/2005	D. A. DeBerry	702	Platanaceae
Pluchea camphorata (L.) DC.	Chesterfield	Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	804	Asteraceae
Polygonum arifolium L.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	9/8/2005	D. A. DeBerry	705	Polygonaceae
Polygonum caespitosum Blume	Sussex	Forested wetlands in Nottoway River floodplain north of Stony Creek VDOT wetland creation site; 1.5 miles east of Town of Stony Creek on the north side of Route 40.	8/24/2005	D. A. DeBerry	686	Polygonaceae
Polygonum hydropiperoides Michx.	Chesterfield	Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection on north side of Proctor's Creek floodplain.	8/23/2005	D. A. DeBerry	680	Polygonaceae

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Polygonum lapathifolium L.	**Caroline**	**Mattaponi VDOT wetland creation site; 0.2 miles west of Town of Milford in Mattaponi River floodplain, northwest region of wetland creation site.**	**10/12/2005**	**D. A. DeBerry**	**820**	**Polygonaceae**
Polygonum pensylvanicum L.	Sussex	Stony Creek VDOT wetland creation site; north line of Route 40 approximately 1.5 miles east of Town of Stony Creek in Nottoway River floodplain.	8/24/2005	D. A. DeBerry	684	Polygonaceae
Polygonum perfoliatum L.	Loudoun	Sleeter Lake VDOT wetland creation site; south line of Route 7 Bypass in Catoctin Creek floodplain approximately 1 mile northwest of Purcellville.	7/13/2005	D. A. DeBerry	652	Polygonaceae
Polygonum persicaria L.	Loudoun	Sleeter Lake VDOT wetland creation site; south line of Route 7 Bypass in Catoctin Creek floodplain approximately 1 mile northwest of Purcellville.	7/13/2005	D. A. DeBerry	650	Polygonaceae
Polygonum punctatum Ell.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	9/8/2005	D. A. DeBerry	699	Polygonaceae
Polygonum punctatum Ell.	Chesterfield	Forested wetlands in Powhite Park 0.3 miles east-northeast of Chippenham Parkway/Powhite Parkway intersection in floodplain of Powhite Creek; south side of floodplain.	9/27/2005	D. A. DeBerry	746	Polygonaceae
Polygonum sagittatum L.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	789	Polygonaceae
Polygonum virginianum L.	Chesterfield	Forested wetlands in Powhite Park 0.3 miles east-northeast of Chippenham Parkway/Powhite Parkway intersection in floodplain of Powhite Creek; south side of floodplain.	9/8/2005	D. A. DeBerry	693	Polygonaceae
Populus heterophylla L.	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	9/27/2005	D. A. DeBerry	759	Salicaceae
Proserpinaca palustris L.	Charles City	Forested wetlands north of Mount Stirling VDOT wetland creation site; just inside treeline on southern perimeter of Chickahominy River east of Route 155.	9/9/2005	D. A. DeBerry	843	Haloragaceae
Prunus serotina Ehrh.	Chesterfield	Forested wetlands in Proctor's Creek floodplain south of Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection.	10/11/2005	D. A. DeBerry	765	Rosaceae
Quercus alba L.	Chesterfield	Forested wetlands in Proctor's Creek floodplain south of Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection.	10/11/2005	D. A. DeBerry	774	Fagaceae
Quercus laurifolia Michx.	Southampton	Forested wetlands east of Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin, approximately 250 feet south of Route 58 Bypass along western flank of Blackwater River floodplain.	10/12/2005	D. A. DeBerry	832	Fagaceae

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Quercus lyrata Walt.	Charles City	Forested wetlands immediately south of Charles City VDOT wetland creation site; 0.2 miles west-southwest of Route 623/Route 621 intersection	10/12/2005	D. A. DeBerry	819	Fagaceae
Quercus michauxii Nutt.	Chesterfield	Forested wetlands in Proctor's Creek floodplain south of Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection.	10/11/2005	D. A. DeBerry	773	Fagaceae
Quercus nigra L.	Chesterfield	Forested wetlands in Proctor's Creek floodplain south of Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection.	10/11/2005	D. A. DeBerry	772	Fagaceae
Quercus palustris Muenchh.	Fairfax	Route 7 bridge at Difficult Run, northwest quadrant in floodplain; forested wetland approximately 100 feet north of road grade.	9/8/2005	D. A. DeBerry	694	Fagaceae
Quercus phellos L.	Prince George	Forested wetlands 150 east of Fort Lee VDOT wetland creation site; south perimeter of Cabin Creek flooplain just off northeast corner of wetland creation site.	10/11/2005	D. A. DeBerry	802	Fagaceae
Rhexia mariana L.	Southampton	Courtland Bypass VDOT wetland creation site; north line of U.S. 58 approximately 1.6 miles south-southwest of Town of Courtland.	9/12/2005	D. A. DeBerry	727	Melastomataceae
Rhynchospora corniculata (Lam.) Gray	Sussex	Forested wetlands in Nottoway River floodplain north of Stony Creek VDOT wetland creation site; 1.5 miles east of Town of Stony Creek on the north side of Route 40.	8/24/2005	D. A. DeBerry	687	Cyperaceae
Rorippa palustris (L.) Bess.	Sussex	Forested wetlands in Nottoway River floodplain north of Stony Creek VDOT wetland creation site; 1.5 miles east of Town of Stony Creek on the north side of Route 40.	8/24/2005	D. A. DeBerry	692	Brassicaceae
Rosa multiflora Thunb. ex Murr.	Chesterfield	Forested wetlands in Proctor's Creek floodplain south of Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection.	10/11/2005	D. A. DeBerry	767	Rosaceae
Rosa palustris Marsh.	Southampton	Forested wetlands east of Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin, approximately 250 feet south of Route 58 Bypass along western flank of Blackwater River floodplain.	10/12/2005	D. A. DeBerry	831	Rosaceae
Rotala ramosior (L.) Koehne	**Charles City**	**Charles City VDOT wetland creation site; 0.2 miles west of Route 623/Route 621 intersection along eastern perimeter of wetland creation site.**	**8/24/2005**	**D. A. DeBerry**	**685**	**Lythraceae**
Rubus hispidus L.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	791	Rosaceae
Rumex crispus L.	Suffolk	Southwest Suffolk VDOT wetland creation site; 1 mile southeast of U.S. 58 and Route 688 intersection.	10/12/2005	D. A. DeBerry	825	Polygonaceae

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Saccharum giganteum (Walt.) Pers.	Prince George	Fort Lee VDOT wetland creation site; approximately 1 mile north of Interstate 295 and Route 36 intersection west of Hopewell; approximately 300 feet due east of Interstate 295.	9/12/2005	D. A. DeBerry	728	Poaceae
Sacciolepis striata (L.) Nash	**Southampton**	**Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin; approximately 250 feet south of Route 58 Bypass just west of Blackwater River floodplain.**	**9/16/2004**	**D. A. DeBerry**	**636**	**Poaceae**
Salix nigra Marsh.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	798	Salicaceae
Saururus cernuus L.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	7/14/2005	D. A. DeBerry	661	Saururaceae
Scirpus atrovirens Willd.	Loudoun	Sleeter Lake VDOT wetland creation site; south line of Route 7 Bypass in Catoctin Creek floodplain approximately 1 mile northwest of Purcellville.	7/13/2005	D. A. DeBerry	648	Cyperaceae
Scirpus cyperinus (L.) Kunth	Chesterfield	Proctor's Creek VDOT wetland creation site; 0.8 miles due east of Route 288/Route 145 intersection on north side of Proctor's Creek floodplain.	8/23/2005	D. A. DeBerry	681	Cyperaceae
Scutellaria lateriflora L.	Chesterfield	Powhite Parkway VDOT wetland creation site; 450 feet south of Piney Lane in Powhite Creek floodplain.	9/27/2005	D. A. DeBerry	744	Lamiaceae
Senecio aureus L.	Chesterfield	Forested wetlands in Powhite Park 0.3 miles east-northeast of Chippenham Parkway/Powhite Parkway intersection in floodplain of Powhite Creek; south side of floodplain.	9/27/2005	D. A. DeBerry	741	Asteraceae
Setaria parviflora (Poir.) Kerguélen	Charles City	Charles City VDOT wetland creation site; 0.2 miles west of Route 623/Route 621 intersection along eastern perimeter of wetland creation site.	9/21/2005	D. A. DeBerry	737	Poaceae
Smilax bona-nox L.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	794	Smilacaceae
Smilax glauca Walt.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	797	Smilacaceae
Smilax laurifolia L.	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	9/27/2005	D. A. DeBerry	748	Smilacaceae
Smilax rotundifolia L.	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	796	Smilacaceae

Table B-1. Herbarium Voucher Checklist (county records in bold).

Scientific Name	County	Location and Site Description	Date	Collector	Coll. #	Family
Smilax walteri Pursh	**Southampton**	**Forested wetlands east of Franklin Bypass VDOT wetland creation site; 2.5 miles southeast of Franklin, approximately 250 feet south of Route 58 Bypass along western flank of Blackwater River floodplain.**	**9/29/2004**	**D. A. DeBerry**	**645**	**Smilacaceae**
Solanum carolinense L.	Charles City	Charles City VDOT wetland creation site; 0.2 miles west of Route 623/Route 621 intersection along eastern perimeter of wetland creation site.	10/12/2005	D. A. DeBerry	816	Solanaceae
Solidago canadensis L. var. scabra Torr. & Gray	Chesapeake	Bowers Hill VDOT wetland creation site; west line of Interstate 664 and 0.25 miles north of Joliff Road.	9/13/2005	D. A. DeBerry	732	Asteraceae
Solidago rugosa P. Mill.	Charles City	Charles City VDOT wetland creation site; 0.2 miles west of Route 623/Route 621 intersection along eastern perimeter of wetland creation site.	9/12/2005	D. A. DeBerry	719	Asteraceae
Symphoricarpos orbiculatus Moench	Chesterfield	Forested wetlands north of Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	811	Caprifoliaceae
Symphyotrichum lateriflorum (L.) A.& D. Löve var. lateriflorum	Chesterfield	Forested wetlands in Powhite Park 0.3 miles east-northeast of Chippenham Parkway/Powhite Parkway intersection in floodplain of Powhite Creek; south side of floodplain.	9/27/2005	D. A. DeBerry	742	Asteraceae
Symphyotrichum lateriflorum (L.) A.& D. Löve var. lateriflorum	Chesterfield	Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	764	Asteraceae
Symphyotrichum lateriflorum (L.) A.& D. Löve var. lateriflorum	Chesterfield	Reedy Creek VDOT wetland creation site; 1/4 mile northeast of Bevils Bridge on the Appomattox River floodplain.	10/11/2005	D. A. DeBerry	814	Asteraceae
Symplocarpus foetidus (L.) Salisb. ex Nutt.	Loudoun	Forested wetlands along south perimeter of Catoctin Creek floodplain south of Sleeter Lake VDOT wetland creation site; 1 mile northwest of Purcellville.	7/13/2005	D. A. DeBerry	653	Araceae
Taxodium distichum (L.) L.C. Rich.	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	9/27/2005	D. A. DeBerry	761	Taxodiaceae
Thelypteris noveboracensis (L.) Nieuwl.	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	9/27/2005	D. A. DeBerry	751	Thelypteridaceae
Triadenum virginicum (L.) Raf.	Suffolk	Forested wetlands east of Route 688 (Turlington Road) at Lake Kilby crossing; backwater reaches of Lake Kilby.	9/27/2005	D. A. DeBerry	756	Clusiaceae
Typha latifolia L.	Suffolk	Southwest Suffolk VDOT wetland creation site; 1 mile southeast of U.S. 58 and Route 688 intersection.	10/12/2005	D. A. DeBerry	826	Typhaceae

APPENDIX C

Species Checklist by Vegetation Layer with Relative IV

Table C-1. **CW herbaceous** species list with relative IV (dominant species in bold).

Species	Bayer Code	C	15-Sleet	12B-BwrH	12A-Rte7	11-Court	10B-Prct	10A-Fkln	7-ChsCty	6-Stony	5-FtLee	4B-Pwhte	4A-Manas	3-MtStir	2-SWSflk	1B-Matta	1A-Reedy	Overall
Acalypha rhomboidea Raf.	ACRH	2	0.3														0.2	0.0
Acer negundo L.	ACNE2	4											1.0					0.1
Acer rubrum L.	ACRU	2		1.6		0.6	0.7	2.9	0.6		0.7		1.7	1.7	0.4		0.5	0.8
Achillea millefolium L.	ACMI2	0							0.3								0.2	0.0
Acorus calamus L.	ACCA4	6				1.0		0.4										0.1
Aeschynomene indica L.	AEIN	6						0.5										0.0
Agalinis purpurea (L.) Pennell	AGPU5	5		4.6		5.1		0.4			0.4	0.8						0.8
Agrimonia parviflora Ait.	AGPA6	4	0.5		0.7													0.1
Agrostis stolonifera L.	AGST2	0					0.7								31.4			2.1
Alisma subcordatum Raf.	ALSU	6			4.6								0.3		0.4		1.4	0.4
Ambrosia artemisiifolia L.	AMAR2	1	0.6			1.1									0.4			0.1
Anagallis arvensis L.	ANAR	2														0.7		0.0
Andropogon virginicus L.	ANVI2	3							0.9									0.1
Apocynum cannabinum L.	APCA	2			1.1													0.1
Arthraxon hispidus (Thunb.) Makino	ARHI3	0	5.1		20.6						0.4		2.3				0.9	1.9
Asclepias incarnata L.	ASIN	5	0.5										0.4					0.1
Betula nigra L.	BENI	4		0.4		1.1								0.7				0.2
Bidens aristosa (Michx.) Britt.	BIAR	2	0.3	5.7				7.5				0.4	5.3		0.8		0.8	1.4
Bidens discoidea (Torr. & Gray) Britt.	BIDI	6					0.4		0.5									0.1
Bidens tripartita L.	BITR	0					4.1				1.3							0.4
Boehmeria cylindrica (L.) Sw.	BOCY	4				5.6	6.5				0.7	2.5	0.3				0.3	1.1
Campsis radicans (L.) Seem. ex Bureau	CARA2	2									0.3							0.0
Carex albolutescens Schwein.	CAAL5	5		0.7														0.0
Carex caroliniana Schwein.	CACA15	5							0.4				0.3					0.0
Carex frankii Kunth	CAFR3	4											3.1			1.3	1.1	0.4
Carex hormathodes Fern.	CAHO8	6			2.1								1.0					0.2
Carex lurida Wahlenb.	CALU5	4	1.4	3.3	3.9								0.3	1.8	2.5			0.9
Carex projecta Mackenzie	CAPR9	6															1.6	0.1
Carex squarrosa L.	CASQ2	6											0.3					0.0
Carex tribuloides Wahlenb.	CATR7	3											0.3					0.0
Carex vulpinoidea Michx.	CAVU2	3	0.7		2.1				0.4				0.4	0.7	9.7			0.9
Cephalanthus occidentalis L.	CEOC2	6			0.4	1.5	3.9	2.9				1.2						0.7
Cinna arundinacea L.	CIAR2	5	0.9		1.1													0.1
Commelina communis L.	COCO3	0	0.4															0.0
Conyza canadensis (L.) Cronq.	COCA5	1															0.2	0.0
Cuphea carthagenensis (Jacq.) J.F. MacBr.	CUCA4	5													0.5			0.0
Cuscuta gronovii Willd. ex J.A. Schultes	CUGR	3	1.6															0.1
Cyperus erythrorhizos Muhl.	CYER2	4								3.5								0.2
Cyperus esculentus L.	CYES	2														15.8		1.1
Cyperus pseudovegetus Steud.	CYPS	4		1.1					0.4		0.8							0.2
Cyperus strigosus L.	CYST	3	0.3	2.1	0.4						0.4		0.7	0.4	4.1	2.4	0.9	0.8
Dichanthelium clandestinum (L.) Gould	DICL	3					2.1											0.1
Dichanthelium dichotomum (L.) Gould	DIDI6	4		0.9		5.1		0.4	0.7									0.5
Dichanthelium scoparium (Lam.) Gould	DISC3	4		0.7		6.2		1.0	0.6		8.4							1.1
Digitaria ischaemum (Schreb.) Schreb. ex Muhl.	DIIS	2							1.5								2.1	0.2
Digitaria sanguinalis (L.) Scop.	DISA														1.2	0.7		0.1
Diodia virginiana L.	DIVI3	3		11.3				5.1	0.3			2.3		9.6				1.9

Table C-1. **CW herbaceous** species list with relative IV (dominant species in bold).

Species	Bayer Code	C	15-Sleet	12B-BwrH	12A-Rte7	11-Court	10B-Prct	10A-Fkln	7-ChsCty	6-Stony	5-FtLee	4B-Pwhte	4A-Manas	3-MtStr	2-SWSfk	1B-Matta	1A-Reedy	Overall
Echinochloa muricata (Beauv.) Fern.	ECMU2	2		0.7			1.3		3.6	9.3	2.4		3.7		2.7	1.0	4.2	1.9
Eclipta prostrata (L.) L.	ECPR	2								0.4					1.7	14.0	7.1	1.6
Eleocharis obtusa (Willd.) J.A. Schultes	ELOB2	2		3.1	2.3		1.3		12.2	47.6	2.4	2.3	3.4	0.4	4.7			**5.3**
Eleocharis tenuis (Willd.) J.A. Schultes	ELTE	6		0.4													3.2	0.2
Elymus virginicus L.	ELVI3	4	0.6															0.0
Erechtites hieraciifolia (L.) Raf. ex DC.	ERHI2	2				1.1			0.3			0.5				1.5	0.4	0.2
Eupatorium capillifolium (Lam.) Small	EUCA5	2				2.3					0.4							0.2
Eupatorium serotinum Michx.	EUSE2	3											2.3					0.2
Euthamia graminifolia (L.) Nutt.	EUGR5	4			1.5				1.9									0.2
Festuca sp.	FEST	0			0.7													0.0
Fraxinus pennsylvanica Marsh.	FRPE	6											1.2				1.0	0.2
Fuirena squarrosa Michx.	FUSQ	3													1.9			0.1
Galium tinctorium L.	GATI	4		1.1	5.0	10.9	5.0	0.9			5.2	19.0	4.7	4.8			0.3	**3.8**
Geum canadense Jacq.	GECA7	5	0.3															0.0
Hibiscus moscheutos L.	HIMO	5										0.9						0.1
Hydrocotyle ranunculoides L. f.	HYRA	6					5.7											0.4
Hydrocotyle umbellata L.	HYUM	5		7.6														0.5
Hydrolea quadrivalvis Walt.	HYQU	7								1.2								0.1
Hypericum mutilum L.	HYMU	3	0.3		1.1			0.5				0.4	0.9			0.6	7.2	0.7
Impatiens capensis Meerb.	IMCA	4	9.5			0.4						3.0	0.7					0.9
Ipomoea lacunosa L.	IPLA	3															0.2	0.0
Juncus acuminatus Michx.	JUAC	4		0.8			1.1	0.5	4.3		2.4		4.0		4.8		1.2	1.3
Juncus effusus L.	JUEF	3	0.5	19.9	8.7	15.1	2.6	23.9	10.3		7.8	14.4	8.0	7.5	8.0	23.4	5.8	**10.4**
Juncus scirpoides Lam.	JUSC	6							0.4						1.3			0.1
Juncus tenuis Willd.	JUTE	2		1.0	0.3				1.8				3.2		0.9		0.2	0.5
Kummerowia striata (Thunb.) Schindl.	KUST2	0							1.0									0.1
Leersia oryzoides (L.) Sw.	LEOR	4	4.6		10.0		8.5			1.2		13.6	2.6	1.5	0.4		2.2	3.0
Leersia virginica Willd.	LEVI2	5	0.3														0.5	0.1
Lespedeza cuneata (Dum.-Cours.) G. Don	LECU	0											24.1					1.6
Lespedeza virginica (L.) Britt.	LEVI7	3				1.1											1.1	0.1
Lindernia dubia (L.) Pennell	LIDU	6							2.0	2.1								0.3
Liquidambar styraciflua L.	LIST2	3		1.1		0.9		1.3			0.4						0.8	0.3
Lobelia cardinalis L.	LOCA2	7															0.2	0.0
Ludwigia alternifolia L.	LUAL2	3		0.3	0.7	2.8		5.1	6.4						0.8		0.4	1.1
Ludwigia decurrens Walt.	LUDE4	4								0.7							0.4	0.1
Ludwigia glandulosa Walt.	LUGL	5							1.6		0.5							0.1
Ludwigia leptocarpa (Nutt.) Hara	LULE4	6										1.2						0.1
Ludwigia palustris (L.) Ell.	LUPA	2		1.7	0.7		14.6	11.1	10.6	3.4	29.0	11.5		4.5		0.8	8.2	**6.4**
Lycopus americanus Muhl. ex W. Bart.	LYAM	4	0.8										0.7				1.5	0.2
Lycopus rubellus Moench	LYRU	6						0.8										0.1
Lycopus virginicus L.	LYVI4	4											0.7					0.0
Lysimachia nummularia L.	LYNU	0															0.9	0.1
Microstegium vimineum (Trin.) A. Camus	MIVI	0	46.3		14.0													**4.0**
Mikania scandens (L.) Willd.	MISC	3		0.4		7.1					1.5						0.4	0.6
Mimulus alatus Ait.	MIAL2	5	0.7														1.9	0.2
Mimulus ringens L.	MIRI	5			0.3							3.3						0.2
Morella cerifera (L.) Small	MOCE2	4		0.5														0.0

Table C-1. **CW herbaceous** species list with relative IV (dominant species in bold).

Species	Bayer Code	C	15-Sleet	12B-BwrH	12A-Rte7	11-Court	10B-Prct	10A-Fkln	7-ChsCty	6-Stony	5-FtLee	4B-Pwhte	4A-Manas	3-MtStir	2-SWSfk	1B-Matta	1A-Reedy	Overall
Murdannia keisak (Hassk.) Hand.-Maz.	MUKE	0				0.3	9.3							47.6			4.5	**4.1**
Onoclea sensibilis L.	ONSE	4				2.2												0.1
Oxalis stricta L.	OXST	2															0.5	0.0
Panicum dichotomiflorum Michx.	PADI	2				2.2			2.9	8.5					5.6	27.5	6.7	**3.6**
Panicum rigidulum Bosc ex Nees	PARI4	4						1.4		0.4								0.1
Panicum rigidulum Bosc ex Nees var. elongatum (Pursh) Lelong	PARIE2	5								0.4		4.1		5.0				0.6
Panicum verrucosum Muhl.	PAVE2	5		1.2		1.5		5.2	0.5		1.0							0.6
Panicum virgatum L.	PAVI2	4	0.3						0.8				5.7					0.5
Parthenocissus quinquefolia (L.) Planch.	PAQU2	4			0.3													0.0
Paspalum laeve Michx.	PALA10	3											0.3					0.0
Peltandra virginica (L.) Schott	PEVI	7										0.8						0.1
Penthorum sedoides L.	PESE6	3											0.3				6.8	0.5
Phalaris arundinacea L.	PHAR3	1			3.0													0.2
Pilea pumila (L.) Gray	PIPU2	4	1.0		1.0	1.5											1.6	0.3
Pluchea camphorata (L.) DC.	PLCA7	5						0.5									0.2	0.1
Poa trivialis L.	POTR2	0							1.4									0.1
Polygonum arifolium L.	POAR6	6	1.7				0.5											0.1
Polygonum caespitosum Blume	POCA5	0	0.3														2.6	0.2
Polygonum hydropiperoides Michx.	POHY2	4		11.5		7.9	5.2	9.1	2.6	4.1	15.5	4.1	5.5	7.3		0.6		**4.9**
Polygonum lapathifolium L.	POLA4	4												1.1		1.5		0.2
Polygonum pensylvanicum L.	POPE2	2	0.3							10.4						2.9	0.2	0.9
Polygonum perfoliatum L.	POPE10	0	2.1															0.1
Polygonum persicaria L.	POPE3	0	1.2									0.8				1.5		0.2
Polygonum punctatum Ell.	POPU5	4	3.0		0.5												5.6	0.6
Polygonum sagittatum L.	POSA5	5	5.8		3.5		4.8					1.5		3.7			0.7	1.3
Proserpinaca palustris L.	PRPA3	6		4.7														0.3
Ptilimnium capillaceum (Michx.) Raf.	PTCA	4		0.6		2.8												0.2
Quercus palustris Muenchh.	QUPA2	7											1.2					0.1
Quercus phellos L.	QUPH	6									0.3							0.0
Rhexia mariana L.	RHMA	4				0.6												0.0
Rhynchospora capitellata (Michx.) Vahl	RHCA12	6							1.5									0.1
Rhynchospora corniculata (Lam.) Gray	RHCO2	4							1.1									0.1
Rhynchospora glomerata (L.) Vahl	RHGL3	6		5.0														0.3
Rhynchospora inexpansa (Michx.) Vahl	RHIN4	4		0.3														0.0
Rotala ramosior (L.) Koehne	RORA	4							0.7	2.5	0.3		0.5					0.3
Rubus phoenicolasius Maxim.	RUPH	2									0.4							0.0
Rumex crispus L.	RUCR														0.9	0.6	0.2	0.1
Rumex verticillatus L.	RUVI	5															0.2	0.0
Saccharum giganteum (Walt.) Pers.	SAGI	4						2.7			0.8			1.2				0.3
Sacciolepis striata (L.) Nash	SAST	7						0.8										0.1
Salix nigra Marsh.	SANI	3	1.2		0.4						0.5				0.4			0.2
Saururus cernuus L.	SACE	6				1.5												0.1
Schoenoplectus tabernaemontani (K.C. Gmel.) Palla	SCTA2	5	0.5														0.2	0.0
Scirpus atrovirens Willd.	SCAT2	5	0.5		0.4								1.3					0.1

Table C-1. **CW herbaceous** species list with relative IV (dominant species in bold).

Species	Bayer Code	C	15-Sleet	12B-BwrH	12A-Rte7	11-Court	10B-Pret	10A-Fkln	7-ChsCty	6-Stony	5-FtLee	4B-Pwhte	4A-Manas	3-MtStir	2-SWSfk	1B-Matta	1A-Reedy	Overall
Scirpus cyperinus (L.) Kunth	SCCY	3	0.9	5.0	3.9	8.1	21.7	10.4	25.3	4.3	12.5	8.6	1.9	0.4	10.5		0.5	**7.6**
Setaria parviflora (Poir.) Kerguélen	SEPA2	3				1.4		0.7			0.8	0.5						0.2
Sida spinosa L.	SISP	3															0.5	0.0
Sium suave Walt.	SISU2	6															0.2	0.0
Solanum carolinense L.	SOCA3	2	0.3															0.0
Solidago canadensis L. var. scabra Torr. & Gray	SOCAS5	3	2.1															0.1
Solidago rugosa P. Mill.	SORU2	3							0.3									0.0
Sparganium americanum Nutt.	SPAM	6	1.5															0.1
Symphyotrichum lateriflorum (L.) A.& D. Löve var. lateriflorum	SYLAL7	6						2.5									9.0	0.8
Taxodium distichum (L.) L.C. Rich.	TADI2	8						0.4										0.0
Typha latifolia L.	TYLA	2	0.5	0.5	4.7	1.1					2.8	2.5	5.0		4.1	3.2		1.6
Verbesina alternifolia (L.) Britt. ex Kearney	VEAL	3	0.5															0.0
Viburnum dentatum L.	VIDE	5						0.8										0.1
Xanthium strumarium L.	XAST	1											0.3					0.0

Table C-2. **CW shrub-sapling** species list with relative IV (dominant species in bold).

Species	Bayer Code	C	15-Sleet	12B-BwrH	12A-Rte7	11-Court	10B-Prct	10A-Fkln	7-ChsCty	6-Stony	5-FtLee	4B-Pwhte	4A-Manas	3-MtStlr	2-SWSflk	1B-Matta	Overall
Acer negundo L.	ACNE2	4			19.6												1.4
Acer rubrum L.	ACRU	2				0.6	49.2	26.3			3.2	30.3		75.2			**13.2**
Alnus incana (L.) Moench ssp. rugosa (Du Roi) Clausen	ALINR	0														28.7	2.1
Baccharis halimifolia L.	BAHA	3		4.0											4.6		0.6
Betula nigra L.	BENI	4		20.7		6.0	10.4	1.5	55.0		4.3		1.4	5.4		40.8	**10.4**
Cephalanthus occidentalis L.	CEOC2	6		1.8	4.0	33.2	13.4	5.6	22.5			43.6	10.8				9.6
Crataegus phaenopyrum (L. f.) Medik.	CRPH	6						2.7									0.2
Diospyros virginiana L.	DIVI5	5	4.9	1.0	1.4							3.8					0.8
Fraxinus pennsylvanica Marsh.	FRPE	6			2.2			5.5		2.6	0.9		36.6		27.1		5.4
Hibiscus moscheutos L.	HIMO	5										18.5		4.4			1.6
Ilex verticillata (L.) Gray	ILVE	7					0.9										0.1
Liquidambar styraciflua L.	LIST2	3		44.1		37.0	25.2	36.5	22.5		15.1			1.9			**13.0**
Morella cerifera (L.) Small	MOCE2	4		3.7		1.9								0.9	9.1		1.1
Nyssa sylvatica Marsh.	NYSY	5				0.6									4.6		0.4
Pinus taeda L.	PITA	3		6.6		3.2	0.9										0.8
Platanus occidentalis L.	PLOC	5				0.9											0.1
Populus deltoides Bartr. ex Marsh.	PODE3	5									1.7						0.1
Populus heterophylla L.	POHE4	8				0.6		13.8									1.0
Quercus lyrata Walt.	QULY	8													11.5		0.8
Quercus michauxii Nutt.	QUMI	7														30.5	2.2
Quercus palustris Muenchh.	QUPA2	7						1.9									0.1
Quercus phellos L.	QUPH	6											5.3				0.4
Rosa multiflora Thunb. ex Murr.	ROMU	0	4.6														0.3
Rosa palustris Marsh.	ROPA	6										3.8		0.9			0.3
Salix nigra Marsh.	SANI	3	90.5	18.0	72.7	6.1		5.7		7.7	72.3		31.9	11.3	9.1		**23.2**
Taxodium distichum (L.) L.C. Rich.	TADI2	8				10.1		0.6		89.7	2.5				34.1		9.8
Ulmus americana L.	ULAM	6											14.0				1.0

Table C-3. **REF herbaceous** species list with relative IV (dominant species in bold).

Species	Bayer Code	C	15-Sleet	12B-BwrH	12A-Rte7	11-Court	10B-Prct	10A-Fkln	7-ChsCty	6-Stony	5-FtLee	4B-Pwhte	4A-Manas	3-MtStir	2-SWSfk	1B-Matta	1A-Reedy	Overall
Acalypha rhomboidea Raf.	ACRH	2										0.3						0.0
Acer rubrum L.	ACRU	2					1.3		15.7	1.2	2.4			0.9			0.7	1.5
Agrimonia parviflora Ait.	AGPA6	4	0.4															0.0
Agrostis perennans (Walt.) Tuckerman	AGPE	4										0.4						0.0
Alisma subcordatum Raf.	ALSU	6	0.7		2.3					0.4							0.7	0.3
Amphicarpaea bracteata (L.) Fern.	AMBR2	4										0.7						0.0
Apios americana Medik.	APAM	5									0.4							0.0
Arisaema triphyllum (L.) Schott	ARTR	6	2.6								4.0	0.8	3.7		1.4			0.8
Arundinaria gigantea (Walt.) Muhl.	ARGI	5		0.7		36.2		9.1							8.5			**3.6**
Asimina triloba (L.) Dunal	ASTR	5											3.8					0.3
Athyrium filix-femina (L.) Roth	ATFI	4									3.9							0.3
Betula nigra L.	BENI	4												1.2				0.1
Bidens aristosa (Michx.) Britt.	BIAR	2								1.5			0.5					0.1
Bidens tripartita L.	BITR	0										0.8						0.1
Bignonia capreolata L.	BICA	5		5.5		1.6								3.5	1.5			0.8
Boehmeria cylindrica (L.) Sw.	BOCY	4	0.4	1.0	4.2	8.0	2.1	2.5		7.7	1.7	0.6	13.3			0.8	7.5	**3.3**
Botrychium dissectum Spreng.	BODI2	5				0.6												0.0
Campsis radicans (L.) Seem. ex Bureau	CARA2	2		2.6		2.1		1.1	2.0	3.2	1.1			3.2	1.0		0.4	1.1
Carex crinita Lam.	CACR6	5									1.0			1.7				0.2
Carex debilis Michx.	CADE5	5					3.2				6.1	3.4			1.0			0.9
Carex folliculata L.	CAFO6	6									2.6							0.2
Carex grayi Carey	CAGR5	6															6.6	0.4
Carex hormathodes Fern.	CAHO8	6	1.1															0.1
Carex intumescens Rudge	CAIN12	5									6.0	0.4	8.2		1.1	3.9		1.3
Carex joorii Bailey	CAJO2	7							20.4		3.1			1.2				1.6
Carex lupulina Muhl. ex Willd.	CALU4	6			5.6							0.8						0.4
Carex lurida Wahlenb.	CALU5	4										1.3			1.1			0.2
Carex projecta Mackenzie	CAPR9	6			16.4					4.6		2.7	2.1				29.1	**3.7**
Carex rosea Schkuhr ex Willd.	CARO22	6	3.2															0.2
Carex seorsa Howe	CASE6	7							8.2		1.3		0.7				0.4	0.7
Carex squarrosa L.	CASQ2	6															5.2	0.3
Carex typhina Michx.	CATY	6															6.8	0.5
Carpinus caroliniana Walt.	CACA18	5										0.4			2.4			0.2
Cephalanthus occidentalis L.	CEOC2	6												1.2				0.1
Chasmanthium latifolium (Michx.) Yates	CHLA5	5															3.7	0.2
Chasmanthium laxum (L.) Yates	CHLA6	4					1.4				1.0	1.3			3.0			0.4
Chelone glabra L.	CHGL2	6													1.7			0.1
Cicuta maculata L.	CIMA2	6		2.2											0.4			0.2
Cinna arundinacea L.	CIAR2	5	8.4	8.4	23.5		3.7				6.7	1.1	6.2				3.4	**4.1**
Circaea lutetiana L.	CILU	6	0.4															0.0
Clethra alnifolia L.	CLAL3	4					1.2	6.1	18.0		4.7							2.0
Commelina communis L.	COCO3	0														0.8	0.8	0.1
Commelina virginica L.	COVI3	5		3.1			0.5			0.5		0.3						0.3
Cornus amomum P. Mill.	COAM2	4				1.5												0.1
Cyperus erythrorhizos Muhl.	CYER2	4								1.9								0.1
Desmodium nudiflorum (L.) DC.	DENU4	5											2.1					0.1
Dichanthelium (A.S. Hitchc. & Chase) Gould	DICHAN	5												0.7				0.0
Dichanthelium clandestinum (L.) Gould	DICL	3					0.5											0.0
Dichanthelium dichotomum (L.) Gould	DIDI6	4									1.9			0.9		3.7		0.4

Table C-3. **REF herbaceous** species list with relative IV (dominant species in bold).

Species	Bayer Code	C	15-Sleet	12B-BwrH	12A-Rte7	11-Court	10B-Prct	10A-Fkln	7-ChsCty	6-Stony	5-FtLee	4B-Pwhte	4A-Manas	3-MtStir	2-SWSfk	1B-Matta	1A-Reedy	Overall
Diodia virginiana L.	DIVI3	3												0.7				0.0
Dioscorea villosa L.	DIVI4	5									3.2							0.2
Diospyros virginiana L.	DIVI5	5												0.9				0.1
Echinochloa muricata (Beauv.) Fern.	ECMU2	2								0.4								0.0
Elymus virginicus L.	ELVI3	4			0.9												1.1	0.1
Erechtites hieraciifolia (L.) Raf. ex DC.	ERHI2	2								2.6								0.2
Euonymus americana L.	EUAM7	5									0.9	2.8			0.4			0.3
Eupatorium capillifolium (Lam.) Small	EUCA5	2								2.5								0.2
Eupatorium dubium Willd. ex Poir.	EUDU	5		3.2			4.6				1.3				1.8			0.7
Fagus grandifolia Ehrh.	FAGR	5													1.9			0.1
Fraxinus pennsylvanica Marsh.	FRPE	6				1.9							1.0		0.4	2.4	1.6	0.5
Galium obtusum Bigelow	GAOB	5			0.9								0.5					0.1
Galium tinctorium L.	GATI	4													0.5		0.7	0.1
Geum canadense Jacq.	GECA7	5	1.3		2.6	0.7						1.1					2.2	0.5
Glyceria striata (Lam.) A.S. Hitchc.	GLST	5	2.8	6.8	4.1							0.4						0.9
Gratiola virginiana L.	GRVI	5													0.4			0.0
Hydrocotyle umbellata L.	HYUM	5													0.8			0.1
Ilex decidua Walt.	ILDE	6															1.9	0.1
Ilex verticillata (L.) Gray	ILVE	7										0.4			0.4	9.9		0.7
Impatiens capensis Meerb.	IMCA	4	22.6	3.5	2.1		0.5			1.1		7.8			3.7			**2.8**
Iris virginica L.	IRVI	7						7.5										0.5
Itea virginica L.	ITVI	7		2.3				1.6			1.6							0.4
Juncus effusus L.	JUEF	3					0.7			0.4					0.4			0.1
Leersia lenticularis Michx.	LELE2	7								2.4								0.2
Leersia oryzoides (L.) Sw.	LEOR	4	3.2	1.6	3.7							2.6						0.7
Leersia virginica Willd.	LEVI2	5	2.3	1.4	1.2					6.3	6.4		12.4	6.2	6.3			**2.8**
Leucothoe racemosa (L.) Gray	LERA4	6						6.1	2.4									0.6
Ligustrum sinense Lour.	LISI	0		1.2						0.3								0.1
Lindera benzoin (L.) Blume	LIBE3	6	0.8			6.6						0.4					0.9	0.6
Lindernia dubia (L.) Pennell	LIDU	4								1.2								0.1
Liquidambar styraciflua L.	LIST2	3					1.1		2.7					2.8			0.7	0.5
Lobelia cardinalis L.	LOCA2	7									2.5	2.8			1.3			0.4
Lobelia L.	LOBEL	5									1.5							0.1
Lonicera japonica Thunb.	LOJA	0	0.9	1.3				1.1			3.0	5.6			5.8			1.2
Ludwigia alternifolia L.	LUAL2	3										0.5						0.0
Ludwigia glandulosa Walt.	LUGL	5								0.4								0.0
Ludwigia leptocarpa (Nutt.) Hara	LULE4	6								2.3								0.2
Ludwigia palustris (L.) Ell.	LUPA	2		0.4						11.8				10.4				1.5
Lycopus virginicus L.	LYVI4	4		1.8			3.6				3.0	3.4			0.6	2.8		1.0
Lysimachia nummularia L.	LYNU	0			17.0					23.2								**2.7**
Microstegium vimineum (Trin.) A. Camus	MIVI	0	1.8	5.0	4.3		14.4				2.1	4.2	4.7					**2.4**
Mikania scandens (L.) Willd.	MISC	3								0.3	0.4	1.8						0.2
Mimulus alatus Ait.	MIAL2	5	1.1															0.1
Murdannia keisak (Hassk.) Hand.-Maz.	MUKE	0		0.8		0.7	21.8			0.4	6.1	22.4		34.0		11.3		**6.5**
Nyssa biflora Walt.	NYBI	6						1.3							0.4			0.1
Onoclea sensibilis L.	ONSE	4				1.5												0.1
Osmunda cinnamomea L.	OSCI	5													3.3			0.2
Oxalis dillenii Jacq.	OXDI2	4											2.0					0.1
Packera aurea (L.) A.& D. Löve	PAAU3	6										0.7						0.0

Table C-3. **REF herbaceous** species list with relative IV (dominant species in bold).

Species	Bayer Code	C	15-Sleet	12B-BwrH	12A-Rte7	11-Court	10B-Prct	10A-Fkln	7-ChsCty	6-Stony	5-FtLee	4B-Pwhte	4A-Manas	3-MtStr	2-SWSfk	1B-Matta	1A-Reedy	Overall
Panicum rigidulum Bosc ex Nees	PARI4	4									1.7							0.1
Parthenocissus quinquefolia (L.) Planch.	PAQU2	4		0.7	0.7	0.6	0.5	1.1		1.2	0.5				0.4		0.4	0.4
Peltandra virginica (L.) Schott	PEVI	7					0.7					0.4				5.0		0.4
Penthorum sedoides L.	PESE6	3								2.1								0.1
Photinia pyrifolia (Lam.) Robertson & Phipps	PHPY4	6	0.4			1.0												0.1
Phytolacca americana L.	PHAM4	1								1.9								0.1
Pilea pumila (L.) Gray	PIPU2	4	15.6	9.1						0.4		2.9	1.5			2.8	1.8	**2.3**
Pluchea camphorata (L.) DC.	PLCA7	5				1.0												0.1
Poa trivialis L.	POTR2	0									1.8							0.1
Polygonum arifolium L.	POAR6	6	3.6		0.9		1.3									1.9		0.5
Polygonum caespitosum Blume	POCA5	0								1.4		2.1						0.2
Polygonum hydropiperoides Michx.	POHY2	4		1.7		2.3				2.5	0.7			10.3	0.9			1.2
Polygonum persicaria L.	POPE3	0	1.6	2.1	3.1		0.6			1.6								0.6
Polygonum punctatum Ell.	POPU5	4	0.4		2.8							0.8					6.5	0.7
Polygonum sagittatum L.	POSA5	5		0.4	2.0		0.8					2.1						0.4
Polygonum setaceum Baldw.	POSE6	4									0.8							0.1
Polygonum virginianum L.	POVI2	5				1.0							1.5		2.1		2.7	0.5
Quercus michauxii Nutt.	QUMI	7										0.8						0.1
Quercus palustris Muenchh.	QUPA2	7								0.8			0.5					0.1
Quercus phellos L.	QUPH	6					0.7		0.8		4.0		1.3					0.5
Rhynchospora corniculata (Lam.) Gray	RHCO2	4								0.4								0.0
Rorippa nasturtium-aquaticum (L.) Hayek	RONA2	0	3.4															0.2
Rorippa palustris (L.) Bess.	ROPA2	3								0.3								0.0
Rosa multiflora Thunb. ex Murr.	ROMU	0	0.4															0.0
Rubus hispidus L.	RUHI	5									4.0	0.9			1.0			0.4
Sagittaria latifolia Willd.	SALA2	6								0.9								0.1
Salix nigra Marsh.	SANI	3								0.4								0.0
Sambucus nigra L. ssp. canadensis (L.) R. Bolli	SANIC4	4										0.4			0.6			0.1
Saururus cernuus L.	SACE	6		16.4		5.6	16.5	30.0				0.4			3.9	43.3		**7.7**
Scutellaria lateriflora L.	SCLA2	6											1.0				0.4	0.1
Smilax bona-nox L.	SMBO2	4															0.9	0.1
Smilax glauca Walt.	SMGL	5					0.5			0.3						0.8		0.1
Smilax rotundifolia L.	SMRO	3	0.9			2.2	3.8	1.3	20.9	3.5	2.8	1.6	3.3	11.3	0.9	1.1	0.4	**3.6**
Smilax walteri Pursh	SMWA	7					0.8	7.7							0.4			0.6
Solidago rugosa P. Mill.	SORU2	3													0.4			0.0
Symphoricarpos orbiculatus Moench	SYOR	3															1.0	0.1
Symphyotrichum lanceolatum (Willd.) Nesom ssp. lanceolatum var. lanceolatum	SYLAL4	3											0.7					0.0
Symphyotrichum lateriflorum (L.) A.& D. Löve var. lateriflorum	SYLAL7	6		2.3			1.2				0.9	2.9		5.4	0.4	8.7	6.9	1.9
Symphyotrichum puniceum (L.) A.& D. Löve var. puniceum	SYPUP	4	2.1															0.1
Symplocarpus foetidus (L.) Salisb. ex Nutt.	SYFO	8	11.9															0.8
Taxodium distichum (L.) L.C. Rich.	TADI2	8		0.4														0.0

Table C-3. **REF herbaceous** species list with relative IV (dominant species in bold).

Species	Bayer Code	C	15-Sleet	12B-BwrH	12A-Rte7	11-Court	10B-Prct	10A-Fkln	7-ChsCty	6-Stony	5-FtLee	4B-Pwhte	4A-Manas	3-MtStir	2-SWSfk	1B-Matta	1A-Reedy	Overall
Thelypteris noveboracensis (L.) Nieuwl.	THNO	5										1.5			9.5			0.7
Toxicodendron radicans (L.) Kuntze	TORA2	2	4.1		1.7	0.6		1.6	0.8		0.7	1.2	2.0	0.7	1.7	0.8	1.2	1.1
Triadenum virginicum (L.) Raf.	TRVI2	5							4.2				0.8		1.3			0.4
Ulmus americana L.	ULAM	6		2.3						3.4								0.4
Urtica dioica L.	URDI	0	0.6							0.5							1.6	0.2
Vaccinium formosum Andr.	VAFO	5							2.0		0.8	0.4						0.2
Viburnum dentatum L.	VIDE	5	0.8				3.5					1.6		2.6				0.6
Viburnum nudum L.	VINU	5					5.9											0.4
Viola sororia Willd.	VISO	3										0.9	26.6				1.7	1.9
Vitis rotundifolia Michx.	VIRO3	4				0.6			2.0	1.6								0.3
Woodwardia areolata (L.) T. Moore	WOAR	5		11.5		24.0	2.7	21.9			1.5	6.9			24.8			**6.2**

Table C-4. **REF shrub-sapling** species list with relative IV (dominant species in bold).

Species	Bayer Code	C	15-Sleet	12B-BwrH	12A-Rte7	11-Court	10B-Prct	10A-Fkln	7-ChsCty	6-Stony	5-FtLee	4B-Pwhte	4A-Manns	3-MtStr	2-SWSfk	1B-Mattn	1A-Reedy	Overall
Acer rubrum L.	ACRU	2		22.4	10.1	11.0	28.0	28.5	19.2	23.1	25.0	2.7	54.4	29.2	4.6	20.7	35.4	**21.0**
Alnus serrulata (Ait.) Willd.	ALSE2	5					1.6					0.5						0.1
Amelanchier arborea (Michx. f.) Fern.	AMAR3	5						1.7										0.1
Arundinaria gigantea (Walt.) Muhl.	ARGI	5				52.1		1.7							56.7			**7.4**
Asimina triloba (L.) Dunal	ASTR	5		1.3								0.5	1.6					0.2
Betula nigra L.	BENI	4			45.2									0.3				3.0
Bignonia capreolata L.	BICA	5		0.9														0.1
Campsis radicans (L.) Seem. ex Bureau	CARA2	2		1.8											0.9			0.2
Carpinus caroliniana Walt.	CACA18	5										40.9			22.1			4.2
Celtis laevigata Willd.	CELA	4		1.3														0.1
Celtis occidentalis L.	CEOC	3			3.8													0.3
Clethra alnifolia L.	CLAL3	4						16.8	18.0		20.7							3.7
Cornus foemina P. Mill.	COFO	5				13.7												0.9
Corylus americana Walt.	COAM3	5										5.9						0.4
Decumaria barbara L.	DEBA4	6		4.6											0.5			0.3
Diospyros virginiana L.	DIVI5	5								1.0								0.1
Euonymus americana L.	EUAM7	5		1.7			0.6					0.5						0.2
Fagus grandifolia Ehrh.	FAGR	5													2.5			0.2
Fraxinus pennsylvanica Marsh.	FRPE	6		18.2	35.6	6.3		4.1		9.6		1.1	4.3		1.3	22.1	18.2	**8.1**
Ilex decidua Walt.	ILDE	6												6.5			5.9	0.8
Ilex opaca Ait.	ILOP	5					3.8	8.1			0.7			2.5	5.9			1.4
Ilex verticillata (L.) Gray	ILVE	7	12.6									1.0			1.9	20.0		2.4
Itea virginica L.	ITVI	7		0.9					0.8		2.4							0.3
Leucothoe racemosa (L.) Gray	LERA4	6				1.6		6.8	5.9							2.0		1.1
Ligustrum sinense Lour.	LISI	0		7.2						13.7		1.0						1.5
Lindera benzoin (L.) Blume	LIBE3	6	36.5			11.7						3.3					35.4	**5.8**
Liquidambar styraciflua L.	LIST2	3		3.5		0.5	10.7	6.3		3.9	3.4	0.5		11.3	0.7	1.5		2.8
Liriodendron tulipifera L.	LITU	4													0.6			0.0
Lonicera japonica Thunb.	LOJA	0		0.9														0.1
Magnolia virginiana L.	MAVI2	6		3.4								1.5			0.3			0.4
Nyssa biflora Walt.	NYBI	6				2.3		8.3										0.7
Nyssa sylvatica Marsh.	NYSY	5					5.8		4.8		0.7	0.9	4.1					1.1
Parthenocissus quinquefolia (L.) Planch.	PAQU2	4		7.1									1.0			0.6		0.6
Photinia pyrifolia (Lam.) Robertson & Phipps	PHPY4	6	1.6															0.1
Pinus taeda L.	PITA	3									3.6							0.2
Populus heterophylla L.	POHE4	8		0.9				1.1							0.3			0.2
Prunus serotina Ehrh.	PRSE2	3									0.4							0.0
Quercus alba L.	QUAL	5									2.4							0.2
Quercus imbricaria Michx.	QUIM	7	1.6															0.1
Quercus laurifolia Michx.	QULA3	7						4.8										0.3
Quercus lyrata Walt.	QULY	8							8.8							2.6		0.8
Quercus michauxii Nutt.	QUMI	7					3.6				0.7	0.5						0.3
Quercus nigra L.	QUNI	4									2.2			0.7				0.2
Quercus palustris Muenchh.	QUPA2	7			5.3					1.0						1.5		0.5
Quercus phellos L.	QUPH	6							5.6	3.8	22.4			5.6				2.5
Rosa multiflora Thunb. ex Murr.	ROMU	0	12.6															0.8
Smilax laurifolia L.	SMLA	6													0.2			0.0
Smilax rotundifolia L.	SMRO	3	13.3	7.1			19.8	1.2	18.2	40.7	11.3	5.5		43.8		13.9		**11.7**
Smilax walteri Pursh	SMWA	7						6.5										0.4
Toxicodendron radicans (L.) Kuntze	TORA2	2						3.3		0.5		4.5	24.9		1.4	12.0		3.1
Ulmus alata Michx.	ULAL	4										0.9						0.1
Ulmus americana L.	ULAM	6	4.7	8.2				0.6		2.8		2.7	8.6				5.1	2.2
Vaccinium elliottii Chapman	VAEL	7				0.8												0.1
Vaccinium formosum Andr.	VAFO	5							18.7		3.8	1.4	1.0					1.7
Viburnum dentatum L.	VIDE	5	14.9				24.0				0.4	12.7				1.1		3.5
Viburnum nudum L.	VINU	6					2.1									0.6		0.2
Viburnum prunifolium L.	VIPR	5	2.4									11.5						0.9
Vitis rotundifolia Michx.	VIRO3	4		8.5												1.5		0.7

Table C-5. **REF tree** species list with relative IV (dominant species in bold).

Species	Bayer Code	C	15-Sleet	12B-BwrH	12A-Rte7	11-Court	10B-Prct	10A-Fkln	7-ChsCty	6-Stony	5-FtLee	4B-Pwhte	4A-Manas	3-MtStr	2-SWSfk	1B-Mattu	1A-Reedy	Overall
Acer negundo L.	ACNE2	4											0.2					0.0
Acer rubrum L.	ACRU	2	34.7	38.2	44.8	48.3	15.4	10.9	15.1	12.8	26.2	45.5	25.7	32.4	15.4	36.9	8.0	**27.3**
Acer saccharinum L.	ACSA2	5			0.5													0.0
Betula nigra L.	BENI	4			12.6		5.8					9.0		3.8		18.5		3.3
Carpinus caroliniana Walt.	CACA18	5	0.7									3.6			3.9	0.6		0.6
Carya aquatica (Michx. f.) Nut	CAAQ2	8												1.1				0.1
Carya cordiformis (Wangenh.) K	CACO15	6	18.4										0.3	1.0				1.3
Carya ovata (P. Mill.) K. Koch	CAOV2	7															0.2	0.0
Carya tomentosa (Lam. ex Poir.	CATO6	5															3.1	0.2
Diospyros virginiana L.	DIVI5	5											0.2	1.9				0.1
Fagus grandifolia Ehrh.	FAGR	5				2.2									7.7			0.7
Fraxinus pennsylvanica Marsh.	FRPE	6	17.0	13.6	3.7	2.0		0.1		47.1		1.6	3.5		5.7	18.1	2.3	7.6
Ilex opaca Ait.	ILOP	5				0.1		0.3	0.1						1.3			0.1
Liquidambar styraciflua L.	LIST2	3		4.8		4.2	24.4	2.9	33.7	4.8	41.4	8.0	1.2	22.2	5.5	1.6	38.5	**12.9**
Liriodendron tulipifera L.	LITU	4	0.2				4.3					2.9			5.8			0.9
Magnolia virginiana L.	MAVI2	6													0.2			0.0
Nyssa biflora Walt.	NYBI	6		25.7		18.9		80.9	1.8			0.6	3.1		14.4			**9.7**
Nyssa sylvatica Marsh.	NYSY	5				0.1	1.2		4.8	0.3	4.2	1.0				4.5		1.1
Pinus taeda L.	PITA	3					13.6	3.4			3.8			2.9				1.6
Platanus occidentalis L.	PLOC	5	3.8		31.4	4.9				0.3			0.8				4.4	3.0
Populus heterophylla L.	POHE4	8		0.9				0.3										0.1
Quercus alba L.	QUAL	5				4.8						0.3						0.3
Quercus bicolor Willd.	QUBI	8	11.5										7.7					1.3
Quercus laurifolia Michx.	QULA3	7		6.4				0.5			0.8					2.7		0.7
Quercus lyrata Walt.	QULY	8					2.6		34.4					1.0	0.4	11.3		3.3
Quercus michauxii Nutt.	QUMI	7					0.8					19.4						1.3
Quercus nigra L.	QUNI	4					1.4				2.2							0.2
Quercus palustris Muenchh.	QUPA2	7	10.4		0.4		0.2		1.5	7.2		0.3	47.0			3.3	14.7	5.7
Quercus phellos L.	QUPH	6					30.4	0.2	8.5	6.6	21.5	1.1		30.1			17.3	**7.7**
Robinia pseudoacacia L.	ROPS	2	0.6															0.0
Salix nigra Marsh.	SANI	3			4.9									3.3				0.5
Taxodium distichum (L.) L.C. R	TADI2	8		3.6		13.4									35.6			3.5
Ulmus alata Michx.	ULAL	4										1.1					3.2	0.3
Ulmus americana L.	ULAM	6	2.7	6.7	1.8	1.0		0.5		21.0		5.5	10.3	0.2	4.2	2.6	8.1	4.3

APPENDIX D

CW and REF Data Matrices

Table D-1. **CW data matrix**. Column header abbreviations are explained in Chapter 3 (Methods).

	Overall					Herbaceous								Shrub-sapling								Soils												
Sites	**Age**	**FQI**	**FQI_{all}**	**S**	**%N**	**FQI_{h}**	**$FQI_{h\text{-}all}$**	**$FQI_{h\text{-}mod}$**	**$FQI_{h\text{-}mod(all)}$**	**S_{h}**	**H'_{h}**	**E_{h}**	**$\%N_{h}$**	**FQI_{s}**	**$FQI_{s(all)}$**	**$FQI_{s\text{-}mod}$**	**$FQI_{s\text{-}mod(all)}$**	**S_{s}**	**H'_{s}**	**E_{s}**	**$\%N_{s}$**	**N** (mg/g)	**C** (mg/g)	**C:N**	**pH**	**P** (mg/kg)	**K** (mg/kg)	**Ca** (mg/kg)	**Mg** (mg/kg)	**CEC** (meq/100g)	**%Sand**	**%Silt**	**%Clay**
15-Sleet	15	22.5	20.5	42	0.83	22.2	19.9	10.9	11.8	40	2.4	0.6	0.86	5.7	4.6	4.2	5.1	3	0.4	0.3	0.67	1.57	20.31	12.8	5.8	7.2	41.4	902.0	170.6	7.1	57.8	31.5	10.7
12B-BwrH	12	22.5	22.5	37	1.00	20.7	20.7	20.7	20.7	32	2.8	0.8	1.00	11.0	11.0	9.4	9.4	8	1.5	0.7	1.00	1.00	16.18	16.3	5.3	5.0	48.8	319.4	85.2	4.7	66.6	20.8	12.6
12A-Rte7	12	21.0	20.1	34	0.91	19.3	18.3	12.4	13.0	31	2.8	0.8	0.90	10.7	10.7	7.6	7.6	5	0.8	0.5	1.00	2.02	28.24	14.1	5.5	7.4	48.6	822.4	102.2	7.3	31.6	53.7	14.7
11-Court	11	23.5	23.2	37	0.97	19.3	19.0	19.3	19.6	30	3.0	0.9	0.97	15.4	15.4	15.4	15.4	11	1.6	0.7	1.00	0.75	14.10	19.4	5.1	2.6	23.8	352.0	55.2	3.7	68.8	23.6	7.7
10B-Prct	10	18.1	16.9	24	0.88	16.0	14.8	12.7	13.8	20	2.5	0.9	0.85	10.2	10.2	7.5	7.5	6	1.3	0.7	1.00	1.21	15.49	13.2	4.4	4.4	35.6	254.0	53.4	6.9	57.9	18.9	23.2
10A-Fkln	10	27.2	27.2	36	1.00	22.7	22.7	17.7	17.7	28	2.6	0.8	1.00	16.8	16.8	12.5	12.5	10	1.7	0.8	1.00	0.88	13.63	16.1	4.8	2.6	31.4	279.8	58.2	5.3	57.3	28.3	14.4
7-ChsCty	7	21.2	20.3	36	0.92	20.1	19.2	16.1	16.9	34	2.7	0.8	0.91	7.5	7.5	7.3	7.3	3	1.0	0.9	1.00	1.13	22.01	19.5	6.9	11.2	49.0	1693.4	390.6	11.8	30.5	46.5	23.0
6-Stony	6	17.0	17.0	19	1.00	14.3	14.3	9.8	9.8	16	1.9	0.7	1.00	9.8	9.8	13.1	13.1	3	0.4	0.4	1.00	0.71	9.69	13.5	4.7	11.0	15.8	323.6	85.0	5.3	55.7	25.8	18.5
5-FtLee	5	20.9	20.2	34	0.94	17.3	16.7	15.3	15.9	29	2.4	0.7	0.93	11.7	11.7	8.5	8.5	7	1.0	0.5	1.00	0.84	13.01	15.4	5.2	3.2	18.2	315.6	81.2	5.0	60.9	21.8	17.3
4B-Pwhte	4	20.8	20.4	28	0.96	18.1	18.2	16.6	17.0	24	2.5	0.8	0.96	10.7	10.7	10.2	10.2	5	1.3	0.8	1.00	0.89	11.89	13.8	5.1	7.2	16.4	435.2	63.6	4.9	61.0	23.4	15.6
4A-Manas	4	25.9	25.3	45	0.96	22.7	22.1	14.9	15.3	39	3.0	0.8	0.95	12.7	12.7	12.3	12.3	6	1.5	0.8	1.00	0.93	10.78	11.6	5.6	2.4	44.0	727.2	145.0	7.0	19.9	59.4	20.6
3-MtStir	3	17.7	17.3	23	0.96	14.3	13.9	7.7	7.9	18	2.0	0.7	0.94	10.2	10.2	6.4	6.4	7	0.9	0.5	1.00	0.75	9.51	12.9	5.8	10.2	11.8	521.4	111.8	4.1	64.9	26.5	8.7
2-SWSfk	2	19.3	18.4	32	0.91	14.3	13.4	9.0	9.6	25	2.5	0.8	0.88	14.0	14.0	16.6	16.6	7	1.7	0.9	1.00	1.45	20.68	14.4	6.1	44.4	119.8	1171.0	200.4	8.4	70.6	17.4	12.0
1B-Matta	1	12.1	10.9	21	0.81	10.1	9.2	8.8	9.7	18	2.1	0.7	0.83	7.8	6.4	5.3	6.5	3	1.1	1.0	0.67	0.75	12.73	17.1	5.2	26.4	47.2	694.4	320.4	8.3	64.5	24.3	11.2
1A-Reedy	1	24.6	22.9	53	0.87	24.6	23.2	21.2	22.5	52	3.3	0.8	0.88	-	-	-	-	-	-	-	-	0.98	15.87	16.2	6.2	3.0	62.0	768.0	187.6	6.9	40.4	39.3	20.4

Table D-2. **REF data matrix**. Column header abbreviations are explained in Chapter 3 (Methods).

	Overall					Herbaceous								Shrub-sapling								Tree						Soils												
Sites	**Age**	**FQI**	**FQI$_{all}$**	**S**	**%N**	**FQI$_h$**	**FQI$_{h\text{-}all}$**	**FQI$_{h\text{-}mod}$**	**FQI$_{h\text{-}mod(all)}$**	**S$_h$**	**H'$_h$**	**E$_h$**	**%N$_h$**	**FQI$_s$**	**FQI$_{s(all)}$**	**FQI$_{s\text{-}mod}$**	**FQI$_{s\text{-}mod(all)}$**	**S$_s$**	**H'$_s$**	**E$_s$**	**%N$_s$**	**FQI$_t$**	**FQI$_{t\text{-}mod}$**	**S$_t$**	**H'$_t$**	**E$_t$**	**%N$_t$**	**N** (mg/g)	**C** (mg/g)	**C:N**	**pH**	**P** (mg/kg)	**K** (mg/kg)	**Ca** (mg/kg)	**Mg** (mg/kg)	**CEC** (meq/100g)	**%Sand**	**%Silt**	**%Clay**
15-Sleet	72	31.0	28.7	43	0.86	24.3	21.7	21.8	24.4	30	2.7	0.8	0.80	15.9	15.0	13.6	14.4	9	1.8	0.8	0.89	16.1	15.4	10	1.8	0.8	1.00	3.14	38.82	12.3	5.1	7.2	68.8	786.2	146.2	9.5	20.9	62.5	16.6
12B-BwrH	78	29.7	27.9	42	0.88	23.7	21.5	22.0	24.1	29	2.9	0.9	0.83	19.0	17.9	15.5	16.5	18	2.4	0.8	0.89	16.3	12.7	8	1.7	0.8	1.00	4.80	74.29	15.5	5.9	13.0	65.4	1749.2	200.8	12.1	26.9	41.7	31.4
12A-Rte7	39	22.4	21.1	27	0.89	19.4	17.9	15.8	17.2	20	2.5	0.8	0.85	9.8	9.8	10.4	10.4	5	1.2	0.8	1.00	13.4	9.9	8	1.5	0.7	1.00	2.39	29.87	12.5	5.0	6.6	65.8	612.4	96.2	6.2	20.0	64.0	16.0
11-Court	65	27.4	27.0	34	0.97	20.1	19.6	21.7	22.2	21	2.1	0.7	0.95	15.3	15.3	14.7	14.7	9	1.5	0.7	1.00	16.9	13.6	11	1.5	0.6	1.00	6.16	98.69	14.7	4.8	6.6	89.6	1190.8	130.2	11.6	52.0	24.6	23.4
10B-Prct	43	28.4	27.3	39	0.92	23.7	22.5	16.0	16.9	29	2.7	0.8	0.90	14.5	14.5	11.5	11.5	10	1.8	0.8	1.00	16.0	13.5	11	1.8	0.8	1.00	3.12	51.05	17.0	4.3	3.6	68.2	181.4	68.8	7.3	33.1	46.9	20.0
10A-Fkln	87	24.2	23.7	25	0.96	18.2	17.6	20.4	21.1	15	2.1	0.8	0.93	19.4	19.4	16.2	16.2	15	2.3	0.8	1.00	16.4	17.0	10	0.9	0.4	1.00	4.89	77.03	15.7	4.5	3.2	69.8	534.0	109.0	9.1	45.7	39.7	14.7
7-ChsCty	82	20.3	20.3	18	1.00	15.5	15.5	15.8	15.8	13	2.1	0.8	1.00	15.3	15.3	12.8	12.8	9	2.0	0.9	1.00	14.8	14.2	8	1.6	0.8	1.00	6.90	119.53	17.1	4.0	4.8	64.4	236.4	54.6	11.6	22.8	46.6	30.6
6-Stony	57	25.8	24.1	47	0.87	22.8	21.0	15.8	17.2	40	3.0	0.8	0.85	13.3	12.6	8.7	9.2	10	1.7	0.7	0.90	14.1	15.3	8	1.4	0.7	1.00	3.38	36.51	10.8	4.2	11.6	62.6	426.0	91.8	8.1	9.9	53.8	36.4
5-FtLee	56	31.6	30.3	50	0.92	28.2	26.7	25.5	26.9	40	3.4	0.9	0.90	17.3	17.3	15.2	15.2	15	2.0	0.7	1.00	11.3	9.3	7	1.4	0.7	1.00	2.00	32.75	16.6	4.6	2.0	64.0	253.6	64.8	6.6	49.8	31.0	19.1
4B-Pwhte	69	37.2	35.5	65	0.91	30.9	29.2	19.9	21.0	47	3.2	0.8	0.89	21.6	21.1	21.0	21.5	21	2.1	0.7	0.95	18.7	14.3	14	2.0	0.8	1.00	5.92	45.40	12.7	4.8	3.4	41.8	297.4	63.0	6.1	33.1	48.3	18.6
4A-Manas	79	29.0	28.6	37	0.97	22.7	22.2	19.3	19.7	24	2.5	0.8	0.96	12.4	12.4	7.8	7.8	8	1.3	0.6	1.00	17.5	18.4	11	1.7	0.7	1.00	2.60	28.81	11.1	4.7	4.6	50.4	510.8	143.8	7.9	10.0	69.6	20.4
3-MtStir	37	27.0	26.6	34	0.97	17.9	17.4	11.0	11.2	20	2.3	0.8	0.95	11.7	11.7	8.9	8.9	8	1.5	0.7	1.00	16.3	12.6	11	1.6	0.7	1.00	1.64	26.29	16.2	4.8	3.8	41.4	286.2	36.2	5.3	75.6	16.9	7.5
2-SWSfk	85	35.7	35.4	52	0.98	30.5	30.1	29.2	29.6	41	3.0	0.8	0.98	18.6	18.6	18.8	18.8	15	1.4	0.5	1.00	18.5	19.7	12	2.1	0.9	1.00	5.62	99.43	17.6	4.7	3.8	84.6	442.8	80.8	8.9	39.3	36.1	24.6
1B-Matta	58	25.5	24.5	27	0.93	18.4	17.3	19.1	20.4	16	2.0	0.7	0.88	17.5	17.5	16.0	16.0	13	2.0	0.8	1.00	16.8	13.7	10	1.8	0.8	1.00	6.05	89.07	15.1	4.4	3.8	61.0	576.4	167.6	8.9	32.1	30.7	37.1
1A-Reedy	71	29.1	28.3	38	0.95	24.7	23.9	27.8	28.7	31	2.7	0.8	0.94	11.6	11.6	10.3	10.3	5	1.4	0.8	1.00	16.1	14.3	10	1.9	0.8	1.00	3.09	39.02	12.7	4.9	4.6	54.6	696.0	187.8	9.4	18.2	51.8	30.1

APPENDIX E

Spearman's Rank-order Correlation Coefficient and P-value Matrices

Table E-1a. **CW Spearman correlation coefficients** (statistifcally significant correlations in red).

	Age	FQI	FQI_{all}	S	%N	FQI_h	FQI_{h-all}	FQI_{h-mod}	$FQI_{h-mod(all)}$	S_h	H'_h	E_h	$\%N_h$	FQI_s	$FQI_{s(all)}$	FQI_{s-mod}	$FQI_{s-mod(all)}$	S_s	H'_s	E_s	$\%N_s$
FQI	0.337	-																			
FQI_{all}	0.272	**0.961**	-																		
S	0.278	**0.913**	**0.852**	-																	
%N	0.270	0.237	0.376	-0.045	-																
FQI_h	0.308	**0.946**	**0.893**	**0.929**	0.093	-															
FQI_{h-all}	0.353	**0.939**	**0.889**	**0.883**	0.201	**0.982**	-														
FQI_{h-mod}	0.246	**0.750**	**0.750**	**0.666**	0.348	**0.718**	**0.779**	-													
$FQI_{h-mod(all)}$	0.240	**0.736**	**0.736**	**0.652**	0.333	**0.711**	**0.775**	**0.996**	-												
S_h	0.295	**0.797**	**0.699**	**0.950**	-0.213	**0.870**	**0.815**	**0.567**	**0.554**	-											
H'_h	0.158	**0.797**	**0.713**	**0.780**	0.088	**0.765**	**0.754**	**0.779**	**0.769**	**0.723**	-										
E_h	0.116	0.475	0.421	0.414	0.154	0.404	0.421	**0.704**	**0.693**	0.297	**0.819**	-									
$\%N_h$	0.254	0.358	0.502	0.099	**0.978**	0.233	0.341	0.437	0.427	-0.068	0.178	0.158	-								
FQI_s	0.165	0.329	0.384	0.078	**0.551**	0.048	0.055	0.209	0.177	-0.116	0.250	0.370	0.490	-							
$FQI_{s(all)}$	0.192	0.357	0.409	0.105	**0.572**	0.080	0.088	0.238	0.202	-0.082	0.275	0.377	0.511	**0.996**	-						
FQI_{s-mod}	0.109	0.111	0.214	-0.113	**0.656**	-0.150	-0.096	0.100	0.057	-0.273	0.079	0.254	**0.599**	**0.817**	**0.824**	-					
$FQI_{s-mod(all)}$	0.100	0.104	0.204	-0.116	**0.624**	-0.161	-0.104	0.104	0.064	-0.273	0.082	0.261	**0.570**	**0.810**	**0.813**	**0.996**	-				
S_s	0.272	0.261	0.313	0.054	**0.578**	0.016	0.016	0.197	0.170	-0.153	0.149	0.308	0.487	**0.878**	**0.878**	**0.611**	**0.583**	-			
H'_s	0.068	0.250	0.293	0.034	0.394	0.014	0.018	0.221	0.200	-0.155	0.259	0.436	0.308	**0.824**	**0.820**	**0.679**	**0.689**	**0.761**	-		
E_s	-0.229	-0.075	-0.061	-0.167	-0.022	-0.179	-0.200	-0.068	-0.061	-0.163	0.098	0.118	-0.082	0.331	0.327	0.289	0.329	0.161	**0.671**	-	
$\%N_s$	0.266	-0.038	0.005	-0.269	**0.685**	-0.197	-0.161	0.018	-0.018	-0.323	0.018	0.176	**0.562**	**0.663**	**0.699**	**0.698**	**0.662**	**0.636**	**0.519**	0.269	-
N	0.357	0.220	0.052	0.365	-0.499	0.320	0.250	0.046	0.014	**0.536**	0.315	0.155	-0.497	-0.136	-0.111	-0.236	-0.231	-0.203	-0.046	0.088	-0.115
C	0.441	0.282	0.107	0.403	-0.384	0.289	0.264	0.232	0.204	**0.558**	0.388	0.204	-0.373	-0.091	-0.059	-0.146	-0.132	-0.101	0.004	0.075	-0.123
C:N	-0.036	0.161	0.132	0.127	0.057	0.043	0.107	0.475	0.493	0.125	0.315	0.261	0.079	0.052	0.059	0.021	0.057	0.096	0.246	0.336	-0.095
pH	-0.253	0.196	0.136	0.442	-0.452	0.318	0.207	-0.064	-0.086	**0.590**	0.214	-0.229	-0.366	-0.397	-0.368	-0.429	-0.443	-0.361	-0.314	0.032	-0.368
P	-0.242	**-0.757**	**-0.750**	**-0.635**	-0.300	**-0.699**	**-0.707**	**-0.667**	**-0.671**	-0.444	**-0.620**	**-0.594**	-0.373	-0.409	-0.413	-0.132	-0.122	-0.383	-0.227	0.258	-0.059
K	-0.075	0.289	0.125	0.453	-0.487	0.314	0.275	0.196	0.179	**0.567**	0.504	0.264	-0.434	-0.143	-0.132	-0.179	-0.146	-0.248	0.089	0.332	-0.332
Ca	-0.186	0.036	-0.007	0.261	**-0.516**	0.129	0.025	-0.254	-0.271	0.441	0.107	-0.279	-0.441	-0.399	-0.377	-0.271	-0.268	-0.507	-0.321	0.146	-0.345
Mg	-0.421	-0.100	-0.157	0.136	**-0.552**	0.014	-0.061	-0.325	-0.321	0.306	-0.052	-0.432	-0.477	**-0.518**	**-0.515**	-0.432	-0.414	**-0.563**	-0.325	0.246	-0.496
CEC	-0.138	-0.150	-0.304	-0.018	**-0.674**	-0.079	-0.129	-0.379	-0.382	0.188	-0.052	-0.257	**-0.663**	-0.343	-0.336	-0.236	-0.196	**-0.567**	-0.146	0.404	-0.286
%Sand	-0.097	-0.336	-0.218	-0.299	0.111	-0.475	-0.496	-0.132	-0.146	-0.420	-0.290	0.029	0.014	0.334	0.302	0.271	0.268	**0.549**	0.429	0.118	0.102
%Silt	0.068	0.432	0.364	0.423	-0.104	**0.543**	**0.518**	0.043	0.064	0.504	0.313	-0.154	0.025	-0.316	-0.295	-0.346	-0.354	-0.437	-0.436	-0.150	-0.246
%Clay	-0.111	0.079	-0.032	0.057	-0.068	0.196	0.239	0.254	0.250	0.157	0.275	0.282	-0.057	-0.206	-0.170	-0.082	-0.075	-0.397	-0.154	0.086	0.148

Table E-1b. **CW Spearman correlation p-values** (statistically significant correlations in red).

	Age	FQI	FQI_{all}	S	%N	FQI_h	FQI_{h-all}	FQI_{h-mod}	$FQI_{h-mod(all)}$	S_h	H'_h	E_h	$\%N_h$	FQI_s	$FQI_{s(all)}$	FQI_{s-mod}	$FQI_{s-mod(all)}$	S_s	H'_s	E_s	$\%N_s$
FQI	0.219	-																			
FQI_{all}	0.326	**0.000**	-																		
S	0.316	**0.000**	**0.000**	-																	
%N	0.331	0.396	0.167	0.874	-																
FQI_h	0.264	**0.000**	**0.000**	**0.000**	0.741	-															
FQI_{h-all}	0.197	**0.000**	**0.000**	**0.000**	0.473	**0.000**	-														
FQI_{h-mod}	0.378	**0.001**	**0.001**	**0.007**	0.204	**0.003**	**0.001**	-													
$FQI_{h-mod(all)}$	0.389	**0.002**	**0.002**	**0.008**	0.225	**0.003**	**0.001**	**0.000**	-												
S_h	0.286	**0.000**	**0.004**	**0.000**	0.445	**0.000**	**0.000**	**0.028**	**0.032**	-											
H'_h	0.574	**0.000**	**0.003**	**0.001**	0.755	**0.001**	**0.001**	**0.001**	**0.001**	**0.002**	-										
E_h	0.679	0.074	0.118	0.125	0.583	0.136	0.118	**0.003**	**0.004**	0.283	**0.000**	-									
$\%N_h$	0.362	0.190	0.057	0.726	**0.000**	0.403	0.214	0.103	0.113	0.809	0.527	0.575	-								
FQI_s	0.557	0.231	0.157	0.782	**0.033**	0.864	0.845	0.454	0.528	0.680	0.370	0.175	0.064	-							
$FQI_{s(all)}$	0.493	0.191	0.130	0.710	**0.026**	0.776	0.756	0.394	0.470	0.771	0.322	0.166	0.051	**0.000**	-						
FQI_{s-mod}	0.698	0.694	0.443	0.689	**0.008**	0.594	0.732	0.723	0.840	0.324	0.781	0.362	**0.018**	**0.000**	**0.000**	-					
$FQI_{s-mod(all)}$	0.722	0.713	0.467	0.680	**0.013**	0.567	0.713	0.713	0.820	0.324	0.771	0.348	**0.027**	**0.000**	**0.000**	**0.000**	-				
S_s	0.327	0.348	0.255	0.847	**0.024**	0.954	0.954	0.481	0.544	0.586	0.597	0.264	0.065	**0.000**	**0.000**	**0.016**	**0.022**	-			
H'_s	0.809	0.369	0.289	0.904	0.146	0.960	0.950	0.428	0.475	0.580	0.351	0.104	0.264	**0.000**	**0.000**	**0.005**	**0.004**	**0.001**	-		
E_s	0.411	0.791	0.830	0.553	0.939	0.524	0.475	0.810	0.830	0.562	0.727	0.676	0.770	0.229	0.234	0.296	0.232	0.566	**0.006**	-	
$\%N_s$	0.339	0.892	0.986	0.332	**0.005**	0.482	0.566	0.950	0.950	0.241	0.949	0.529	**0.029**	**0.007**	**0.004**	**0.004**	**0.007**	**0.011**	**0.047**	0.333	-
N	0.192	0.431	0.854	0.181	0.058	0.245	0.368	0.869	0.960	**0.040**	0.253	0.580	0.060	0.629	0.694	0.397	0.408	0.468	0.869	0.756	0.683
C	0.100	0.308	0.704	0.137	0.158	0.296	0.341	0.405	0.467	**0.031**	0.153	0.467	0.171	0.747	0.835	0.603	0.639	0.719	0.990	0.791	0.663
C:N	0.899	0.567	0.639	0.652	0.839	0.879	0.704	0.074	0.062	0.657	0.253	0.348	0.780	0.854	0.835	0.940	0.840	0.734	0.376	0.221	0.737
pH	0.364	0.483	0.630	0.099	0.091	0.248	0.459	0.820	0.761	**0.021**	0.443	0.413	0.180	0.143	0.177	0.111	0.098	0.187	0.254	0.909	0.177
P	0.384	**0.001**	**0.001**	**0.011**	0.278	**0.004**	**0.003**	**0.007**	**0.006**	0.097	**0.014**	**0.020**	0.170	0.130	0.126	0.638	0.666	0.159	0.415	0.354	0.835
K	0.790	0.296	0.657	0.090	0.065	0.254	0.321	0.483	0.524	**0.028**	0.055	0.341	0.106	0.611	0.638	0.524	0.603	0.372	0.752	0.226	0.226
Ca	0.506	0.899	0.980	0.347	**0.049**	0.648	0.930	0.362	0.328	0.099	0.704	0.315	0.100	0.141	0.166	0.328	0.334	0.054	0.243	0.603	0.208
Mg	0.118	0.723	0.576	0.629	**0.033**	0.960	0.830	0.237	0.243	0.268	0.854	0.108	0.072	**0.048**	**0.050**	0.108	0.125	**0.029**	0.237	0.376	0.060
CEC	0.624	0.594	0.271	0.950	**0.006**	0.781	0.648	0.164	0.160	0.503	0.854	0.355	**0.007**	0.210	0.221	0.398	0.483	**0.027**	0.603	0.136	0.301
%Sand	0.732	0.221	0.435	0.279	0.693	0.074	0.060	0.639	0.603	0.119	0.295	0.919	0.960	0.223	0.274	0.328	0.334	**0.034**	0.111	0.676	0.717
%Silt	0.809	0.108	0.182	0.117	0.712	**0.037**	**0.048**	0.879	0.820	0.055	0.256	0.585	0.929	0.251	0.286	0.206	0.196	0.104	0.104	0.594	0.378
%Clay	0.693	0.781	0.909	0.839	0.809	0.483	0.390	0.362	0.369	0.576	0.321	0.308	0.839	0.462	0.545	0.771	0.791	0.143	0.585	0.761	0.598

Table E-2a. **REF Spearman correlation coefficients** (statistifcally significant correlations in red).

	Age	FQI	FQI$_{all}$	S	%N	FQI$_{h}$	FQI$_{h-all}$	FQI$_{h-mod}$	FQI$_{h-mod(all)}$	S$_{h}$	H'$_{h}$	E$_{h}$	%N$_{h}$	FQI$_{s}$	FQI$_{s(all)}$	FQI$_{s-mod}$	FQI$_{s-mod(all)}$	S$_{s}$	H'$_{s}$	E$_{s}$	%N$_{s}$	FQI$_{t}$	FQI$_{t-mod}$	S$_{t}$	H'$_{t}$	E$_{t}$
FQI	0.132																									
FQI$_{all}$	0.143	**0.982**																								
S	-0.050	**0.882**	**0.830**																							
%N	0.372	-0.209	-0.116	-0.417																						
FQI$_{h}$	0.054	**0.907**	**0.879**	**0.911**	-0.354																					
FQI$_{h-all}$	0.100	**0.889**	**0.886**	**0.859**	-0.163	**0.957**																				
FQI$_{h-mod}$	0.454	**0.718**	**0.689**	**0.522**	-0.066	**0.704**	**0.679**																			
FQI$_{h-mod(all)}$	0.432	**0.671**	**0.643**	0.504	-0.120	**0.675**	**0.618**	**0.982**																		
S$_{h}$	-0.047	**0.850**	**0.806**	**0.972**	-0.381	**0.940**	**0.897**	**0.559**	**0.550**																	
H'$_{h}$	-0.057	**0.768**	**0.696**	**0.921**	-0.475	**0.857**	**0.829**	0.493	0.475	**0.927**																
E$_{h}$	0.061	0.336	0.264	0.462	-0.336	0.432	0.404	0.164	0.157	0.453	**0.675**															
%N$_{h}$	0.338	-0.095	-0.011	-0.264	**0.964**	-0.209	-0.007	-0.002	-0.059	-0.206	-0.291	-0.214														
FQI$_{s}$	0.504	0.390	0.347	0.305	-0.078	0.288	0.195	0.425	0.415	0.192	0.195	0.157	-0.127													
FQI$_{s(all)}$	**0.515**	0.343	0.307	0.264	0.049	0.252	0.181	0.400	0.386	0.165	0.152	0.139	0.005	**0.986**												
FQI$_{s-mod}$	0.382	0.357	0.321	0.231	-0.014	0.314	0.211	0.471	0.482	0.163	0.114	0.107	-0.077	**0.908**	**0.919**											
FQI$_{s-mod(all)}$	0.400	0.407	0.350	0.306	-0.091	0.375	0.261	**0.514**	**0.518**	0.235	0.204	0.211	-0.139	**0.919**	**0.922**	**0.986**										
S$_{s}$	0.289	0.433	0.363	0.479	-0.203	0.393	0.310	0.361	0.330	0.362	0.413	0.323	-0.211	**0.922**	**0.915**	**0.803**	**0.842**									
H'$_{s}$	0.218	0.118	0.039	0.102	-0.270	0.046	-0.079	0.132	0.104	-0.023	0.107	0.200	-0.311	**0.808**	**0.769**	**0.643**	**0.668**	**0.813**								
E$_{s}$	0.196	-0.318	-0.386	-0.372	-0.234	-0.211	-0.321	-0.011	-0.014	-0.347	-0.196	0.118	-0.286	0.046	-0.011	0.029	0.054	-0.032	0.418							
%N$_{s}$	-0.099	-0.370	-0.259	**-0.517**	**0.744**	-0.349	-0.172	-0.145	-0.177	-0.436	-0.482	-0.358	**0.708**	-0.331	-0.214	-0.117	-0.227	-0.369	-0.379	-0.165						
FQI$_{t}$	0.438	0.347	0.411	0.124	0.406	0.138	0.195	0.245	0.214	0.099	-0.120	-0.356	0.326	0.449	0.481	0.433	0.393	0.288	0.023	-0.488	0.026					
FQI$_{t-mod}$	**0.679**	0.286	0.350	0.261	0.207	0.293	0.339	0.264	0.268	0.294	0.136	-0.125	0.204	0.332	0.336	0.207	0.189	0.206	-0.068	-0.221	-0.163	**0.633**				
S$_{t}$	0.121	0.378	0.452	0.224	0.388	0.246	0.345	0.077	0.018	0.222	-0.039	-0.446	0.367	0.152	0.191	0.200	0.141	0.069	-0.215	**-0.564**	0.151	**0.827**	**0.545**			
H'$_{t}$	0.206	**0.593**	**0.622**	0.426	0.098	**0.572**	**0.547**	0.356	0.306	0.442	0.222	-0.007	0.077	0.170	0.157	0.261	0.268	0.109	-0.109	-0.048	-0.109	0.478	0.447	**0.599**		
E$_{t}$	0.375	0.489	0.457	0.381	-0.002	**0.518**	0.439	0.471	0.450	0.397	0.332	0.389	-0.002	0.214	0.193	0.271	0.332	0.180	0.057	0.311	-0.239	0.077	0.250	0.026	**0.777**	
N	**0.521**	-0.129	-0.146	-0.148	0.245	-0.114	-0.218	0.071	0.093	-0.159	-0.321	-0.164	0.173	**0.574**	**0.634**	**0.571**	**0.579**	0.420	0.404	0.132	-0.110	0.422	0.361	0.178	0.188	0.214
C	**0.554**	-0.093	-0.125	-0.174	0.365	-0.061	-0.125	0.250	0.236	-0.179	-0.311	-0.175	0.286	**0.554**	**0.626**	**0.625**	**0.629**	0.420	0.389	0.257	0.096	0.298	0.236	0.121	0.250	0.354
C:N	0.132	0.007	-0.018	-0.107	**0.525**	-0.075	-0.011	0.100	0.025	-0.172	-0.132	-0.018	0.488	0.302	0.377	0.407	0.371	0.319	0.296	0.132	0.464	-0.013	-0.218	0.062	0.138	0.250
pH	-0.014	0.425	0.375	0.216	-0.357	0.318	0.257	0.432	0.450	0.229	0.207	0.121	-0.359	-0.032	-0.114	0.096	0.146	-0.144	-0.179	-0.011	-0.370	0.164	-0.139	0.088	0.243	0.214
P	0.047	-0.194	-0.269	-0.079	-0.319	-0.172	-0.268	-0.093	-0.047	-0.069	-0.083	0.075	-0.332	-0.328	-0.376	-0.397	-0.289	-0.349	-0.269	0.160	**-0.526**	-0.204	-0.097	-0.321	-0.087	0.135
K	0.318	-0.061	-0.107	-0.081	0.018	0.021	0.011	0.346	0.343	-0.100	-0.150	-0.179	-0.004	0.256	0.270	0.361	0.379	0.157	0.064	0.071	0.034	-0.046	0.018	-0.042	-0.111	-0.032
Ca	0.239	0.057	0.021	-0.106	-0.282	0.014	-0.082	0.436	0.489	-0.068	-0.139	-0.179	-0.363	0.043	-0.021	0.107	0.154	-0.133	-0.100	0.125	-0.321	0.213	0.029	-0.090	0.013	0.071
Mg	0.296	0.061	0.054	-0.089	-0.284	0.079	0.004	0.471	0.486	-0.047	-0.104	-0.182	-0.381	0.025	-0.050	0.004	0.054	-0.094	-0.029	0.282	-0.259	0.132	0.143	-0.163	0.122	0.207
CEC	**0.615**	-0.086	-0.145	-0.223	0.084	-0.122	-0.202	0.406	0.404	-0.215	-0.266	-0.152	0.034	0.243	0.231	0.182	0.245	0.060	0.227	0.475	-0.232	0.054	0.109	-0.234	0.032	0.318
%Sand	-0.150	0.136	0.125	-0.020	0.327	-0.064	-0.025	0.107	0.068	-0.111	-0.139	-0.311	0.306	0.382	0.433	0.489	0.418	0.355	0.325	-0.268	0.353	0.257	-0.300	0.318	-0.098	-0.289
%Silt	0.121	0.029	0.054	0.140	-0.381	0.225	0.243	-0.082	-0.075	0.217	0.268	0.371	-0.315	-0.347	-0.411	-0.432	-0.375	-0.332	-0.346	0.157	-0.340	-0.222	0.343	-0.127	0.129	0.168
%Clay	0.211	-0.054	-0.086	0.057	0.039	0.046	-0.046	0.146	0.150	0.090	0.000	0.089	0.009	0.080	0.116	0.004	0.082	0.159	0.104	0.171	-0.149	-0.002	0.114	-0.237	0.195	0.450

Table E-2b. **REF Spearman correlation p-values** (statistically significant correlations in red).

	Age	**FQI**	**FQI$_{all}$**	**S**	**%N**	**FQI$_{h}$**	**FQI$_{h\text{-}all}$**	**FQI$_{h\text{-}mod}$**	**FQI$_{h\text{-}mod(all)}$**	**S$_{h}$**	**H'$_{h}$**	**E$_{h}$**	**%N$_{h}$**	**FQI$_{s}$**	**FQI$_{s(all)}$**	**FQI$_{s\text{-}mod}$**	**FQI$_{s\text{-}mod(all)}$**	**S$_{s}$**	**H'$_{s}$**	**E$_{s}$**	**%N$_{s}$**	**FQI$_{t}$**	**FQI$_{t\text{-}mod}$**	**S$_{t}$**	**H'$_{t}$**	**E$_{t}$**
FQI	0.639																									
FQI$_{all}$	0.612	**0.000**																								
S	0.859	**0.000**	**0.000**																							
%N	0.172	0.454	0.680	0.122																						
FQI$_{h}$	0.850	**0.000**	**0.000**	**0.000**	0.196																					
FQI$_{h\text{-}all}$	0.723	**0.000**	**0.000**	**0.000**	0.562	**0.000**																				
FQI$_{h\text{-}mod}$	0.089	**0.003**	**0.004**	**0.046**	0.815	**0.003**	**0.005**																			
FQI$_{h\text{-}mod(all)}$	0.108	**0.006**	**0.010**	0.055	0.671	**0.006**	**0.014**	**0.000**																		
S$_{h}$	0.869	**0.000**	**0.000**	**0.000**	0.161	**0.000**	**0.000**	**0.030**	**0.034**																	
H'$_{h}$	0.840	**0.001**	**0.004**	**0.000**	0.073	**0.000**	**0.000**	0.062	0.074	**0.000**																
E$_{h}$	0.830	0.221	0.341	0.083	0.221	0.108	0.136	0.558	0.576	0.090	**0.006**															
%N$_{h}$	0.218	0.737	0.970	0.342	**0.000**	0.454	0.980	0.995	0.835	0.461	0.292	0.443														
FQI$_{s}$	0.055	0.151	0.205	0.269	0.783	0.298	0.487	0.114	0.124	0.494	0.487	0.576	0.652													
FQI$_{s(all)}$	**0.050**	0.210	0.265	0.342	0.862	0.365	0.520	0.139	0.155	0.557	0.589	0.620	0.985	**0.000**												
FQI$_{s\text{-}mod}$	0.160	0.191	0.243	0.408	0.960	0.254	0.451	0.076	0.069	0.562	0.685	0.704	0.785	**0.000**	**0.000**											
FQI$_{s\text{-}mod(all)}$	0.140	0.132	0.201	0.268	0.747	0.168	0.348	**0.050**	**0.048**	0.400	0.467	0.451	0.620	**0.000**	**0.000**	**0.000**										
S$_{s}$	0.297	0.107	0.184	0.071	0.468	0.147	0.260	0.187	0.230	0.185	0.126	0.241	0.450	**0.000**	**0.000**	**0.000**	**0.000**									
H'$_{s}$	0.435	0.676	0.889	0.718	0.331	0.869	0.781	0.639	0.713	0.934	0.704	0.475	0.259	**0.000**	**0.001**	**0.010**	**0.007**	**0.000**								
E$_{s}$	0.483	0.248	0.156	0.172	0.401	0.451	0.243	0.970	0.960	0.205	0.483	0.676	0.301	0.869	0.970	0.919	0.850	0.909	0.121							
%N$_{s}$	0.726	0.175	0.351	**0.048**	**0.001**	0.203	0.540	0.607	0.529	0.104	0.069	0.190	**0.003**	0.228	0.445	0.678	0.415	0.176	0.164	0.556						
FQI$_{t}$	0.103	0.205	0.128	0.661	0.133	0.625	0.487	0.379	0.443	0.727	0.671	0.193	0.236	0.093	0.069	0.107	0.147	0.298	0.934	0.065	0.926					
FQI$_{t\text{-}mod}$	**0.005**	0.302	0.201	0.347	0.458	0.289	0.216	0.341	0.334	0.288	0.630	0.657	0.466	0.226	0.221	0.459	0.499	0.462	0.810	0.428	0.562	**0.011**				
S$_{t}$	0.667	0.165	0.091	0.422	0.153	0.377	0.208	0.785	0.948	0.427	0.892	0.096	0.178	0.587	0.495	0.475	0.615	0.808	0.442	**0.029**	0.591	**0.000**	**0.036**			
H'$_{t}$	0.462	**0.020**	**0.013**	0.113	0.727	**0.026**	**0.035**	0.193	0.268	0.099	0.427	0.980	0.785	0.545	0.575	0.348	0.334	0.698	0.699	0.864	0.699	0.072	0.095	**0.018**		
E$_{t}$	0.168	0.064	0.087	0.161	0.995	**0.048**	0.101	0.076	0.092	0.142	0.226	0.152	0.995	0.443	0.491	0.328	0.226	0.520	0.840	0.260	0.392	0.785	0.369	0.928	**0.001**	
N	**0.046**	0.648	0.603	0.597	0.379	0.685	0.435	0.800	0.742	0.571	0.243	0.558	0.537	**0.025**	**0.011**	**0.026**	**0.024**	0.119	0.136	0.639	0.696	0.117	0.187	0.526	0.503	0.443
C	**0.032**	0.742	0.657	0.536	0.181	0.830	0.657	0.369	0.398	0.523	0.260	0.533	0.301	**0.032**	**0.013**	**0.013**	**0.012**	0.119	0.152	0.355	0.733	0.280	0.398	0.667	0.368	0.196
C:N	0.639	0.980	0.950	0.703	**0.044**	0.791	0.970	0.723	0.930	0.540	0.639	0.950	0.065	0.274	0.166	0.132	0.173	0.246	0.283	0.639	0.082	0.965	0.435	0.825	0.625	0.369
pH	0.960	0.114	0.168	0.438	0.191	0.248	0.355	0.108	0.092	0.411	0.459	0.666	0.188	0.909	0.685	0.732	0.603	0.608	0.524	0.970	0.175	0.558	0.621	0.755	0.383	0.443
P	0.869	0.489	0.332	0.779	0.247	0.539	0.335	0.741	0.869	0.806	0.770	0.789	0.227	0.233	0.167	0.143	0.296	0.202	0.332	0.569	**0.044**	0.466	0.731	0.243	0.757	0.632
K	0.248	0.830	0.704	0.775	0.950	0.940	0.970	0.206	0.211	0.722	0.594	0.524	0.990	0.358	0.331	0.187	0.164	0.577	0.820	0.800	0.903	0.869	0.950	0.881	0.694	0.909
Ca	0.390	0.840	0.940	0.708	0.308	0.960	0.771	0.104	0.064	0.810	0.621	0.524	0.184	0.879	0.940	0.704	0.585	0.635	0.723	0.657	0.243	0.447	0.919	0.750	0.965	0.800
Mg	0.283	0.830	0.850	0.751	0.305	0.781	0.990	0.076	0.066	0.869	0.713	0.516	0.162	0.929	0.859	0.990	0.850	0.740	0.919	0.308	0.351	0.638	0.612	0.561	0.666	0.459
CEC	**0.015**	0.761	0.607	0.425	0.766	0.666	0.470	0.134	0.135	0.441	0.337	0.589	0.904	0.382	0.408	0.516	0.379	0.833	0.416	0.073	0.405	0.849	0.699	0.401	0.909	0.248
%Sand	0.594	0.630	0.657	0.945	0.234	0.820	0.930	0.704	0.810	0.694	0.621	0.260	0.268	0.159	0.107	0.064	0.121	0.194	0.237	0.334	0.196	0.354	0.277	0.249	0.727	0.296
%Silt	0.666	0.919	0.850	0.620	0.162	0.420	0.383	0.771	0.791	0.438	0.334	0.173	0.253	0.205	0.128	0.108	0.168	0.227	0.206	0.576	0.215	0.427	0.211	0.653	0.648	0.550
%Clay	0.451	0.850	0.761	0.839	0.889	0.869	0.869	0.603	0.594	0.751	1.000	0.752	0.975	0.776	0.680	0.990	0.771	0.572	0.713	0.541	0.596	0.995	0.685	0.395	0.487	0.092

APPENDIX F

PC-ORD Statistical Output by CCA Run

CW HERBACEOUS

```
********************* Canonical Correspondence Analysis **************
PC-ORD, Version 4.25
 1 Mar 2006,  0:26
CCA CW herbaceous


DATA MATRICES
---------------------------------------
     Main matrix:
             15 sites    (rows)
            152 species  (columns)

     Second matrix:
             15 sites    (rows)
             13 environ  (columns)

     Finished reading data.
---------------------------------------


OPTIONS SELECTED
     Axis scores centered and standardized to unit variance
     Axes scaled to optimize representation of rows: sites
          (Scores for sites    are weighted mean scores for species )
     Scores for graphing sites    are linear combinations of environ
     Monte Carlo test: null hypothesis is no relationship between
matrices
     Random number seed:        1550


AXIS SUMMARY STATISTICS
Number of canonical axes: 3
Total variance ("inertia") in the species data:   4.6759
-----------------------------------------------------------
                                  Axis 1   Axis 2   Axis 3
-----------------------------------------------------------
Eigenvalue                         0.677    0.557    0.461
Variance in species data
     % of variance explained        14.5     11.9      9.9
     Cumulative % explained         14.5     26.4     36.2
Pearson Correlation, Spp-Envt*     1.000    1.000    0.999
Kendall (Rank) Corr., Spp-Envt     0.962    1.000    0.943
-----------------------------------------------------------
* Correlation between sample scores for an axis derived from the
species
     data and the sample scores that are linear combinations of the
     environmental variables. Set to 0.000 if axis is not canonical.
```

```
Scores that are linear combinations of environ  (LC Scores)
FINAL SCORES and raw data totals (weights) for  15 sites
----------------------------------------------------------------
                                                        Raw Data
                    Axis 1       Axis 2       Axis 3      Totals
----------------------------------------------------------------
   1 15-Sleet     2.656898     0.150037     0.150275    100.0000
   2 12B-BwrH    -0.456104    -0.548275    -0.104743    100.0000
   3 12A-Rte7     1.217809     0.037653     0.130085    100.0000
   4 11-Court    -0.377633    -0.621548    -0.093813    100.0000
   5 10B-Prct    -0.138202    -0.688211     0.303105    100.0000
   6 10A-Fkln    -0.414013    -0.487271    -0.087235    100.0000
   7 7-ChsCty    -0.444696     0.182948     0.624648    100.0000
   8 6-Stony     -0.546055     1.258314     1.700966    100.0000
   9 5-FtLee     -0.441425    -0.427563     0.190445    100.0000
  10 4B-Pwhte    -0.036618    -0.509913     0.067166    100.0000
  11 4A-Manas    -0.112520     0.219268     0.134406    100.0000
  12 3-MtStir    -0.192380    -1.361467    -0.265895    100.0000
  13 2-SWSfk     -0.331618     1.079171    -0.190185    100.0000
  14 1B-Matta    -0.455789     1.266062    -1.408856    100.0000
  15 1A-Reedy     0.072346     0.450794    -1.150369    100.0000
----------------------------------------------------------------


CORRELATIONS AND BIPLOT SCORES for  13 environ
----------------------------------------------------------------
                    Correlations*              Biplot Scores
    Variable     Axis 1  Axis 2  Axis 3     Axis 1  Axis 2  Axis 3
----------------------------------------------------------------
   1 Age           0.531  -0.352   0.368      0.437  -0.263   0.250
   2 N             0.695   0.119   0.058      0.571   0.089   0.039
   3 C             0.517   0.156  -0.009      0.425   0.116  -0.006
   4 C:N          -0.378   0.039  -0.231     -0.311   0.029  -0.157
   5 pH            0.162   0.186  -0.193      0.134   0.139  -0.131
   6 P            -0.135   0.595  -0.200     -0.111   0.444  -0.136
   7 K             0.054   0.521  -0.315      0.044   0.389  -0.214
   8 Ca            0.220   0.406  -0.051      0.181   0.303  -0.034
   9 Mg           -0.007   0.535  -0.275     -0.006   0.399  -0.186
  10 CEC           0.119   0.531  -0.043      0.098   0.396  -0.030
  11 %Sand        -0.181  -0.157  -0.155     -0.149  -0.117  -0.105
  12 %Silt         0.293   0.127   0.059      0.241   0.095   0.040
  13 %Clay        -0.196   0.162   0.333     -0.161   0.121   0.226
--------------------------------------------------------------
* Correlations are "intraset correlations" of ter Braak (1986)
```

```
 MONTE CARLO TEST RESULTS -- EIGENVALUES
------------------------------------------------------------
                              Randomized data
           Real data    Monte Carlo test,  499 runs
          ------------  ---------------------------
  Axis     Eigenvalue    Mean     Minimum   Maximum       p
------------------------------------------------------------
     1         0.677     0.656      0.560     0.677    0.1100
     2         0.557     0.539      0.467     0.557    0.0140
     3         0.461     0.460      0.446     0.467    0.5740
------------------------------------------------------------
p = proportion of randomized runs with eigenvalue greater
    than or equal to the observed eigenvalue; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)

MONTE CARLO TEST RESULTS -- SPECIES-ENVIRONMENT CORRELATIONS
------------------------------------------------------------
                              Randomized data
           Real data    Monte Carlo test,  499 runs
          ------------  ---------------------------
  Axis   Spp-Envt Corr.  Mean     Minimum   Maximum      p
------------------------------------------------------------
    1         1.000     0.994      0.967     1.000    0.1120
    2         1.000     0.995      0.959     1.000    0.0140
    3         0.999     0.999      0.971     1.000    0.5420
------------------------------------------------------------
p = proportion of randomized runs with species-environment
    correlation greater than or equal to the observed
    species-environment correlation; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)

***************************** Operation completed *******************
```

CW SHRUB-SAPLING

```
********************* Canonical Correspondence Analysis *************
PC-ORD, Version 4.25
28 Feb 2006, 23:58
CCA CW shrub-sapling


DATA MATRICES
--------------------------------------
     Main matrix:
             14 sites    (rows)
             27 species  (columns)

     Second matrix:
             14 sites    (rows)
             11 environ  (columns)

     Finished reading data.
--------------------------------------


OPTIONS SELECTED
     Axis scores centered and standardized to unit variance
     Axes scaled to optimize representation of rows: sites
          (Scores for sites    are weighted mean scores for species )
     Scores for graphing sites    are linear combinations of environ
     Monte Carlo test: null hypothesis is no relationship between
matrices
     Random number seed:        1085


AXIS SUMMARY STATISTICS
Number of canonical axes: 3
Total variance ("inertia") in the species data:   3.8783
-----------------------------------------------------------
                                   Axis 1   Axis 2   Axis 3
-----------------------------------------------------------
Eigenvalue                          0.742    0.697    0.511
Variance in species data
     % of variance explained         19.1     18.0     13.2
     Cumulative % explained          19.1     37.1     50.3
Pearson Correlation, Spp-Envt*      0.988    0.998    0.908
Kendall (Rank) Corr., Spp-Envt      0.846    0.934    0.846
-----------------------------------------------------------
* Correlation between sample scores for an axis derived from the
species
     data and the sample scores that are linear combinations of the
     environmental variables. Set to 0.000 if axis is not canonical.
```

```
Scores that are linear combinations of environ  (LC Scores)
FINAL SCORES and raw data totals (weights) for  14 sites
---------------------------------------------------------------------
                                                            Raw Data
                    Axis 1        Axis 2        Axis 3        Totals
---------------------------------------------------------------------
   1 15-Sleet     -0.062359      0.816884      0.716439      100.0000
   2 12B-BwrH     -0.108632      0.074636      0.185359      100.0000
   3 12A-Rte7      0.136728      0.735506      1.442769      100.0000
   4 11-Court      0.098797      0.010153     -0.381454      100.0000
   5 10B-Prct      0.041081      0.392495     -0.474737      100.0000
   6 10A-Fkln     -0.113148      0.539951     -1.359153      100.0000
   7 7-ChsCty     -0.695247     -0.140514     -0.312222      100.0000
   8 6-Stony       1.404348     -1.856803     -0.351467      100.0000
   9 5-FtLee      -0.332852      0.648735     -0.214810      100.0000
  10 4B-Pwhte      0.444252      0.655135     -0.509326      100.0000
  11 4A-Manas      0.435571      0.101153      1.155956      100.0000
  12 3-MtStir      0.181221      0.617551     -0.500380      100.0000
  13 2-SWSfk       1.063269     -1.177587      0.363516      100.0000
  14 1B-Matta     -2.493030     -1.417297      0.239511      100.0000
---------------------------------------------------------------------

CORRELATIONS AND BIPLOT SCORES for  11 environ
---------------------------------------------------------------------
                        Correlations*               Biplot Scores
    Variable      Axis 1  Axis 2  Axis 3      Axis 1  Axis 2  Axis 3
---------------------------------------------------------------------
   1 Age           0.106   0.481   0.106       0.091   0.402   0.075
   2 N             0.143   0.285   0.635       0.123   0.238   0.454
   3 C            -0.044   0.195   0.503      -0.038   0.163   0.359
   4 C:N Rati     -0.481  -0.174  -0.338      -0.414  -0.146  -0.242
   5 P            -0.043  -0.640   0.166      -0.037  -0.534   0.119
   6 K             0.062  -0.348   0.411       0.053  -0.290   0.294
   7 Ca           -0.140  -0.149   0.375      -0.121  -0.125   0.268
   8 Mg           -0.548  -0.387   0.220      -0.472  -0.323   0.158
   9 Est. CEC     -0.325  -0.261   0.312      -0.280  -0.218   0.223
  10 %Sand        -0.029  -0.174  -0.486      -0.025  -0.145  -0.347
  11 %Silt        -0.008   0.215   0.586      -0.007   0.180   0.419
--------------------------------------------------------------------
 * Correlations are "intraset correlations" of ter Braak (1986)
```

```
            MONTE CARLO TEST RESULTS -- EIGENVALUES
------------------------------------------------------------
                                Randomized data
            Real data    Monte Carlo test,  499 runs
           ------------  ---------------------------
  Axis     Eigenvalue    Mean     Minimum   Maximum       p
------------------------------------------------------------
     1         0.742     0.750     0.641     0.796    0.6320
     2         0.697     0.646     0.461     0.703    0.0520
     3         0.511     0.520     0.383     0.637    0.5720
------------------------------------------------------------
p = proportion of randomized runs with eigenvalue greater
    than or equal to the observed eigenvalue; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)

MONTE CARLO TEST RESULTS -- SPECIES-ENVIRONMENT CORRELATIONS
------------------------------------------------------------
                                Randomized data
            Real data    Monte Carlo test,  499 runs
           ------------  ---------------------------
  Axis   Spp-Envt Corr.  Mean     Minimum   Maximum      p
------------------------------------------------------------
    1         0.988     0.991     0.960     1.000    0.7320
    2         0.998     0.980     0.860     1.000    0.0900
    3         0.908     0.940     0.810     1.000    0.8560
------------------------------------------------------------
p = proportion of randomized runs with species-environment
    correlation greater than or equal to the observed
    species-environment correlation; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)

***************************** Operation completed ********************
```

REF HERBACEOUS

```
********************** Canonical Correspondence Analysis **************
PC-ORD, Version 4.25
 1 Mar 2006,  1:25
CCA REF herbaceous


DATA MATRICES
---------------------------------------
     Main matrix:
             15 sites    (rows)
            150 species  (columns)

     Second matrix:
             15 sites    (rows)
              9 environ  (columns)

     Finished reading data.
---------------------------------------


OPTIONS SELECTED
     Axis scores centered and standardized to unit variance
     Axes scaled to optimize representation of rows: sites
          (Scores for sites    are weighted mean scores for species )
     Scores for graphing sites    are linear combinations of environ
     Monte Carlo test: null hypothesis is no relationship between
matrices
     Random number seed:         962


AXIS SUMMARY STATISTICS
Number of canonical axes: 3
Total variance ("inertia") in the species data:   4.9916
-----------------------------------------------------------
                                  Axis 1   Axis 2   Axis 3
-----------------------------------------------------------
Eigenvalue                         0.640    0.587    0.442
Variance in species data
     % of variance explained        12.8     11.8      8.9
     Cumulative % explained         12.8     24.6     33.4
Pearson Correlation, Spp-Envt*     0.995    0.993    0.985
Kendall (Rank) Corr., Spp-Envt     0.867    0.924    0.886
-----------------------------------------------------------
* Correlation between sample scores for an axis derived from the
species
     data and the sample scores that are linear combinations of the
     environmental variables. Set to 0.000 if axis is not canonical.
```

```
CORRELATIONS AND BIPLOT SCORES for   9 environ
--------------------------------------------------------------------
                       Correlations*            Biplot Scores
    Variable      Axis 1  Axis 2  Axis 3     Axis 1  Axis 2  Axis 3
--------------------------------------------------------------------
   1 N            -0.626  -0.233  -0.197     -0.501  -0.178  -0.131
   2 C            -0.765  -0.194  -0.236     -0.612  -0.149  -0.157
   3 C:N          -0.815  -0.076   0.234     -0.652  -0.058   0.155
   4 pH            0.372  -0.534   0.025      0.297  -0.409   0.017
   5 K            -0.291  -0.485  -0.581     -0.233  -0.372  -0.387
   6 Ca            0.147  -0.512  -0.309      0.118  -0.392  -0.206
   7 Mg            0.393  -0.485   0.065      0.314  -0.371   0.043
   8 %Sand        -0.577  -0.207   0.098     -0.461  -0.159   0.065
   9 %Silt         0.688   0.161  -0.058      0.550   0.123  -0.038
------------------------------------------------------------------
* Correlations are "intraset correlations" of ter Braak (1986)


            MONTE CARLO TEST RESULTS -- EIGENVALUES
------------------------------------------------------------
                            Randomized data
            Real data    Monte Carlo test,  499 runs
           ------------  ---------------------------
  Axis     Eigenvalue      Mean    Minimum   Maximum       p
------------------------------------------------------------
    1         0.640       0.589     0.481     0.651    0.0300
    2         0.587       0.519     0.441     0.602    0.0220
    3         0.442       0.459     0.356     0.518    0.7780
------------------------------------------------------------
p = proportion of randomized runs with eigenvalue greater
    than or equal to the observed eigenvalue; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)

MONTE CARLO TEST RESULTS -- SPECIES-ENVIRONMENT CORRELATIONS
------------------------------------------------------------
                            Randomized data
            Real data    Monte Carlo test,  499 runs
           ------------  ---------------------------
  Axis   Spp-Envt Corr.  Mean    Minimum   Maximum       p
------------------------------------------------------------
    1        0.995      0.985     0.948     0.999    0.0920
    2        0.993      0.978     0.927     0.999    0.0900
    3        0.985      0.981     0.919     1.000    0.5140
------------------------------------------------------------
p = proportion of randomized runs with species-environment
    correlation greater than or equal to the observed
    species-environment correlation; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)

**************************** Operation completed ********************
```

REF SHRUB-SAPLING (1ST RUN)

```
********************* Canonical Correspondence Analysis *************
PC-ORD, Version 4.25
 1 Mar 2006,  9:24
CCA REF shrub-sapling


DATA MATRICES
---------------------------------------
     Main matrix:
             15 sites    (rows)
             58 species  (columns)

     Second matrix:
             15 sites    (rows)
              7 environ  (columns)

     Finished reading data.
---------------------------------------


OPTIONS SELECTED
     Axis scores centered and standardized to unit variance
     Axes scaled to optimize representation of rows: sites
          (Scores for sites    are weighted mean scores for species )
     Scores for graphing sites    are linear combinations of environ
     Monte Carlo test: null hypothesis is no relationship between
matrices
     Random number seed:        5049


AXIS SUMMARY STATISTICS
Number of canonical axes: 3
Total variance ("inertia") in the species data:   4.2129
-----------------------------------------------------------
                                   Axis 1   Axis 2   Axis 3
-----------------------------------------------------------
Eigenvalue                          0.557    0.459    0.385
Variance in species data
     % of variance explained         13.2     10.9      9.1
     Cumulative % explained          13.2     24.1     33.2
Pearson Correlation, Spp-Envt*      0.941    0.983    0.876
Kendall (Rank) Corr., Spp-Envt      0.790    0.638    0.619
-----------------------------------------------------------
* Correlation between sample scores for an axis derived from the
species
     data and the sample scores that are linear combinations of the
     environmental variables. Set to 0.000 if axis is not canonical.
```

```
Scores that are linear combinations of environ  (LC Scores)
FINAL SCORES and raw data totals (weights) for  15 sites
--------------------------------------------------------------------
                                                           Raw Data
                   Axis 1       Axis 2       Axis 3          Totals
--------------------------------------------------------------------
 1 15-Sleet      0.270788     0.058937    -0.011663        100.0000
 2 12B-BwrH      0.210378     0.085800    -1.157962        100.0000
 3 12A-Rte7      0.977284     0.255811     1.433014        100.0000
 4 11-Court     -1.221210     0.990404     0.413089        100.0000
 5 10B-Prct      0.649882    -0.199933     0.582747        100.0000
 6 10A-Fkln     -1.026378    -0.092767    -0.392304        100.0000
 7 7-ChsCty      0.198398     0.143232    -0.439772        100.0000
 8 6-Stony       0.305183     0.352083     0.584130        100.0000
 9 5-FtLee      -0.233151     0.004868    -0.296354        100.0000
10 4B-Pwhte     -0.282567    -2.335728     0.198555        100.0000
11 4A-Manas      0.702646     0.017439    -0.270444        100.0000
12 3-MtStir      0.669483     0.374721    -0.550474        100.0000
13 2-SWSfk      -1.647288     0.112747     0.307406        100.0000
14 1B-Matta     -0.170681     0.066041     0.300531        100.0000
15 1A-Reedy      0.597233     0.166346    -0.700498        100.0000
--------------------------------------------------------------------

CORRELATIONS AND BIPLOT SCORES for   7 environ
--------------------------------------------------------------------
                      Correlations*              Biplot Scores
    Variable      Axis 1  Axis 2  Axis 3     Axis 1  Axis 2  Axis 3
--------------------------------------------------------------------
 1 Age            -0.523  -0.124  -0.481     -0.390  -0.084  -0.299
 2 N              -0.621  -0.189  -0.029     -0.463  -0.128  -0.018
 3 C              -0.641   0.180  -0.099     -0.478   0.122  -0.061
 4 C:N            -0.418   0.136  -0.236     -0.312   0.092  -0.146
 5 K              -0.623   0.525   0.290     -0.465   0.356   0.180
 6 Est. CEC       -0.333   0.387  -0.380     -0.248   0.262  -0.235
 7 %Silt           0.489  -0.203   0.238      0.365  -0.138   0.147
------------------------------------------------------------------
* Correlations are "intraset correlations" of ter Braak (1986)

            MONTE CARLO TEST RESULTS -- EIGENVALUES
------------------------------------------------------------
                               Randomized data
             Real data    Monte Carlo test,  499 runs
            ------------  --------------------------
  Axis      Eigenvalue    Mean     Minimum   Maximum       p
------------------------------------------------------------
    1          0.557      0.550     0.366     0.676    0.4740
    2          0.459      0.437     0.292     0.609    0.3140
    3          0.385      0.344     0.231     0.463    0.1780
------------------------------------------------------------
p = proportion of randomized runs with eigenvalue greater
    than or equal to the observed eigenvalue; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)
```

```
MONTE CARLO TEST RESULTS -- SPECIES-ENVIRONMENT CORRELATIONS
------------------------------------------------------------
                              Randomized data
            Real data    Monte Carlo test,  499 runs
           ------------  ---------------------------
  Axis   Spp-Envt Corr.  Mean     Minimum   Maximum      p
------------------------------------------------------------
    1         0.941     0.953     0.858     0.997    0.7440
    2         0.983     0.927     0.824     0.991    0.0080
    3         0.876     0.911     0.807     0.989    0.8380
------------------------------------------------------------
p = proportion of randomized runs with species-environment
    correlation greater than or equal to the observed
    species-environment correlation; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)

***************************** Operation completed *********************
```

REF SHRUB-SAPLING (FINAL RUN)

```
********************* Canonical Correspondence Analysis **************
PC-ORD, Version 4.25
 1 Mar 2006,  9:37
CCA REF shrub-sapling

DATA MATRICES
---------------------------------------
     Main matrix:
             14 sites    (rows)
             56 species  (columns)

     Second matrix:
             14 sites    (rows)
              7 environ  (columns)

     Finished reading data.
---------------------------------------


OPTIONS SELECTED
     Axis scores centered and standardized to unit variance
     Axes scaled to optimize representation of rows: sites
          (Scores for sites    are weighted mean scores for species )
     Scores for graphing sites    are linear combinations of environ
     Monte Carlo test: null hypothesis is no relationship between
matrices
     Random number seed:        1885

AXIS SUMMARY STATISTICS
Number of canonical axes: 3
Total variance ("inertia") in the species data:   4.0369
-----------------------------------------------------------
                                 Axis 1   Axis 2   Axis 3
-----------------------------------------------------------
Eigenvalue                        0.673    0.422    0.324
Variance in species data
     % of variance explained       16.7     10.5      8.0
     Cumulative % explained        16.7     27.1     35.2
Pearson Correlation, Spp-Envt*    0.976    0.913    0.884
Kendall (Rank) Corr., Spp-Envt    0.582    0.692    0.626
-----------------------------------------------------------
* Correlation between sample scores for an axis derived from the
species
     data and the sample scores that are linear combinations of the
     environmental variables. Set to 0.000 if axis is not canonical.
```

```
Scores that are linear combinations of environ  (LC Scores)
FINAL SCORES and raw data totals (weights) for  14 sites
-----------------------------------------------------------------
                                                         Raw Data
                  Axis 1       Axis 2       Axis 3         Totals
-----------------------------------------------------------------
  1 15-Sleet     0.393907     0.002977    -0.689080      100.0000
  2 12B-BwrH     0.570091    -1.010473    -0.705495      100.0000
  3 12A-Rte7     0.359525     1.712625     0.133002      100.0000
  4 11-Court    -1.671338     0.458696    -1.139197      100.0000
  5 10B-Prct     0.674745     0.623746     0.410599      100.0000
  6 10A-Fkln    -0.636833    -0.833564     0.298602      100.0000
  7 7-ChsCty    -0.189823    -0.131509     0.665575      100.0000
  8 6-Stony      0.425011     0.474564    -0.557682      100.0000
  9 5-FtLee     -0.182032    -0.317248     0.215885      100.0000
 10 4A-Manas     0.566453    -0.092723     0.134376      100.0000
 11 3-MtStir     0.385869    -0.154655     0.684816      100.0000
 12 2-SWSfk     -1.917317    -0.029381     0.619131      100.0000
 13 1B-Matta     0.519719    -0.214492     0.363044      100.0000
 14 1A-Reedy     0.702022    -0.488563    -0.433576      100.0000
-----------------------------------------------------------------


CORRELATIONS AND BIPLOT SCORES for   7 environ
-----------------------------------------------------------------
                      Correlations*              Biplot Scores
   Variable      Axis 1  Axis 2  Axis 3     Axis 1  Axis 2  Axis 3
-----------------------------------------------------------------
  1 Age          -0.391  -0.616  -0.124     -0.321  -0.400  -0.070
  2 N            -0.531  -0.231  -0.043     -0.435  -0.150  -0.024
  3 C            -0.609  -0.242   0.088     -0.499  -0.157   0.050
  4 C:N          -0.431  -0.290   0.538     -0.353  -0.189   0.306
  5 K            -0.777   0.186  -0.323     -0.638   0.121  -0.184
  6 Est. CEC     -0.295  -0.410  -0.494     -0.242  -0.266  -0.281
  7 %Silt         0.432   0.315  -0.178      0.354   0.205  -0.101
---------------------------------------------------------------
* Correlations are "intraset correlations" of ter Braak (1986)


           MONTE CARLO TEST RESULTS -- EIGENVALUES
----------------------------------------------------------
                            Randomized data
           Real data    Monte Carlo test,  499 runs
          ------------  --------------------------
  Axis     Eigenvalue    Mean     Minimum   Maximum       p
---------------------------------------------------------
    1         0.673     0.583     0.387     0.720    0.0800
    2         0.422     0.450     0.309     0.600    0.6760
    3         0.324     0.347     0.240     0.483    0.6760
----------------------------------------------------------
p = proportion of randomized runs with eigenvalue greater
    than or equal to the observed eigenvalue; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)
```

```
MONTE CARLO TEST RESULTS -- SPECIES-ENVIRONMENT CORRELATIONS
------------------------------------------------------------
                              Randomized data
           Real data    Monte Carlo test,  499 runs
          ------------  ---------------------------
  Axis   Spp-Envt Corr.  Mean     Minimum   Maximum      p
------------------------------------------------------------
    1         0.976     0.953     0.866     0.996    0.1440
    2         0.913     0.924     0.813     0.998    0.6500
    3         0.884     0.918     0.808     0.996    0.8380
------------------------------------------------------------
p = proportion of randomized runs with species-environment
    correlation greater than or equal to the observed
    species-environment correlation; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)

***************************** Operation completed ********************
```

REF TREE

```
********************* Canonical Correspondence Analysis *************
PC-ORD, Version 4.25
 2 Mar 2006, 19:58
CCA REF tree


DATA MATRICES
--------------------------------------
     Main matrix:
             15 sites    (rows)
             34 species  (columns)

     Second matrix:
             15 sites    (rows)
             13 environ  (columns)

     Finished reading data.
--------------------------------------


OPTIONS SELECTED
     Axis scores centered and standardized to unit variance
     Axes scaled to optimize representation of rows: sites
          (Scores for sites    are weighted mean scores for species )
     Scores for graphing sites    are linear combinations of environ
     Monte Carlo test: null hypothesis is no relationship between
matrices
     Random number seed:        3826


AXIS SUMMARY STATISTICS
Number of canonical axes: 3
Total variance ("inertia") in the species data:   2.9913
-----------------------------------------------------------
                                  Axis 1   Axis 2   Axis 3
-----------------------------------------------------------
Eigenvalue                         0.574    0.490    0.358
Variance in species data
     % of variance explained        19.2     16.4     12.0
     Cumulative % explained         19.2     35.6     47.5
Pearson Correlation, Spp-Envt*     1.000    1.000    1.000
Kendall (Rank) Corr., Spp-Envt     0.924    0.981    1.000
-----------------------------------------------------------
* Correlation between sample scores for an axis derived from the
species
     data and the sample scores that are linear combinations of the
     environmental variables. Set to 0.000 if axis is not canonical.
```

```
Scores that are linear combinations of environ  (LC Scores)
FINAL SCORES and raw data totals (weights) for  15 sites
--------------------------------------------------------------------
                                                            Raw Data
                   Axis 1       Axis 2       Axis 3          Totals
--------------------------------------------------------------------
  1 15-Sleet     0.169522     1.326878     0.271572        100.0000
  2 12B-BwrH    -0.696414     0.075160     0.161444        100.0000
  3 12A-Rte7     0.193889     0.515025    -1.148951        100.0000
  4 11-Court    -0.755298    -0.061866    -0.448816        100.0000
  5 10B-Prct     0.651321    -0.912215     0.126122        100.0000
  6 10A-Fkln    -1.909011    -0.654841     0.970767        100.0000
  7 7-ChsCty     0.773741    -0.890456     0.251994        100.0000
  8 6-Stony      0.174578     0.850656     0.282739        100.0000
  9 5-FrtLee     0.678226    -0.761402     0.180904        100.0000
 10 4B-Pwhte     0.151968     0.082801    -0.786522        100.0000
 11 4A-Manas     0.185586     1.206819     0.909071        100.0000
 12 3-MtStir     0.608167    -0.578354     0.002489        100.0000
 13 2-SWSfk     -1.177879    -0.226570    -0.922056        100.0000
 14 1B-Matta     0.290391     0.239185    -0.320233        100.0000
 15 1A-Reedy     0.661214    -0.210820     0.469477        100.0000
--------------------------------------------------------------------


CORRELATIONS AND BIPLOT SCORES for  13 environ
--------------------------------------------------------------------
                     Correlations*                Biplot Scores
    Variable      Axis 1  Axis 2  Axis 3     Axis 1  Axis 2  Axis 3
--------------------------------------------------------------------
  1 Age           -0.549   0.080   0.344     -0.416   0.056   0.206
  2 N             -0.394  -0.186  -0.243     -0.298  -0.130  -0.145
  3 C             -0.423  -0.373  -0.148     -0.321  -0.261  -0.089
  4 C:N           -0.162  -0.836  -0.113     -0.123  -0.585  -0.068
  5 pH            -0.262   0.294  -0.177     -0.199   0.206  -0.106
  6 P             -0.142   0.474   0.033     -0.108   0.332   0.019
  7 K             -0.540  -0.089  -0.206     -0.410  -0.062  -0.123
  8 Ca            -0.422   0.292  -0.003     -0.320   0.205  -0.002
  9 Mg            -0.214   0.458   0.250     -0.162   0.321   0.150
 10 Est. CEC      -0.356  -0.002   0.228     -0.270  -0.002   0.136
 11 %Sand         -0.181  -0.596  -0.163     -0.137  -0.417  -0.097
 12 %Silt          0.169   0.633   0.174      0.128   0.443   0.104
 13 %Clay          0.079   0.130   0.032      0.060   0.091   0.019
------------------------------------------------------------------
* Correlations are "intraset correlations" of ter Braak (1986)
```

```
MONTE CARLO TEST RESULTS -- EIGENVALUES
------------------------------------------------------------
                              Randomized data
            Real data    Monte Carlo test,  499 runs
           ------------  ---------------------------
  Axis     Eigenvalue    Mean     Minimum   Maximum       p
------------------------------------------------------------
     1         0.574     0.555      0.491     0.575    0.0580
     2         0.490     0.464      0.360     0.490    0.0420
     3         0.358     0.348      0.324     0.358    0.1100
------------------------------------------------------------
p = proportion of randomized runs with eigenvalue greater
    than or equal to the observed eigenvalue; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)

MONTE CARLO TEST RESULTS -- SPECIES-ENVIRONMENT CORRELATIONS
------------------------------------------------------------
                              Randomized data
            Real data    Monte Carlo test,  499 runs
           ------------  ---------------------------
  Axis   Spp-Envt Corr.  Mean     Minimum   Maximum      p
------------------------------------------------------------
    1         1.000     0.993      0.959     1.000    0.0780
    2         1.000     0.984      0.910     1.000    0.0400
    3         1.000     0.995      0.916     1.000    0.0880
------------------------------------------------------------
p = proportion of randomized runs with species-environment
    correlation greater than or equal to the observed
    species-environment correlation; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)

***************************** Operation completed ********************
```

CW-REF COMBINED HERBACEOUS

```
********************** Canonical Correspondence Analysis***************
PC-ORD, Version 4.25
26 Apr 2006, 21:27
CCA combined herbaceous 2


DATA MATRICES
---------------------------------------
     Main matrix:
            29 sites    (rows)
           240 species  (columns)

     Second matrix:
            29 sites    (rows)
            12 environ  (columns)

     Finished reading data.
---------------------------------------


OPTIONS SELECTED
     Axis scores centered and standardized to unit variance
     Axes scaled to optimize representation of rows: sites
          (Scores for sites    are weighted mean scores for species )
     Scores for graphing sites    are linear combinations of environ
     Monte Carlo test: null hypothesis is no relationship between
matrices
     Random number seed:         440


AXIS SUMMARY STATISTICS
Number of canonical axes: 3
Total variance ("inertia") in the species data:   8.5813
-----------------------------------------------------------
                                  Axis 1   Axis 2   Axis 3
-----------------------------------------------------------
Eigenvalue                         0.755    0.520    0.467
Variance in species data
     % of variance explained         8.8      6.1      5.4
     Cumulative % explained          8.8     14.9     20.3
Pearson Correlation, Spp-Envt*     0.981    0.964    0.984
Kendall (Rank) Corr., Spp-Envt     0.862    0.808    0.818
-----------------------------------------------------------
* Correlation between sample scores for an axis derived from the
species
     data and the sample scores that are linear combinations of the
     environmental variables. Set to 0.000 if axis is not canonical.




Scores that are linear combinations of environ  (LC Scores)
```

```
FINAL SCORES and raw data totals (weights) for  29 sites
---------------------------------------------------------------------
                                                           Raw Data
                   Axis 1        Axis 2        Axis 3       Totals
---------------------------------------------------------------------
   1 C-15       -0.060259      0.209070     -0.043701      100.0000
   2 C-12B      -0.698170     -0.406676     -0.512538      100.0000
   3 C-12A       0.022870      0.514657     -0.178402      100.0000
   4 C-11       -0.698757     -0.545738     -0.735612      100.0000
   5 C-10B      -0.479844     -0.046821     -0.369815      100.0000
   6 C-10A      -0.655066     -0.119979     -0.896817      100.0000
   7 C-7        -0.936900     -0.159687      0.057909      100.0000
   8 C-6        -0.860611     -0.116142     -0.106231      100.0000
   9 C-5        -0.718692     -0.418975     -0.586739      100.0000
  10 C-4B       -0.763563     -0.247761     -0.651935      100.0000
  11 C-4A       -0.394102      1.444495     -0.470059      100.0000
  12 C-3        -0.800216     -0.364599     -0.515832      100.0000
  13 C-2        -1.269841     -0.809061      2.584288      100.0000
  14 C-1B       -1.140275     -0.869114      1.381496      100.0000
  15 C-1A       -0.647968      0.354957     -0.118311      100.0000
  16 R-15        0.637400      0.794413      0.217713      100.0000
  17 R-12B       0.738927     -0.158062      0.119834      100.0000
  18 R-12A       0.474511      1.487471      0.700082      100.0000
  19 R-11        2.096652     -0.649841      0.340332      100.0000
  20 R-10B       0.557134     -0.135559      0.078919      100.0000
  21 R-10A       1.733590     -0.554885      0.327295      100.0000
  22 R-6        -0.072957      1.163688      0.471965      100.0000
  23 R-5        -0.063306     -0.120152     -0.379175      100.0000
  24 R-4B        0.594793     -0.095210     -0.346806      100.3206
  25 R-4A        0.457959      1.479487      0.303770      100.0000
  26 R-3        -0.092093     -0.728112     -0.656581      100.0000
  27 R-2         1.570539     -1.289039     -0.230649      100.0000
  28 R-1B        1.186113     -0.448466      0.027724      100.0000
  29 R-1A        0.280225      0.835945      0.188988      100.0000
```

```
MONTE CARLO TEST RESULTS -- EIGENVALUES
------------------------------------------------------------
                         Randomized data
           Real data   Monte Carlo test,  499 runs
          ------------ --------------------------
  Axis     Eigenvalue   Mean    Minimum   Maximum       p
------------------------------------------------------------
    1         0.755     0.552     0.443     0.695    0.0020
    2         0.520     0.456     0.393     0.538    0.0320
    3         0.467     0.409     0.362     0.470    0.0040
------------------------------------------------------------
p = proportion of randomized runs with eigenvalue greater
    than or equal to the observed eigenvalue; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)
```

```
MONTE CARLO TEST RESULTS -- SPECIES-ENVIRONMENT CORRELATIONS
```

```
-----------------------------------------------------------
                              Randomized data
           Real data     Monte Carlo test,  499 runs
          ------------  ---------------------------
  Axis   Spp-Envt Corr.  Mean     Minimum   Maximum      p
-----------------------------------------------------------
    1        0.981     0.928     0.867     0.984    0.0040
    2        0.964     0.949     0.856     0.988    0.2880
    3        0.984     0.955     0.858     0.993    0.0340
-----------------------------------------------------------
p = proportion of randomized runs with species-environment
    correlation greater than or equal to the observed
    species-environment correlation; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)
```

CW-REF COMBINED SHRUB SAPLING

```
********************* Canonical Correspondence Analysis**************
PC-ORD, Version 4.25
26 Apr 2006, 22:30
CCA combined shrub-sapling 2


DATA MATRICES
---------------------------------------
     Main matrix:
             28 sites    (rows)
             69 species  (columns)

     Second matrix:
             28 sites    (rows)
             12 environ  (columns)

     Finished reading data.
---------------------------------------


OPTIONS SELECTED
     Axis scores centered and standardized to unit variance
     Axes scaled to optimize representation of rows: sites
          (Scores for sites    are weighted mean scores for species )
     Scores for graphing sites    are linear combinations of environ
     Monte Carlo test: null hypothesis is no relationship between
matrices
     Random number seed:        5368


AXIS SUMMARY STATISTICS
Number of canonical axes: 3
Total variance ("inertia") in the species data:   6.7413
-----------------------------------------------------------
```

```
                                   Axis 1   Axis 2   Axis 3
-----------------------------------------------------------
Eigenvalue                          0.648    0.461    0.436
Variance in species data
     % of variance explained          9.6      6.8      6.5
     Cumulative % explained           9.6     16.4     22.9
Pearson Correlation, Spp-Envt*      0.940    0.903    0.956
Kendall (Rank) Corr., Spp-Envt      0.783    0.693    0.720
-----------------------------------------------------------
* Correlation between sample scores for an axis derived from the
species
     data and the sample scores that are linear combinations of the
     environmental variables. Set to 0.000 if axis is not canonical.

Scores that are linear combinations of environ  (LC Scores)
FINAL SCORES and raw data totals (weights) for  28 sites
--------------------------------------------------------------------
                                                            Raw Data
                   Axis 1       Axis 2       Axis 3           Totals
--------------------------------------------------------------------
   1 C-15       -0.117218     0.632868     0.581456         100.0000
   2 C-12B       0.000666     0.708156    -0.007131         100.0000
   3 C-12A      -0.178082     0.657939     0.104711         100.0000
   4 C-11       -1.027297     0.069540    -0.475364         100.0000
   5 C-10B      -0.437057    -0.222564     0.043353         100.0000
   6 C-10A      -0.538505    -0.517758    -0.401913         100.0000
   7 C-7        -0.908768     0.920307    -0.207480         100.0000
   8 C-6        -1.601790    -1.009500    -0.276692         100.0000
   9 C-5        -0.807742     0.869873    -0.030580         100.0000
  10 C-4B       -0.933487     0.087348    -0.022257         100.0000
  11 C-4A       -0.062119     1.048673     0.465268         100.0000
  12 C-3        -0.961511     0.252450     0.026601         100.0000
  13 C-2        -0.800296    -1.020987    -0.111437         100.0000
  14 R-15        0.670006     0.047568    -0.165126         100.0000
  15 R-12B       0.116444     0.619166     0.936100         100.0000
  16 R-12A      -0.060940     0.648187     0.421250         100.0000
  17 R-11        1.381113    -0.180908     1.576781         100.0000
  18 R-10B       0.195061    -0.363695    -0.252448         100.0000
  19 R-10A       0.765188    -0.582146     0.383302         100.0000
  20 R-7         1.133968    -1.503553    -0.264703         100.0000
  21 R-6        -0.069084    -0.869829    -0.488422         100.0000
  22 R-5         0.324322     0.130853    -0.027134         100.0000
  23 R-4B        1.855933     1.039476    -2.508718         100.0000
  24 R-4A       -0.050194    -0.484510    -0.256528         100.0000
  25 R-3        -0.045263    -0.384700    -0.079623         100.0000
  26 R-2         1.306866     0.195877     0.769956         100.0000
  27 R-1B        0.721394    -0.743620     0.284751         100.0000
  28 R-1A        0.128392    -0.044510    -0.017972         100.0000


MONTE CARLO TEST RESULTS -- EIGENVALUES
------------------------------------------------------------
                              Randomized data
            Real data    Monte Carlo test,  499 runs
```

```
                ------------  ---------------------------
 Axis     Eigenvalue    Mean     Minimum   Maximum        p
------------------------------------------------------------
   1         0.648     0.566      0.399     0.713    0.0720
   2         0.461     0.459      0.331     0.584    0.4440
   3         0.436     0.385      0.285     0.501    0.0980
------------------------------------------------------------
p = proportion of randomized runs with eigenvalue greater
    than or equal to the observed eigenvalue; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)

MONTE CARLO TEST RESULTS -- SPECIES-ENVIRONMENT CORRELATIONS
------------------------------------------------------------
                                   Randomized data
              Real data    Monte Carlo test,  499 runs
             ------------  ---------------------------
 Axis   Spp-Envt Corr.  Mean     Minimum   Maximum       p
------------------------------------------------------------
   1         0.940     0.923      0.829     0.987    0.2840
   2         0.903     0.901      0.779     0.972    0.4900
   3         0.956     0.881      0.762     0.970    0.0260
------------------------------------------------------------
p = proportion of randomized runs with species-environment
    correlation greater than or equal to the observed
    species-environment correlation; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)
```

VITA

Douglas A. DeBerry was born in Newport News, Virginia on June 25, 1971. He graduated from Menchville High School in June 1989, received his B.A. in Environmental Science from the University of Virginia in May 1993, and his M.A. in Biology from the College of William and Mary in 1999. Mr. DeBerry entered the Ph.D. program at the School of Marine Science, College of William Mary in August 2003, and defended his dissertation in April 2006. In July 1993, he began his professional career as a staff ecologist at Williamsburg Environmental Group, Inc. (WEG), an environmental consulting firm based in Williamsburg, Virginia, and currently holds the position of corporate Program Director for Ecology at WEG.