A Floristic Ecological Survey of Seepage Fens in the Western Highland Rim of Tennessee

A Thesis
Presented to
The College of Graduate Studies
Austin Peay State University
In Partial Fulfillment
Of the Requirements for the Degree
Masters of Science in Biology

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December, 2016

December 2016

To the College of Graduate Studies:

We are submitting a thesis written by Judy Redden entitled "A Floristic Ecological Survey of Seepage Fens in the Western Highland Rim of Tennessee" We have examined the final copy of this thesis for form and content. We recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science in Biology.

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ACKNOWLEDGMENTS

Appreciation is extended to the Center of Excellence for Field Biology at Austin Peay State University for financial support. I also thank Dr. Dwayne Estes, major professor, for his mentorship throughout my project. Committee member Drs. Rebecca Johansen and Willodean Burton provided invaluable assistance and encouragement. I am also grateful to my undergraduate professors, Dr. Lisa Kruger and Dr. Jennifer Greenwood, and Tennessee Natural Heritage Program Stewardship Ecologist Allan Trently for their assistance on collecting trips. My thankfulness extends to my lab mate Mason Brock for his aid in collection and identification of specimens. I am much indebted to Kelly Anderson who contributed to my research in so many ways. I truly could not have done it without her. I would also like to express my gratitude to my family, especially my son, Kyle King, for answering my GIS questions, to my son Adam King, for his unconditional support, and to my nephew, Lucas Redden for being my field partner. Each person's contribution proved invaluable.

DEDICATION

I dedicate my thesis to United States Navy Rear Admiral Grace Brewster Murray Hopper, a pioneer in so many ways. Her work has always inspired me.

ABSTRACT

A floristic survey was conducted of 14 Western Highland Rim (WHR) seepage fens in central Tennessee ranging from circa 100 m^2 to 770 m^2 in size. Seepage fens are botanically unique ecosystems supporting a distinct array of vascular plant species, several of which are rare and endangered. These small-patch, ground water fed wetlands are characterized by saturated soils with an open to semi-open canopy often dominated by herbaceous vegetation (USNVC 2016). Twenty-four collecting trips were made between March 2012 and May 2016. The vascular flora includes 160 species and infraspecific taxa in 121 genera and 58 families. Thirty-six percent belong to three families: Asteraceae (11), Cyperaceae (11) and Poaceae (14). Fifty-one percent are either obligate or facultative wetland taxa. Forbs and graminoids make up the dominant vegetation in all 14 sites.

Within the 14 federal, state and privately owned study sites, some of the most commonly collected species and infraspecific taxa include *Juncus coriaceus* (11 sites), *Carex lurida* (10 sites), *Oxypolis rigidior* (10 sites), *Lindera benzoin* (9 sites), and *Carex atlantica* var. *atlantica* (9 sites). Notable species documented include the federally and state endangered *Xyris tennesseensis* (5 sites); and the state listed: *Eleocharis tortilis* (1 site), *Fuirena squarrosa* (2 sites), *Lathyrus palustris* (1 site), and *Parnassia grandifolia* (7 sites). A Sørensen's index presence/absence comparison to fen floras of Missouri, Ohio, and North Carolina indicate that while there is a similar family distribution of taxa, the WHR seepage fen species are floristically distinct. This may be explained by elevational and latitudinal gradients. These fens are largely intact with a low percentage (1.9%) of invasive species.

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ABBREVIATIONS

APSC	Austin Peay State University Herbarium
BONAP	Biota of North America Program
c.	circa = about
CC	Coefficient of Conservatism
FQI	Floristic Quality Index
m	meters(s)
mya	million years ago
TN-EPPC	Tennessee Exotic Pest Plant Council
USNVC	U.S. National Vegetation Classification System
WHR	Western Highland Rim
ybp	years before present

Site codes:

A1	Auntney Hollow stream side seep 1
A2	Auntney Hollow stream side seep 2
A3	Auntney Hollow stream side seep 3
BC	Brush Creek stream side sloping seep
D1	Dry Branch woodland seep
D2	Dry Branch *Parnassia* seep
D3	Dry Branch perched woodland seep
D4	Dry Branch graminoid seep
LB	Langford Branch *Parnassia* seep
N1	Natchez Trace seep 1
N2	Natchez Trace acid seep 2
PM	Powdermill Branch woodland seep
R1	Rattlesnake Falls *Impatiens* cliff seep
R2	Rattlesnake Falls perched seep

CHAPTER I

INTRODUCTION

The contribution of floristics to science

Botanical research and floristics contributes to the larger scientific community in many ways. Floristic research is comprised of collecting specimens and then identifying, labeling and preserving specimens in a herbarium with the collector's name, and locality data including, date, location, landscape characteristics, abundance, and associated species. Herbarium data can also be digitized and made available on-line. Herbaria maintain detailed historical flora records that inform the phytogeography of an area or region. Continued flora surveys can help to build this historical record, and are useful in detecting patterns of extinctions, non-native invasion, and species abundance (Carter et al. 2007).

Species of plants remain unrecognized and undescribed (Estes et al. 2015). For example, there has been a consistent increase in the number of new species of grasses over time (Joppa et al. 2011). Local floras are important to new discoveries, as recently described species are most often rare with a limited distribution (Donoghue & Alverson 2012). Herbariuma records can also be used to identify new species and diversity within a species (Bebber et al. 2010). Conversely, these records can also be used to identify synonyms (Costello et al. 2012). Organisms are not static. They evolve, become extinct, and migrate. Due to the changing nature of our world, botanical research should be progressive and on-going.

Ecology in general, and accordingly conservation of plant communities and animal habitats, relies on botanical research. Knowledge about the environment gleaned from floristic data, such as location, abundance, and associations, can be used to identify plant communities, which in turn can contribute to the conservation of at-risk mammals, insects, reptiles, and amphibians that rely on these communities for resources (Cotterill 1995, Donoghue & Alverson 2012).

Botanical research is also important to human health and medicine. Botany and medicine have been closely coupled since at least the first century when Dioscorides wrote his description of plant species and their medicinal uses in *Materia Meidca,* (Porter 1959) and that synergy is still important today. For example, in 2015 the Nobel Prize in medicine was awarded to Youyou Tu for her work in developing a botanically based drug to fight malaria. Her research team used ancient medical and herbarium records to locate and collect the species *Artemisia annua* and to find regional populations with the highest concentration of artemisinin, the active malaria fighting compound found in the plant (Tu 2011).

Seepage fens

Seepage fens are a botanically unique part of the Western Highland Rim (WHR) landscape. The flora includes a distinct array of rare and endangered species. These small-patch, ground-water-fed wetlands are characterized by saturated soils, with an open to semi-open canopy, and an understory often dominated by graminoids and pteridophytes. These fens are underlain by Mississippian age chert and shale usually resulting in a circumneutral to alkaline soil. The substrate often contains cherty gravel, peat, and muck (USNVC 2016).

The physical characteristics of fens such as the presence and amount of peat accumulation, pH, slope, water level and duration of saturation may vary. Fen soils can be either organic or mineral (Messina & Conner 1997). The unifying characteristic of most fens is the presence of minerotrophic groundwater (Bedford & Godwin 2003). Descriptions for specific fen types are varied and are not synonymous. Fen types are described as poor, rich, calcareous, and marl. Generally, poor fens are acidic, and rich fens are alkaline due to the presence of bicarbonate and calcium. Marl fens have rich fen characteristics but, in addition, have a marl bed substrate and have relatively high pH, possibly higher than a rich fen. Calcareous fens also have a high pH, and like rich fens are high in calcium carbonate, but may have a marl or peat substrate. Additionally, calcareous fens are described as having a distinctive flora of rare calciphilic species.

State classifications of fens vary. Schafale's (2012) classification of fens for North Carolina is confounded by the interchangeable use of bog and fen. For example the Southern Appalachian Fen community found at Bluff Mountain (Ashe Co.) may be analogous to an intermediate, or possibly rich fen, while the acidic Southern Appalachian Bog community and acidic French Broad Valley Bog community would be considered poor fens. Fen classification in Missouri is more granular than rich, poor, etc. Fens in this state are described as acid, forested, glacial, Ozark, and prairie fens (Nelson 2010). Following Bedford and Godwin (2003) some Ozark fens would be classified as rich fens and others as marl fens. Prairie, forested, and glacial fens could also be considered rich fens.

Slack et al. (1980) and Thormann et al. (1999) followed Sjors's (1950) Scandinavian classifications based strictly on water chemistry and divide fens into five types (ranging from extremely poor to extremely rich). Amon et al. (2002) determined that four characteristics may be used to separate fens from wet prairies, meadows, bogs and marshes: (1) high water-flow and saturation, (2) little standing water and water fluctuation, (3) intermediate to high conductivity, and (4) organic soils.

Fens are known to occur at geologic breaks in bedrock (Amon et al. 2002). Groundwater that is pushed to the surface, often by low porosity bedrock, allow fens to maintain saturated conditions most of the time. Fen distribution is constrained by these local gradients. Fen communities are regulated by base cation concentrations, water-level fluctuation and the alkalinity-acidity gradient. It is possible that fens can be classified by chemical, physical and spatial landscape properties as they can be correlated to distinct hydrogeological settings. The most important chemical property is the presence of calcium-bearing minerals. The presence of these minerals is the result of the underlying geological materials. Rich fens are found on calcareous glacial deposits, or base-rich bedrock such as limestone, dolostone, marble, amphibolite (Schafale 2012), or sandstone containing dolomite and limestone. Poor fens may be found on sandstone, basalt, quartzite, or granite. Fen substrates differ and can be peat, muck, gravelly loam, sandy loam, or clay loam. Physical properties relevant to classification include soil texture and thickness, the maximum length from wetland centroid to surface watershed boundary, and elevation gradient. Important spatial properties are landscape position, general landform and the presence of surface water inflows and outflows. (Godwin et al. 2002).

Fens are wetland ecosystems with significant plant diversity. For example, while only 0.01% of the northeastern Iowa land surface area is covered by fens, they support 18% of the total state flora and 12% of the state's total rare taxa. Five states, Idaho, Iowa, New Hampshire, New Jersey, and North Carolina report that over 10% of their uncommon and rare species are found in fens (Bedford & Godwin 2003). Fens also have high species density. Rich fens in New York have plant species densities in the range of 10-12 species per square meter. Although fens comprise less than one percent of the landscape for most states, they are the interface between groundwater and surface water, and therefore strongly influence the flow, chemistry and temperature of lakes and streams and support many rare mammals, insect and reptile species listed under the federal Endangered Species Act.

Importance of study

Most studies of fens are focused on those in the northeastern or Midwestern United States (Amon et al. 2002, Drexler et al. 1999, Carpenter 1995, Orzell & Kurz 1986). In Tennessee, emphasis has been placed on the fens and bogs of the Southern Appalachians (Richardson & Gibbons 1993). In contrast, the WHR seepage fens are poorly documented and understudied. Botanical studies of the WHR include floristic studies of barrens (Chester et al. 1997, DeSelm 1994, DeSelm 1988), including one fen site. There are also floras of wetlands such as the Tennessee National Wildlife Refuge's Duck River Unit (Gunn 2003), Land Between the Lakes National Recreation Area (Chester 1992), and a Cross Creeks National Wildlife Refuge in Stewart County (Joyner & Chester 1994). Three of the fen study areas, two at Rattlesnake Falls in Maury County (Estes & Walck 2005) and the Powermill Branch site in Giles County (Estes 2005) were included in previously published floras, but the fens were only a part of the overall study. Although the Tennessee Natural Heritage Inventory Program monitors rare plant populations, such as the federally-endangered *Xyris tennesseensis* that occur in five of these sites; to date there is no published, comprehensive vascular plant flora of seepage fens in the WHR.

Objectives

Primary objectives of this research were to: (1) conduct an inventory of the vascular flora of 14 seepage fen sites in the WHR Physiographic Subsection of Tennessee, (2) describe the site conditions, geology and soil pH of each site, (3) use β-diversity to measure differentiation among sites, (4) assess the site quality by measuring the mean Coefficient of Conservatism (CC) and Floristic Quality Index (FQI) for each site, (5) and compare sites qualitatively to the U.S. National Vegetation classification system.

CHAPTER II

STUDY AREA

Geography

The WHR is a subsection within the Highland Rim Section of the Interior Low Plateaus Province (Fig. 1). The WHR, elevation c. 150-300 m, includes parts of three states and is centered in Tennessee. It is bounded to the north by the Pennyroyal Plains Subsection, to the east by the Nashville Basin Section, to the southeast by the Eastern Highland Rim Subsection, to the south by the Cumberland Plateau Section, and to the southwest and west by the East Gulf Coastal Plain Section (TFC 2015, Nicholson et al. 2007). The WHR is a partially dissected, low plateau bisected by many streams (Miller 1974). The Tennessee portion of the WHR encompasses over 1,500,000 hectares and is recognized as a level IV ecoregion (EPA 2014). The 14 sites are in Giles, Lewis, Maury, and Williamson counties (Fig. 2).

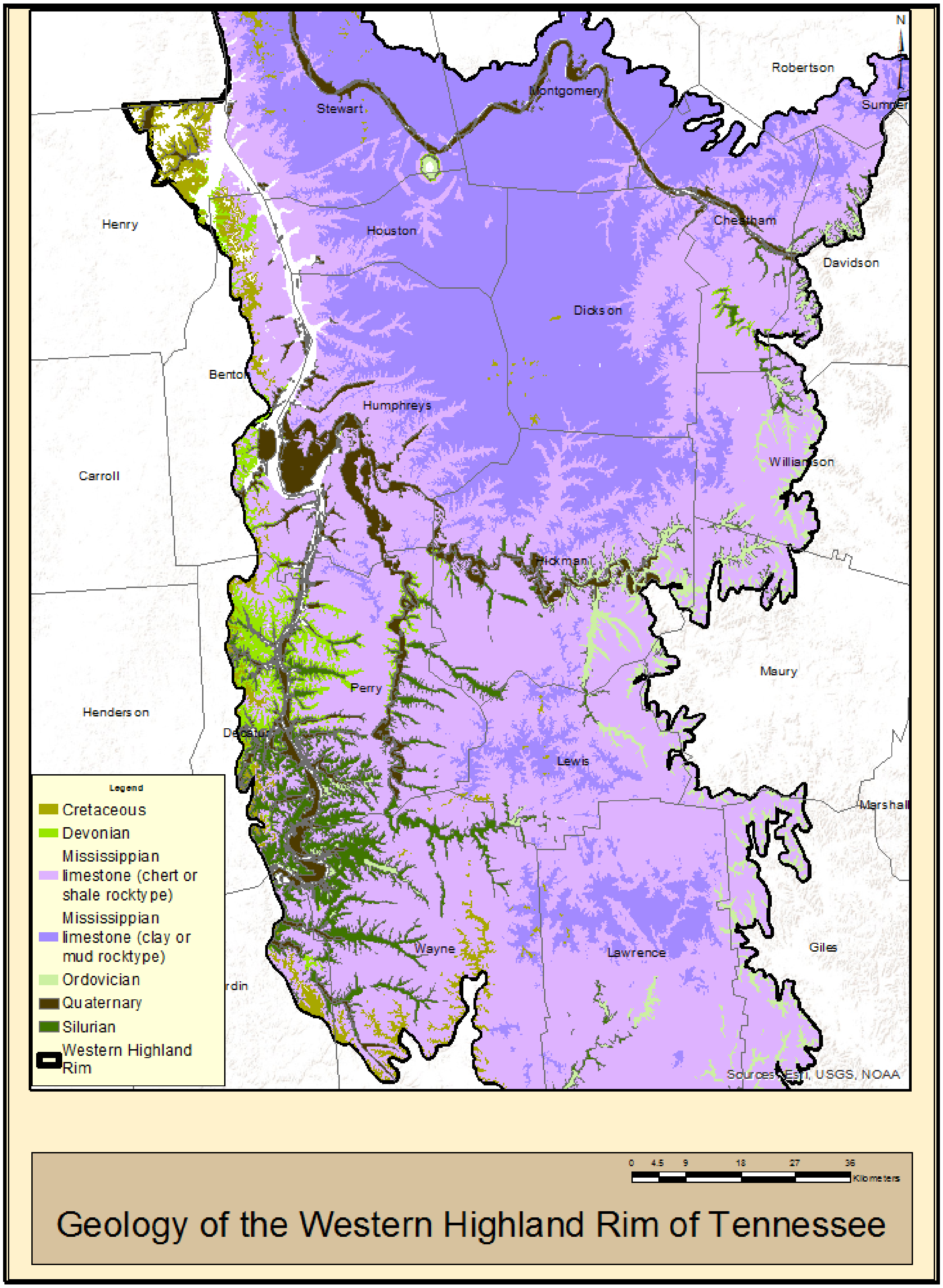


Fig. 1. Geology of the Western Highland Rim of Tennessee.

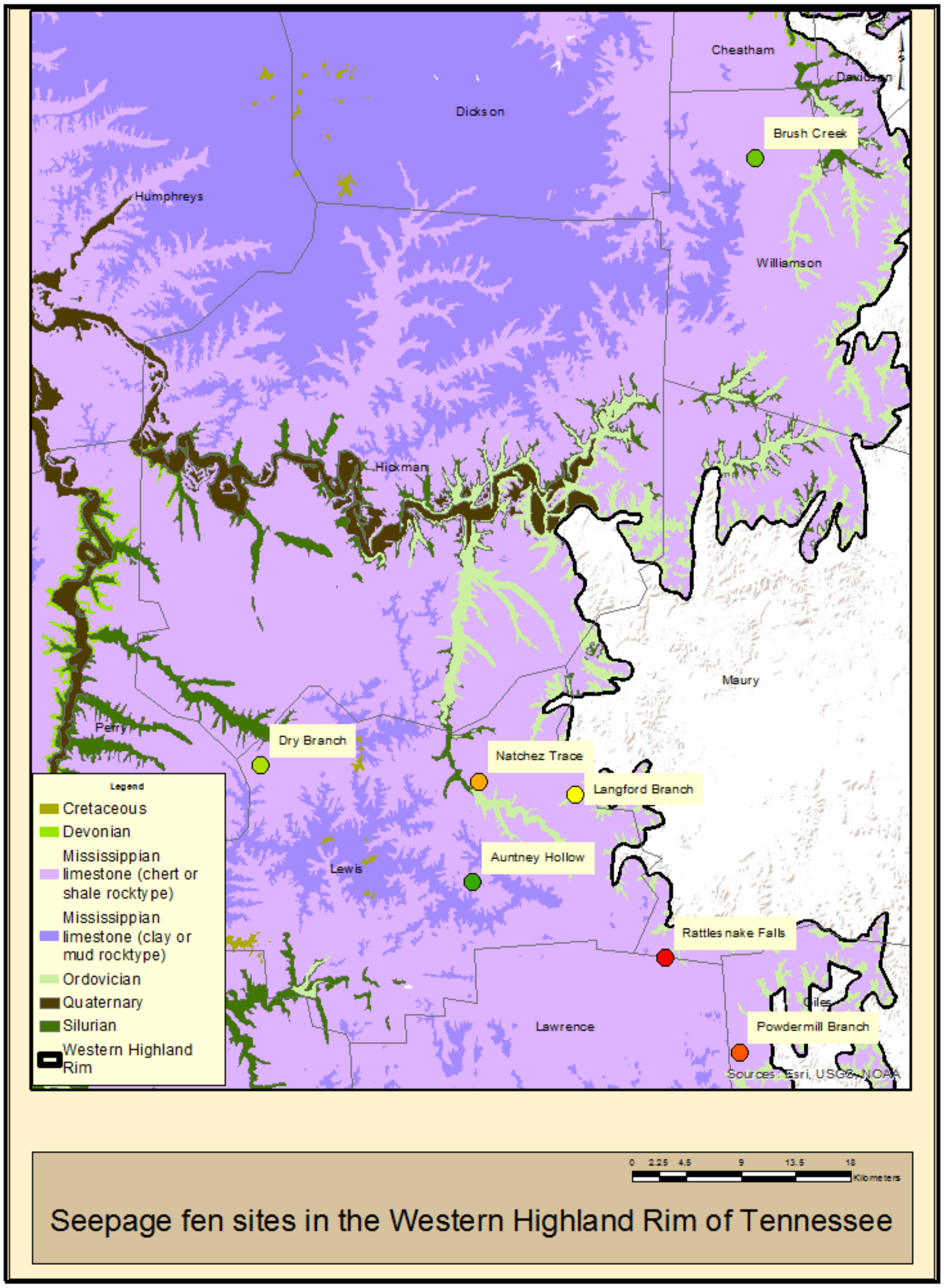


Fig. 2. Seepage fen study areas in the Western Highland Rim of Tennessee. There was a total of 14 sites: Three at Auntney Hollow, one at Brush Creek, four at Dry Branch, two at Natchez Trace, one at Langford Branch, one at Powermill Branch and two at Rattlesnake Falls.

Geology and soils

The geology of the WHR is as old as 500 million years (Luther 1997). It is a peneplain underlain, in part, by Ordovician, Silurian, and Devonian limestone bedrock, and Quaternary and Cretaceous sand and gravel. But the primary bedrock is Mississippian-aged limestone, chert, and shale (Fig. 1) (Nicholson et al. 2007). During the Cretaceous period (75 mya) this region was inundated by seas (Luther 1977). After the seas retreated, a series of uplift, weathering and erosion, was responsible for the loss of most of the Cretaceous material and has led to the modern landscape we see today (Hack 1966).

Typical lithologic units are St. Louis Limestone, Warsaw Limestone, Fort Payne Chert and Chattanooga Shale. Due to the carbonate limestone bedrock, the WHR is susceptible to karst conditions, where the bedrock is dissolved by water flow resulting in caverns or fractures (USGS 2016, Nicholson et al. 2007). The WHR has a topography of rolling and hilly terrain with many varying sized streams. Dissection of the WHR is a result of contrast in resistance to erosion between the limestone bedrock and the more resistant Fort Payne Chert, found at the base of the Mississippian sequence. The oldest exposed rock is found to the east near the Central Basin, to the west along the Western Valley edge, and in the deeper stream valleys where the WHR is more heavily dissected, leaving the interior with areas of relatively flat terrain (Hack 1966). The more dissected portions of the WHR are referred to as the Dissected Rim whereas the areas that are little dissected with flat to rolling terrain is the Undissected Rim (APSC 2016).

Predominant soils of the WHR are Ultisols and Alfisols. Ultisols have an appreciable amount of silicate clay and a base saturation of less than 35 percent. Ultisols are strongly leached, acid forest soils. Alfisols differ from Ultisols in that they have a base saturation of 35%

or greater (Soil Survey Staff 2010). They are moderately leached, highly fertile soils formed mainly under forest conditions.

Hydrology

The Highland Rim aquifer system occurs west of the Valley and Ridge province and east of the Southeastern Coastal Plain aquifer (Brahana & Bradley 1986). In this aquifer, secondary openings for water flow are created by joints, faults, and karst-induced caverns and fractures. While primary porosity is low, these secondary openings are where most groundwater occurs. The lower confining layer for this aquifer is Chattanooga Shale which has relatively weak dissolution porosity. On the eastern end of the aquifer, the Upper Mississippian Pennington Formation is the upper boundary. Local pockets of ground water near the upper boundary contain highly mineralized water. Groundwater flow can vary from concentrated to diffuse, depending on local lithology (Worthington & Gunn 2009). Hydrology is more variable in dissected areas, forming numerous springs and seeps along dissected escarpments (Fig. 3).

The WHR contains three watershed basins: (1) the Cumberland River Basin and Barren River Watershed, which covers much of the northern portion of the WHR, (2) the Middle Tennessee River Basin & Conasuaga River Watershed which covers the southernmost part of the WHR, and (3) the Lower Tennessee River Basin which covers the western and central portions of the WHR. All three basins are impacted by impounded water resulting from major dams on the Cumberland and Tennessee Rivers (TDEC 2016).

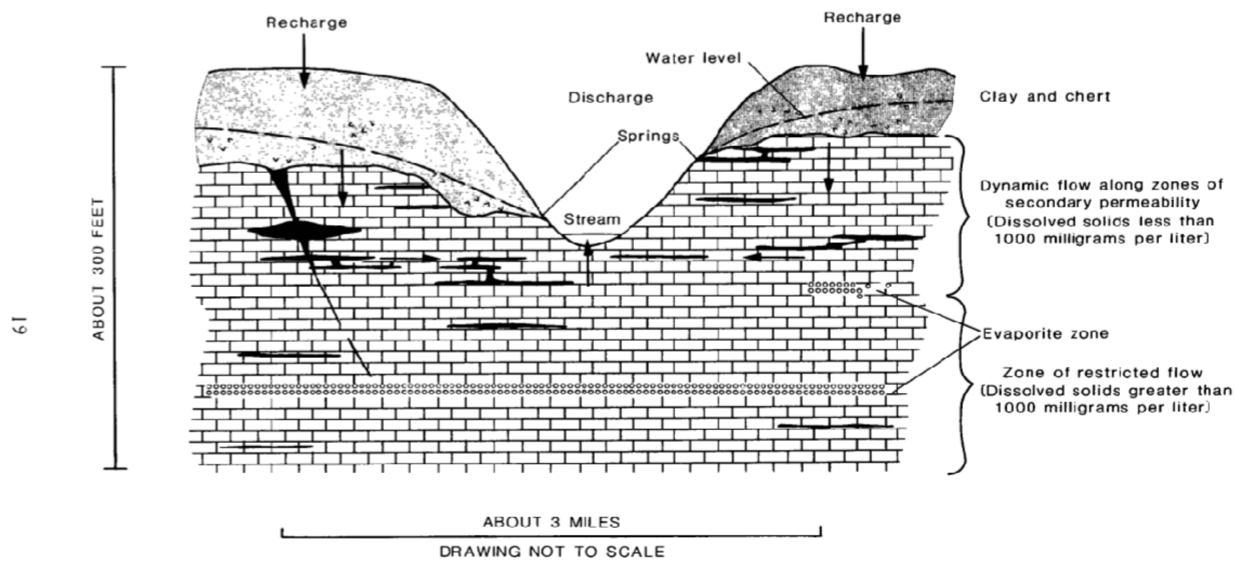


Fig. 3. Conceptual model of ground-water occurrence in the limestones of the Highland Rim aquifer system from Brahana & Bradley (1986).

Climate

The climate of the WHR is Humid Subtropical Warm Temperate (Thornwaite 1948). Annual average precipitation is about 127 cm (50 inches) with the greatest precipitation occurring in the winter and early spring (Smalley 1980). Average seasonal snowfall for Columbia, Tennessee, located in the southern part of the WHR is 14.2 cm (5.6 inches). Soils are wettest from December to April and driest from July to October. Average windspeed is highest (16 km) in March. The probability of drought days is greatest in August and the length of the growing season is in the range of 190 to 205 days. Mean temperature is about 14.4℃ (58℉) and average relative humidity in mid-afternoon is 57%. The sun shines 64% of the daylight hours in summer and 43% in winter and the prevailing wind is from the south. Microclimates are created by the hilly terrain which can greatly affect vegetation (TFC 2015, USDA, NCRS 2000).

Vegetation

During the Pleistocene Epoch of the Quaternary period, climatic changes caused a major shift in the vegetation of the southeastern United States. Glaciation events allowed northern temperate species to migrate southward. *Pinus banksiana* (Jack pine), a northern species, grew in the south and a boreal forest extended from the glacial margin south to the coast (Dyer 2006). During times of cool moist intervals, the mesic deciduous vegetation for the north was introduced to the Southeast while oak or oak-hickory savannas were established during warmer drier times. As the glaciers retreated, and the climate warmed, some cold-temperate species remained in refugia at higher elevations or along cooler river valleys and ravines. About 16,300 ybp, the jack pine-spruce-fir forest was replaced by deciduous forest (Delcourt 1979). During the early Holocene, between 12,500 and 8,000 ybp, grassy openings appeared and mixed mesophytic forest taxa such as *Carya* ssp., *Fagus* ssp., and *Acer saccharum* were abundant (Graham 1999). The warming Hypsithermal, between 8,000 and 5,000 ypb, saw an increase in *Quercus* ssp. and a forest composition similar to the modern day.

Braun (1947, 1950) classified the WHR as part of a western mesophytic forest region. This region is a transition zone between the mixed mesophytic forest region to the east and the drier oak-hickory forest region to the west. Species characteristic of the mixed mesophytic forest found in this region are *Acer saccharum*, *Aesculus flava, Fagus grandifolia*, *Halesia carolina, Magnolia acuminate*, and *Tila heterophylla* (Greenberg et al.1997). Oak-hickory forest indicator species that are commonly found the WHR are *Quercus stellate, Q. marilandica*, and *Carya* *tomentosa* (Dyer 2006, Greenberg et al. 1997). This region has fewer dominant tree species than either adjoining regions. Chester et al. (1998) described this region as upland and mesic temperate deciduous forests.

The dry to submesic uplands are composed of forest, woodlands, savannas and grasslands. Some of the more important oaks of upland forest are *Quercus alba, Q. rubra, Q. montana, Q. velutina*, *Q. falcata, Q.shumardii*, *Q. cocciniea*, *Q. muehlenbergii*, *Q. stellata.* Common hickories are *Carya glabra* and *C. tomentosa* (Chester 1995, Chester et al. 1998). Woodlands have similar composition to forest with a more open canopy and a denser herbaceous layer characterized by an abundance of members of the Asteraceae, Fabaceae, and Poaceae familes. Historically, dry upland savannas were oak dominated with a graminoid understory. Per DeSelm (1994), grasslands, sometimes called barrens, of the WHR developed during the hot, dry Hypsitermal period though it also possible that grasslands have been present in the region for much longer (D. Estes, pers. comm., Dec. 5, 2016). Safford (1869) described Highland Rim savannas as “barrens in great part level and thinly wooded. At some points 'shrub-oaks' occupy whole square miles". Killebrew (1874) described the grasslands of Lewis County as “wild grasses upon the broad areas of flat lands grow with spontaneous luxuriance”. The soils were key in the development of grasslands, due to a hardpan created from water percolating through the limestone-derived clay (DeSelm 1988). Grasslands of the WHR were historically maintained by wildfires and by Native American burning of grasslands (Stambaugh et al. 2016). In addition to prairie grasses such as *Andropodon gerardii, Sorghastrum nutans,* and *Schizachyrium scoparium*, common herbaceous families are Asteraceae, Fabaceae, Rosaceae, and members of the former Scrophulariaceae.

The ravines of the WHR are areas of more mesic forest communities, which have similar composition to upland forest with the addition of mesic association species such as *Fagus grandifolia*, *Liriodendron tulipifera*, and *Acer saccharum* (Chester et al. 1998). Forest slopes exposed to less sunlight may also include *Juglans nigra* (Braun 1950).

Swamps, wet forest, marshes, bogs and fens are all types of WHR wetlands. Swamp and wet forests are dominated by *Q. phellos, Q. lyrata, Q. palustris,* with *A. rubrum, Liquidambar styraciflua*, and *Q. pagoda*. Floodplains are dominated by *Platanus occidentalis, A. saccharinum, L. styraciflua, A. negundo,* and *Populus deltoides* (Ellis & Chester 1989). Marshes are home to many *Carex* and *Juncus* species and forbs such as *Lobelia cardinalis* and *Hibiscus laevis.* Seasonally wet floodplain meadows adjoin emergent marshes and are home to *Carex* ssp., and *Juncus* ssp. The state rare *Liparis loeselii* can be found in bogs (Joyner & Chester 1994) and the globally rare *Xyris tennesseensis* and the state rare *Parnassia grandifolia* are fen species (Crabtree 2012).

Fire is important to the maintenance to some WHR vegetation communities. Oak-pine savannas, woodland, and prairies are all fire-adapted ecosystems (Nowacki & Abrams 2008). *Pinus echinata* depends on fire to encourage regeneration. Grasslands require fire to control the encroachment of woody vegetation. The relatively flat undissected portions of the southern WHR probably had a frequent fire history judging from the frequency of fire reported for the southern Eastern Highland Rim to the east which Stambaugh et al. (2016) reported burned on average every 3 years. Such a frequent fire return interval would tend to support savanna vegetation. Killebrew and Safford (1874) reported annual fires were used to by locals on the undissected WHR of Lewis County, TN.

Phytogeography

The development of the Lexington peneplain contributed to the mosaic of vegetation types in this western mesophytic forest region (Braun 1947). While the WHR remained unglaciated throughout the Pleistocene, glaciation of North America did influence the phytogeography of the region. Pollen records indicate that, during glaciation events, tundra vegetation extended into Tennessee and the modern day, diverse, floral mosaic of this region did not occur until the late Holocene (Delcourt 1979).

Disjunct distributions can occur from changes in the environment, such as climate changes (Davis 1983). Pleistocene glaciation events created such disjuncts. The geography of the WHR lends itself as a refuge for these populations. Steep ravines are areas of microclimates that have cooler summers and offer protection in the winter from harsh weather (Greenberg et al. 1997). Numerous seeps also provide waters and soils that are cooler in summer and warmer in winter than the surrounding area (Amon et al. 2002). Groundwater flow can protect species from climatic aridity (Kaul et al. 1988). As per Delcourt and Delcourt's Bluffland Migration Corridor Hypothesis (1975), rivers and stream valleys may also act as corridors for species migration.

The WHR has northern and southern affiliated taxa. These taxa may be disjunct from the main population, or peninsular (located at the end of the range). Species with low mobility may be more likely to become disjunct, relict populations (Kaul et al. 1988). Northern affiliated taxa are likely remnants from when cooler vegetation extended more broadly across the region. Some strictly northern species moved southward during the Pleistocene to the high elevations of the Southern Appalachians whereas other more general northern species were able to advance far into the South, including to the cool, moist, forests portions of the WHR. During glaciation, relatively few extinctions occurred as northern species migrated southward. Appalachian species, for example, were displaced to the southern Coastal Plain (Davis 1983). After the last glaciers retreated about 18,000-15,000 ybp, the climate warmed and most temperate species rapidly extended their ranges northward from southern refugia, resulting in a continuous range.

Braun (1937) contended that southern or Coastal Plain species on the Highland Rim and Cumberland Plateau are ancient species that originated in the Appalachian highlands and migrated out onto the Coast Plain. Shinners (1962), however, posited that they are emigrants from the Coastal Plain. This ecoregion bounds the Western Highland Rim and the Cumberland Plateau and the moderate gradient from the Coastal Plain to the Cumberland Plateau in northern Alabama offers a continuation of streams and wetland communities (Harvill 1984) creating a migration corridor for the Coastal Plain taxa.

Floristic review of the WHR

While Native Americans were Tennessee's original botanists, one of the earliest European botanists to visit Tennessee was explorer André Michaux in the late 18th century. He visited the area around Clarksville and the lower Cumberland River in the northern WHR but he, like most other early settlers, did not venture into the central and southern WHR. Most of the early botanical efforts were concentrated in the eastern and north-central portions of the state (Michaux 1805). The WHR was not the subject of botanical study until after the 1860s. German émigré and amateur botanist Augustin Gattinger did much to advance the botanical record in Tennessee. In 1877, after urging from Asa Gray, Gattinger began work on a flora of Tennessee. His flora, the first of the state, was published in 1887 and the second edition in 1901. There is very little documentation of Gattinger visiting the WHR. He did visit Picadilly Prairie west of Dickson on the WHR where he documented rare grassland species such as *Nabalus barbatus*

(Gattinger 1887). He also visited West Tennessee (Carroll Co.) and presumably crossed the WHR to get there. Throughout his lifetime, Gattinger focused much of his work in Middle Tennessee (TFC 2015).

Lucy Braun, circa 1940s, was one of the first modern botanists to study the WHR. Her classification of the WHR forests as a western mesophytic forest region was part of her broader study of the forest regions of the eastern United States (Braun 1947, 1950). In 1934, the University of Tennessee Herbarium (TENN) collection was lost to fire. In order to rebuild the collection, H.M. Jennison, Arron Sharp, Royal Shanks, and others traveled throughout the state on collecting expeditions. The rare *Crataegus harbisonii* was collected by Shanks and Sharp near Nashville, Tennessee (Lance & Phipps 2000) as part of these trips. In 1941, the Austin Peay State University Herbarium (APSC) in Clarksville, Tennessee was established by Royal E. Shanks and Alfred Clebsch. Clebsch collected widely in the northern WHR and adjacent Pennyroyal Plains region until the mid-1960s. He published one of the most complete references to the bryophytes of the Lower Cumberland River Valley of the northern WHR (Clebsch 1947). Shanks's successors, William Ellis, Edward Chester and Dwayne Estes, continued to add to the APSC collection (TFC 2015). A curator of the Vanderbilt University Herbarium (VDB) for 30 years, Kral made extensive collections throughout the southeastern United States including the WHR. Kral discovered and described as a new species, the globally rare *Xyris tennesseensis*, found in seepage fens in Lewis County (Kral 1978).

Recent botanical studies covered a variety of land types, including forest, barrens, and wetlands. These studies include the following investigators: Chester (1992, 1995), Chester et al. (1997, 1998), Ellis et al. (1971), Estes (2005), Estes & Walak (2005), Gunn (2003), Joyner & Chester (1994), Souza (1987), and Kelly (1989). Chester conducted numerous floras, concentrating primarily in the northernmost portion of the WHR, especially Land Between the Lakes, and the Pennyroyal Plain. Additionally, two wetland-focused floras were conducted: (1) Joyner and Chester's 1994 flora of Cross Creeks National Wildlife Refuge in Stewart County and (2) Gunn's 2003 flora of the Tennessee National Wildlife Refuge's Duck River Unit in Humphreys County in the central WHR. Subsequently, Souza's flora of Dickson County and Kelly's flora of Williamson County (western portion of county only) was also in the central WHR. Two floras of the southern WHR were conducted, one of Rattlesnake Falls in Maury County (Estes & Walck 2005) and another of Giles County (Estes 2005), of which about half of the county is in the WHR. In 1983, the Tennessee Department of Conservation Natural Heritage Program published a report of WHR potential natural areas (Smith et al. 1983) that included a study of two Lewis County seepage fen sites, one at Langford Branch adjacent to Highway 99 and the other on Little Swan Creek at the intersection of the Natchez Trace Parkway. Langford Branch species include *Xyris tennesseensis*, *Juncus brachycephalus,* and *Parnassia grandifolia.* In 1988, DeSelm include a fen site at Langford Branch in his study of 18 barrens of the Western Highland Rim of Tennessee.

Land-use history

Before European settlement, the WHR was primarily occupied by the Shawnee and Chickasaw Native American tribes. Native Americans were known to use fire to clear land and keep it open (Witthoft & Hunter 1955). This practice was continued by European settlers until the mid-20th century. Killebrew (1874) said of fires in Lewis County, "In spite of the damage done to the timber and the destruction to the mast, many persons living in the county, having inherited the pernicious practice from their fathers, still persist in firing the woods every fall".

Anecdotally, most farmers in Hickman County were known to burn the rangeland and occasionally the woods, every spring, to encourage new grass growth for livestock. This is a practice that Forrest Redden participated in for most of his adult life (1888-1966). It was said that he would light a broomsedge field on fire, regardless of who owned it, because it needed burning (R. Redden, pers. comm., Dec. 4, 2016).

Current land use consists primarily of agriculture and timber production. Cultivation of corn, cotton, soybeans and tobacco contributed to deforestation (TFC 2015). In addition, grazing patterns by both livestock and wildlife are important to botanical richness. DeSelm (1994) estimated that continuous heaving grazing may have reduced richness by up to 71 percent. These factors have led to a decrease in natural lands and their botanical diversity.

Historically, due to the abundance of wood and raw materials, the WHR was utilized for the mining and smelting of limonite iron ore. It is estimated that a 10.88 metric-ton-per-day (12-ton-per-day) iron production would use 202 hectares (500 acres) of forest per year and in 1873 there were 11 furnaces, producing about 45,359 metric tons (50,000 tons) per year (Luther, 1977). Timber was also used as fuel for steamboats on the Cumberland and Tennessee rivers. After the demise of the iron smelting industry the forests recovered and in 1980, the U.S. Department of Agriculture estimated that about 68% of the region was forested (Smalley 1980).

CHAPTER III

METHODS

Fourteen seeps located in the Western Highland Rim (WHR) Physiographic Subsection in Tennessee were selected for study (Table 1). The study sites varied from forest and woodland to open canopy with a dominant herbaceous layer and sparsely woody vegetation, surrounded by an oak-hickory dominate mixed mesophytic forest (Greenberg et al. 1997). Both publicly and privately owned sites were selected based on a diversity of vegetation and a lesser amount of anthropogenic disturbance.

The boundary of each seep was mapped using a Garmin handheld GPS navigator (accurate to 10 m). The soil pH was measured at two representative points within each site using a Rapitest soil pH test kit, where pH was determined by combining one-half teaspoon of soil, the pH reagent and distilled water and comparing it with the provided color chart after 1 minute. Each site was mapped in ArcGIS, additional map layers included the Environmental Protection Agency Level IV Western Highland Rim ecoregion (EPA 2014) shapefile and USGS Tennessee geologic map data shapefile (Fig. 2) (Nicholson et al. 2007). The soil map for each site was determined from the USDA, NRCS Web Soil Survey (2016). A photograph of each site was taken and included in Appendix C. Field indicators of hydric soil in the United States, version 7.0 (Vasilas et al. 2010) protocol was used assess the soil organic (O) horizon.
Sites were visited a total of 24 times from April 2013 through May 2016. Taxa unique to each site were collected in duplicate and when possible with inflorescence or infrutescence. Based on data from Tennessee Natural Heritage Program (Crabtree 2014) and a review of WHR floras, 10

state listed rare plants were identified as possible seepage fen species (Table 2). Specimens were identified using the *Guide to the Vascular Flora of Tennessee* (TFC 2015), *Flora of the Southern and Mid-Atlantic States* (Weakley 2015) and the *Flora of North America North of Mexico* (Flora of North America Editorial Committee, eds 1993+). The Austin Peay State University Herbarium (APSC) and the University of Tennessee's online Database of Tennessee Vascular Plants images and maps (TENN 2016) were used for comparison to identify collected specimens. From the 14 sites, 430 specimens were collected and deposited at the APSC herbarium and duplicates sent to the Vanderbilt Herbarium (VDB) housed at the Botanical Research Institute of Texas in Fort Worth. Wetland delineation codes were determined for each species and infraspecific taxon using *The National Wetland Plant List* for Eastern Mountains and Piedmont region (Table 3) from Lichvar (2016). Rare plants and their status were determined from data provided by the Tennessee Natural Heritage Program (Crabtree 2014). Each species and infraspecific taxon were classified with a growth habit using classifications from the USDA, NRCS (2016).

β-diversity, a measure of dissimilarity between sites was calculated using presence-absence data via 1-Jaccard's index as follows:

$$\text{1-Jaccard's index} = 1 - S_{12}/(S_1 + S_2 - S_{12})$$

S_1 – count of site 1 taxon
S_2 – count of site 2 taxon
S_{12} – count of taxon common to both sites

Following numerous other studies, this method is used to calculate β-diversity when there is little change in the latitudinal gradient (Koleff et al. 2003, Harrison et al. 2006, Jaccard 1912). A higher number (between 0 and 1) equals greater β-diversity (less similarity between sites) and a lower number equals less β-diversity or a greater similarity between sites (Harrison et al. 2006).

Table 1. Description, soils, location, area, soil pH, county, and ownership status of seepage fen sites in the Western Highland Rim of Tennessee .

Site	Name	Detailed Soil Map Unit	Location	Area (M^2)	pH Category	County	Status
A1	Auntney Hollow stream side seep 1	Tarklin-Humphreys complex, 5 to 12% slopes, eroded	35.513921N 87.439420W	203.69	circumneutral (7)	Lewis	TN Natural Area
A2	Auntney Hollow stream side seep 2	Tarklin-Humphreys complex, 5 to 12% slopes, eroded	35.514137N 87.439423W	124.44	circumneutral (7.25)	Lewis	TN Natural Area
A3	Auntney Hollow stream side seep 3	Tarklin-Humphreys complex, 5 to 12% slopes, eroded	35.514301N 87.439452W	101.09	circumneutral (7.125)	Lewis	TN Natural Area
BC	Brush Creek stream side sloping seep	Lindside cherty silt loam	36.003670N 87.104420W	295.93	calcareous (7.5)	Williamson	Private
D1	Dry Branch woodland circumneutral seep	Tarklin-Humphreys complex, 5 to 12% slopes, eroded	35.611570N 87.629070W	225.36	circumneutral (6.75)	Lewis	TN Natural Area
D2	Dry Branch *Parnassia* seep	Tarklin-Humphreys complex, 5 to 12% slopes, eroded	35.612190N 87.629240W	168.40	circumneutral (6.875)	Lewis	TN Natural Area
D3	Dry Branch perched woodland seep	Biffle gravelly silt loam, 30 to 60% slopes	35.609250N 87.631969W	374.95	acid (6.375)	Lewis	TN Natural Area
D4	Dry Branch graminoid seep	Biffle gravelly silt loam, 30 to 60% slopes	35.602060N 87.639700W	619.09	circumneutral (6.5)	Lewis	TN Natural Area
LB	Langford Branch *Parnassia* seep	Biffle-Sulphura-Rock outcrop association, very steep	35.568819N 87.333559W	767.09	circumneutral (6.875)	Lewis	Non-profit Trust
N1	Natchez Trace seep 1	Biffle-Sulphura-Rock outcrop association, very steep	35.584580N 87.425110W	302.84	circumneutral (6.625)	Lewis	National Park Service
N2	Natchez Trace acid seep 2	Biffle-Sulphura-Rock outcrop association, very steep	35.584460N 87.424410W	452.70	acid (6.25)	Lewis	National Park Service
PM	Powdermill Branch woodland seep	Greendale cherty silt loam	35.377710N 87.200420W	470.73	circumneutral (6.625)	Giles	Private
R1	Rattlesnake Falls *Impatiens* cliff seep	Rockland, steep	35.448722N 87.262667W	187.18	circumneutral (7.25)	Maury	Private
R2	Rattlesnake Falls perched seep	Bodine cherty silt loam, steep phase	35.449722N 87.256722W	237.60	circumneutral (7.125)	Maury	Private

Table 2. State listed rare plants identified as possible seepage fen species in the Western Highland Rim of Tennessee. Global rank G2 is imperiled, G3 is vulnerable, G4 is apparently secure, G5 is secure. State status S is special concern species; E is endangered species. State rank S1 is extremely rare and critically imperiled, S2 is very rare and imperiled, S3 is rare and uncommon, in Tennessee. Federal status LE is listed endangered.

Scientific name	Common name	Global rank	State rank	Fed. status	State status	Habitat	Counties
Fuirena squarrosa	Hairy Umbrella-sedge	G4G5	S1	--	S	Stream And Lake Margins	Lewis
Juncus brachycephalus	Small-headed Rush	G5	S2	--	S	Seeps And Wet Bluffs	Lewis, Maury, Williamson
Liparis loeselii	Fen Orchid	G5	S1	--	T	Calcareous Seeps	Lewis
Marshallia trinervia	Broad-leaved Barbara's-buttons	G3	S2S3	--	T	Rocky Ravines	Lewis
Minuartia godfreyi	Godfrey's Stitchwort	G1	S1	--	E	Wet Meadows And Marshes	Lewis
Parnassia grandifolia	Large-leaved Grass-of-parnassus	G3	S3	--	S	Calcareous Seeps	Lewis, Maury, Williamson
Scleria verticillata	Low Nutrush	G5	S2	--	S	Wet Prairies And Fens	Lewis
Spiranthes lucida	Shining Ladies'-tresses	G5	S1S2	--	T	Alluvial Woods And Moist Slopes	Lewis
Stellaria fontinalis	Water Stitchwort	G3	S3	--	S	Seeps And Limestone Creek Beds	Giles, Lewis, Maury, Williamson
Xyris tennesseensis	Tennessee Yellow-eyed Grass	G2	S1	LE	E	Calcareous Seeps	Lewis

Table 3. Plant indicator status categories from Lichvar (2016)

Indicator Symbol	Indicator Category	Description
OBL	Obligate Wetland Plants	Plants that occur almost always in wetlands.
FACW	Facultative Wetland Plants	Plants that occur usually in wetlands.
FAC	Facultative Plants	Plants with a similar likelihood of occurring in both wetlands and nonwetlands.
FACU	Facultative Upland	Plants that occur sometimes in wetlands, but occur more often in nonwetlands.
UPL	Obligate Upland Plants	Plants that occur rarely in wetlands, but occur almost always in nonwetlands.

Following Valverde et al. (2006), the results the β-diversity estimation was used calculate a hierarchical cluster and represented as dendrogram to show the relationship between the 14 sites. The distance matrix measure parameter was “euclidean”, commonly used in cluster analysis, and the agglomeration method parameter was “mcquitty” or WPGMA (R Core Team 2016).

The Floristic Quality Index (FQI) was calculated for each site, first by assigning Coefficient of Conservatism values (CC) for wetland species from Gianopulos (2013) and assigning all other species CC values following Estes (Unpublished manuscript). The CC value is a score from 0 to 10, where 0 is assigned to a non-native; a 1 to 10 rank is then assigned to each native species based on the level of disturbance tolerated by the species, with a higher number being less tolerant of disturbance (Table 4). The FQI for each site was then calculated as the sum of that site’s CC divided by the square root of native species count:

$$FQI = \sum CC \div \sqrt[N]{NativeSpecies}$$

Table 4. Coefficient of Conservatism ranges and definitions from Taft et al. (1997) and Gianopulos (2013).

Value	Description
0-1	Non-native species.
1	Species adapted to severe disturbances.
2-3	Species associated with somewhat more stable, though degraded, environments.
4-6	Dominant or matrix species for several habitats; they have a high consistency of occurrence within given community types.
7-8	Species associate mostly with natural areas, but that can be found persisting where the habitat has been degraded somewhat.
9-10	Species restricted to high-quality natural areas.

Study sites were compared to the USNVC (2016) Interior Low Plateau Seepage Fen ecological system and associations based on characteristic and association taxa. Seven sites were compared qualitatively to three USNVC ecological systems based on six abiotic characteristics: spatial pattern, soil pH, canopy cover, landscape position, soils, and moisture. Sites were given a Vegetation of Tennessee community classification following Estes (2015).

The WHR fen flora was compared to four fen floras from the Midwestern United States by family. The WHR fen flora was also comparted to three similar fen floras from other states using a Sørensen's Similarity Index, a measure of β-diversity using presence/absence data. The indexed is calculated as two times the number of common taxa divided by the sum of the taxa from each flora (Sørensen 1948). The Sørensen’s Similarity Index falls between 0 and 1, where a value closer to 0 indicates dissimilarity of sites and a value closer to 1 signifies higher similarity. Phytogeographic affinities were determined from Blyveis and Shaw (2011), USDA, NRCS PLANTS Database (2016), and BONAP (Kartesz 2015).

CHAPTER IV

RESULTS

Site characteristics

All sites are underlain by Mississippian bedrock (Nicholson et al. 2007) within the Western Highland Rim ecoregion. Sites ranged in area from 102 m^2 to 768 m^2 for a total area of 0.45 hectares. Seven soil maps units were identified for the 14 sites; Greendale, Rockland, Biffle, Bodine, Tarklin-Humphreys, Biffle-Sulphura, and Lindside (Table 1) (Soil Survey Staff 2016a). Soils varied from muck, mucky peat to cherty gravel (Vasilas et al. 2010). All sites had apparent hydrological inputs from groundwater sources and were located adjacent to or near (within 75 m) a solid limestone-bottom stream. The Williamson county site (BC) is in the Harpeth River watershed. Dry Branch sites (D1, D2, D3, D4) are in the Buffalo River watershed. All other sites are in the Lower Duck River watershed (TDEC 2016).

Based on a strict interpretation of soil pH, two sites are acidic (D2, N1), one is alkaline (BC) and the remaining 11 sites are circumneutral (Table 1). Powdermill Branch was observed as being the driest site and became quite dry by late summer.

Auntney Hollow State Natural Area, Lewis County, Tennessee

Auntney Hollow State Natural Area is privately owned and designated as a state natural area in 2002 (Fig. 4). From the intersection of Highway 412 and the Natchez Trace Parkway, travel 7.1 km south on Natchez Trace Parkway to Little Swan Creek Bridge. From Little Swan Creek Bridge travel 1.4 km upstream to Collier Branch and 400 m upstream on Collier Branch. Within Auntney Hollow State Natural Area, Site 1 (A1), located at coordinates 35.513921N, 87.439420W, is a 204 m^2, circumneutral (pH 7) woodland seepage fen. Site 2 (A2), located at coordinates 35.514137N, 87.439423W, is a 124 m^2, circumneutral (pH 7.25) woodland seepage fen. Site 3 (A3), located at coordinates 35.514301N, 87.439452W, is a 101 m^2, circumneutral (pH 7.125) woodland fen. All Auntney Hollow sites have a Tarklin-Humphreys complex, 5 to 12% slopes, erode detailed soil map unit.

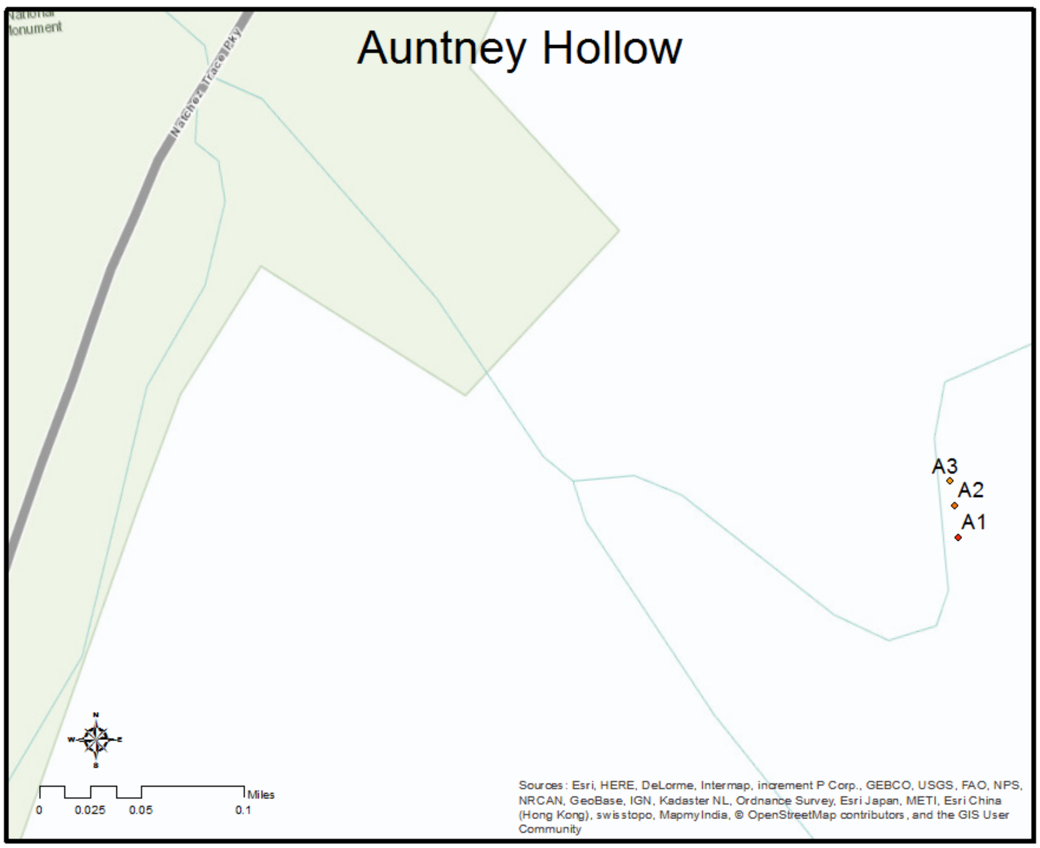


Fig. 4. Three seepage fen sites (A1, A2, A3) at Auntney Hollow in Lewis County, Tennessee.

Brush Creek, Williamson County, Tennessee

Brush Creek is privately owned (Fig. 5). From Fairview, Tennessee at the intersection TN-96 and TN-100 travel east 1.9 km. Turn right on Horn Tavern Road. Travel 0.2 km. and then a left on Hill Hughes Road for 1.7 km to GroWild, Inc. This site (BC) (Fig. n) is c. 662 m upstream from GroWild on Brush Creek. This site is a 767.09 m2, calcareous (pH 7.5) stream side fen, located at 36.003670N, 87.104420W on the east bank of the stream. The soil map unit was identified as Lindside cherty silt loam.

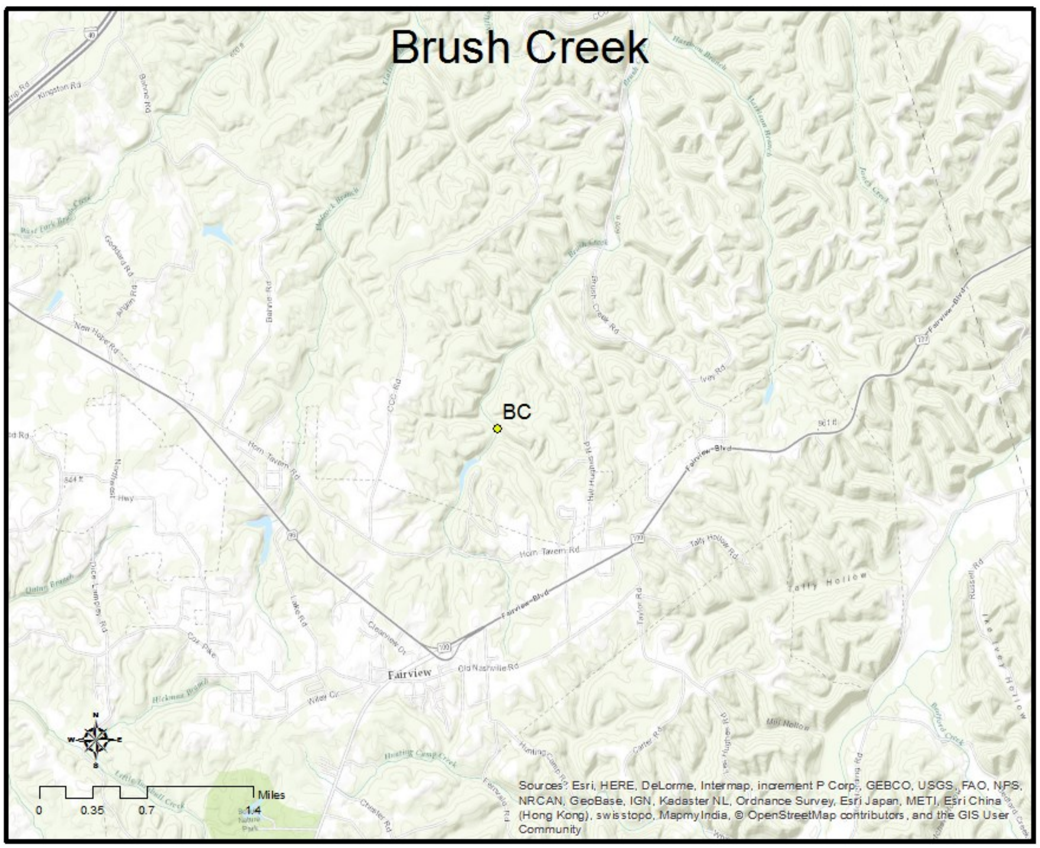


Fig. 5. The seepage fen site (BC) at Brush Creek in Williamson County, Tennessee.

Dry Branch State Natural Area, Lewis County, Tennessee

Dry Branch State Natural Area is state owned and was designated in 2007 as a natural area (Fig. 6). From Hohenwald, Tennessee travel 9.0 km west on US-412, turn right on Brush Creek Road. Travel 4.0 km turning right onto unnamed dirt road. After traveling through the gate turn right at the fork. Then continue on for 3.5 km turning left onto a dirt track. Continue, on foot, following the trail in a northwesterly direction for c. 320 m. Site 1 (D1) (Fig n.) is on the left c. 85 m from Dry Branch Creek (35.61157N, 87.62907W). D1 is a 225.36 m^2, circumneutral (pH 6.75) woodland fen. Site 2 (D2) is on the left c. 38 m from Dry Branch Creek (35.612190N, 87.629240W). Site 2 (D2) is a 168.40 m^2 circumneutral (pH 6.875) *Parnassia* seep. After reaching Dry Branch Creek from the trail, travel c. 345 m upstream. Site 3 (D3), an acid (pH 6.375), wooded perched seep, is c. 47 m from the stream on the south bank (35.609250N, 87.631960W) and 374.9 m^2 in area. D4, the largest seep at Dry Branch is c. 1.5 km upstream from the trail and on the south fork. Site 4 (D4) is a circumneutral gentle sloping seep on the SE bank of Dry Branch (35.602144N, 87.639778W) and 619.09 m^2 in area. Three Dry Branch sites (D1, D2, D4) have a Tarklin-Humphreys complex, 5 to 12% slopes, erode detailed soil map unit. One site (D3) is on Biffle gravelly silt loam, 30 to 60% slopes.

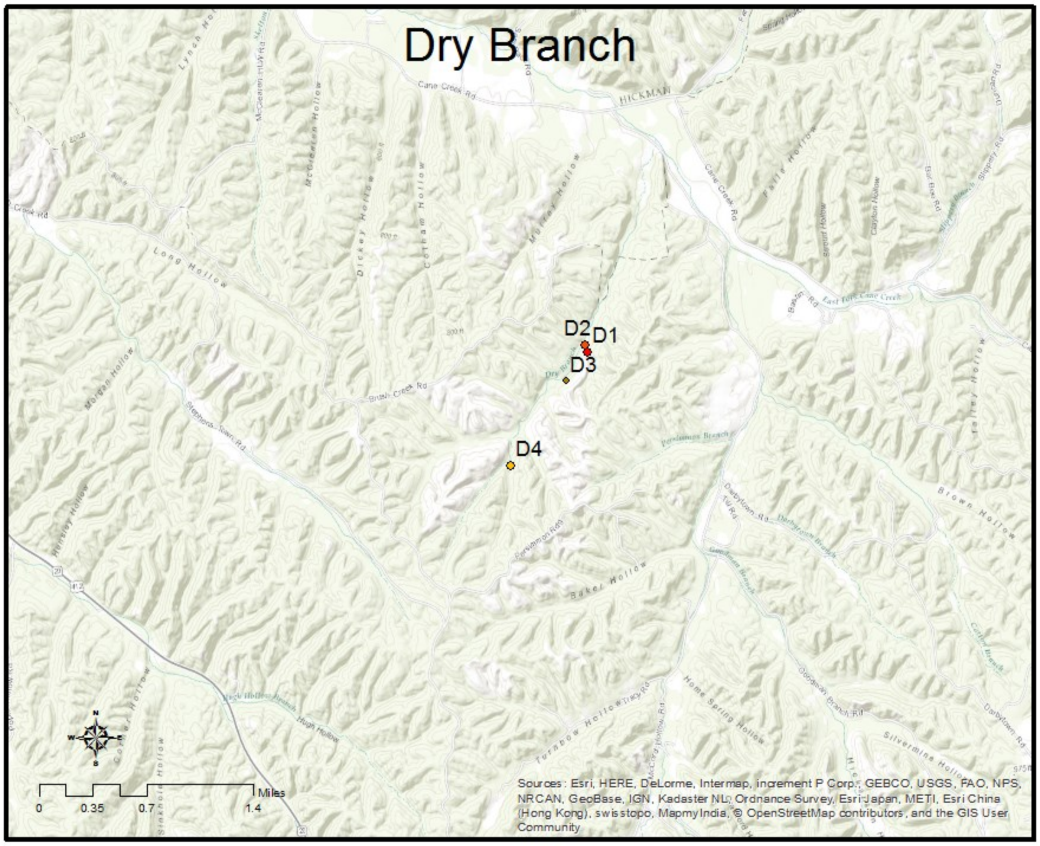


Fig. 6. Four seepage fens site (D1, D2, D3, D4) at Dry Branch in Lewis County, Tennessee.

Langford Branch, Lewis County, Tennessee

Langford Branch became a part of the Swan Conservation Trust in 2002 (Fig. 7). From Hohenwald, Tennessee travel east 23.0 km on US-412. The site (LB) (Fig. 7) is 20 m south of US-412 near Langford Branch. Located at 35.568819N, 87.333559W, the site is a sloping seep with a circumneutral pH (pH 6.875) and 767 m^2 in area. This site has a Biffle-Sulphura-Rock outcrop association, very steep detailed soil map unit.

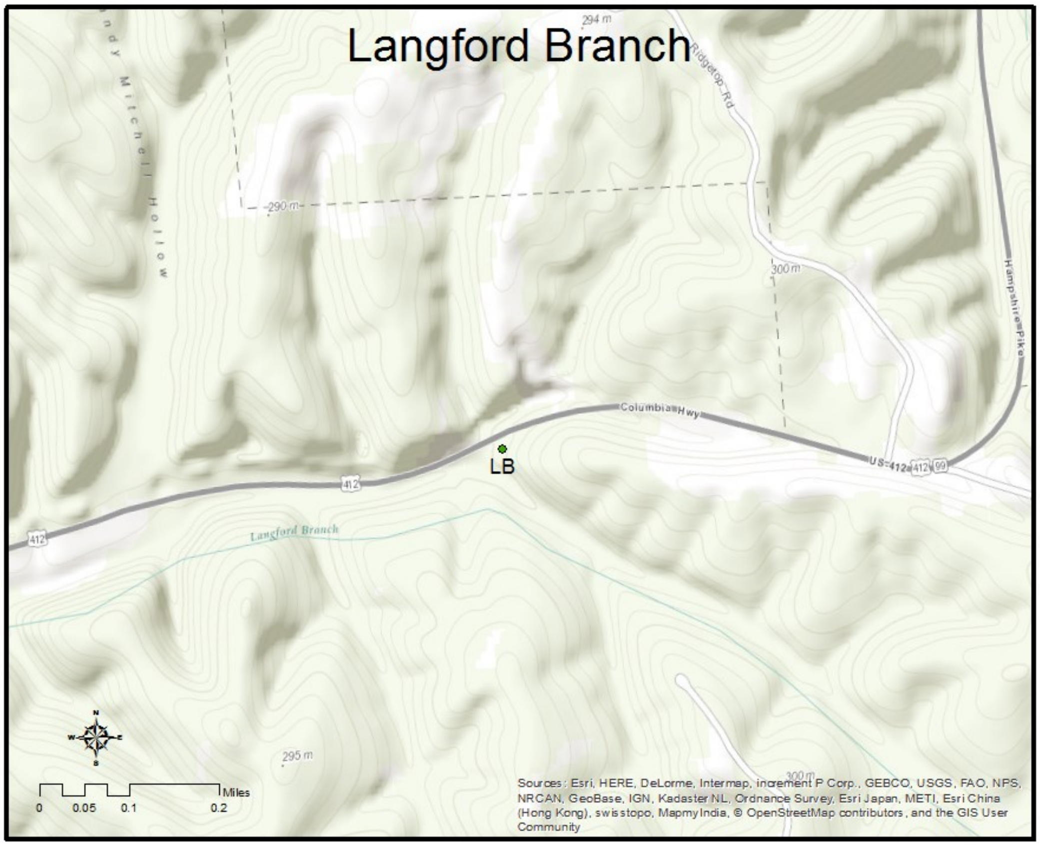


Fig. 7. A seepage fen site (LB) at Langford Branch in Lewis County, Tennessee

Natchez Trace Parkway, Lewis County, Tennessee

The Natchez Trace Parkway is a part of the National Parks system (Fig. 8). From Hohenwald, Tennessee head east on US Highway 412 for 13.4 km. Turn right onto the Natchez Trace Parkway and travel north for 1.5 km to the Fall Hollow Falls parking area. Take the Fall Hollow Trail to the bridge, then travel upstream c. 300 m then travel north for 65 m. to the first site. This site (N1) (Fig. 8), located at 35.584580N, 87.425110W, is a circumneutral woodland site and 302.84 m^2 in area. The second site (N2), located at 35.584460N, 87.424410W, is c. 65 m east by southeast of N1 and is an acidic woodland site and 452.70 m^2 in area. Both sites have a Biffle-Sulphura-Rock outcrop association, very steep detailed soil map unit.

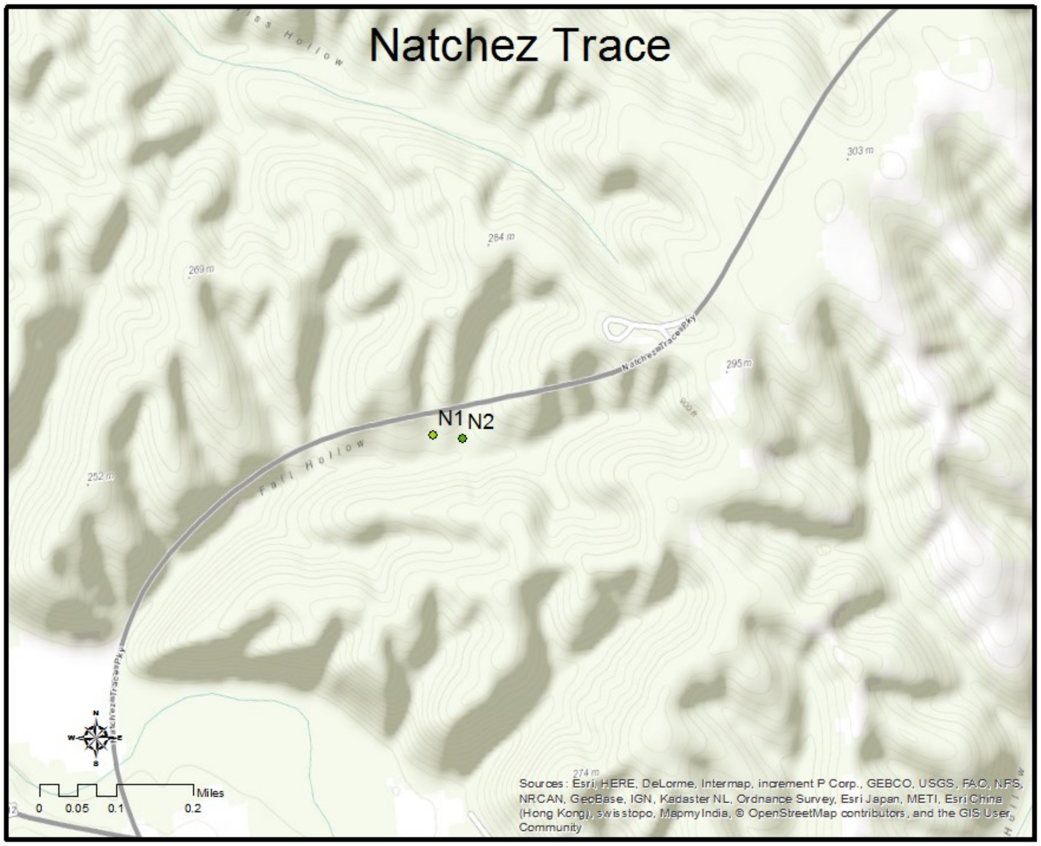


Fig. 8. Two seepage fen sites (N1, N2) on the Natchez Trace Parkway in Lewis County, Tennessee

Powdermill Branch, Giles County, Tennessee

The fen at Powermill Branch is privately owned (Fig. 9). From Summertown, TN, head south on US highway 43. Turn left onto Alexander Springs Rd. for 1.1 km. Turn left onto Marcella Falls Road for 1.9 km. Continue onto Marcella Falls Road for 8.3 km. Turn left on Woodward Hollow Road and travel 1.6 km. Continue 0.8 km on Powdermill Branch Road. This site (PM) (Fig. 9) is a privately owned, 471 m^2 in area, streamside circumneutral (pH 6.625) seep and is c. 70 m southeast of road (35.377710N, 87.200420W). This site has a Greendale cherty silt loam detailed soil map unit.

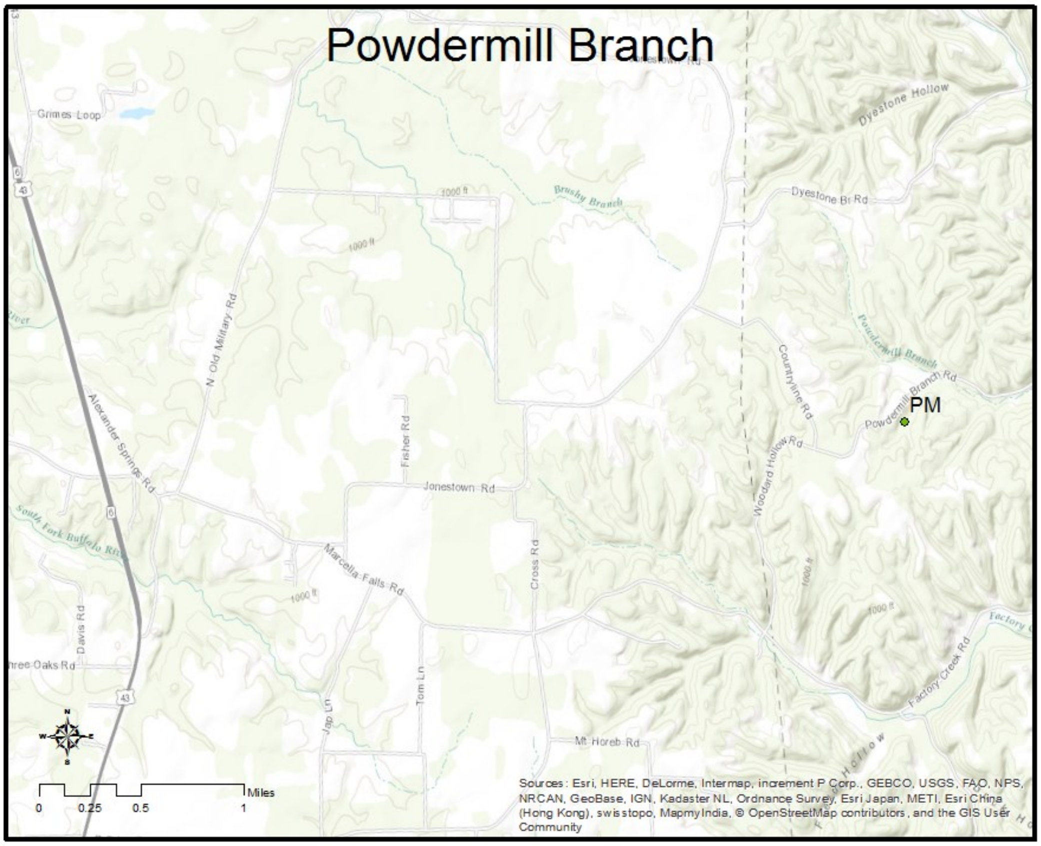


Fig. 9. A seepage fen site (PM) at Powermill Branch in Giles County, Tennessee.

Rattlesnake Falls, Maury County, Tennessee

Rattlesnake Falls is privately owned (Fig. 10). From the intersection of 1st Ave and US-43 in Mt. Pleasant, Tennessee, travel south on US-43 for 13.04 km. After crossing to the northbound lanes take the dirt track to south for c. 25 m and park. Take the trail for c. 600 m to Rattlesnake Falls on Falls Creek. Site 1 (R1) (Fig. 10) is a steep cliff-side circumneutral seep on the north bank just below the falls (35.448722N, 87.262667W) with an area of 187.18 m^2 and a Rockland, steep detailed soil map unit. Site 2 (R2) is 720 m downstream from the falls. The site is a 237.60 m^2, circumneutral *Parnassia* seep perched on the east bank c. 75m from Fall Creek. This site has a Bodine cherty silt loam, steep phase detailed soil map unit.

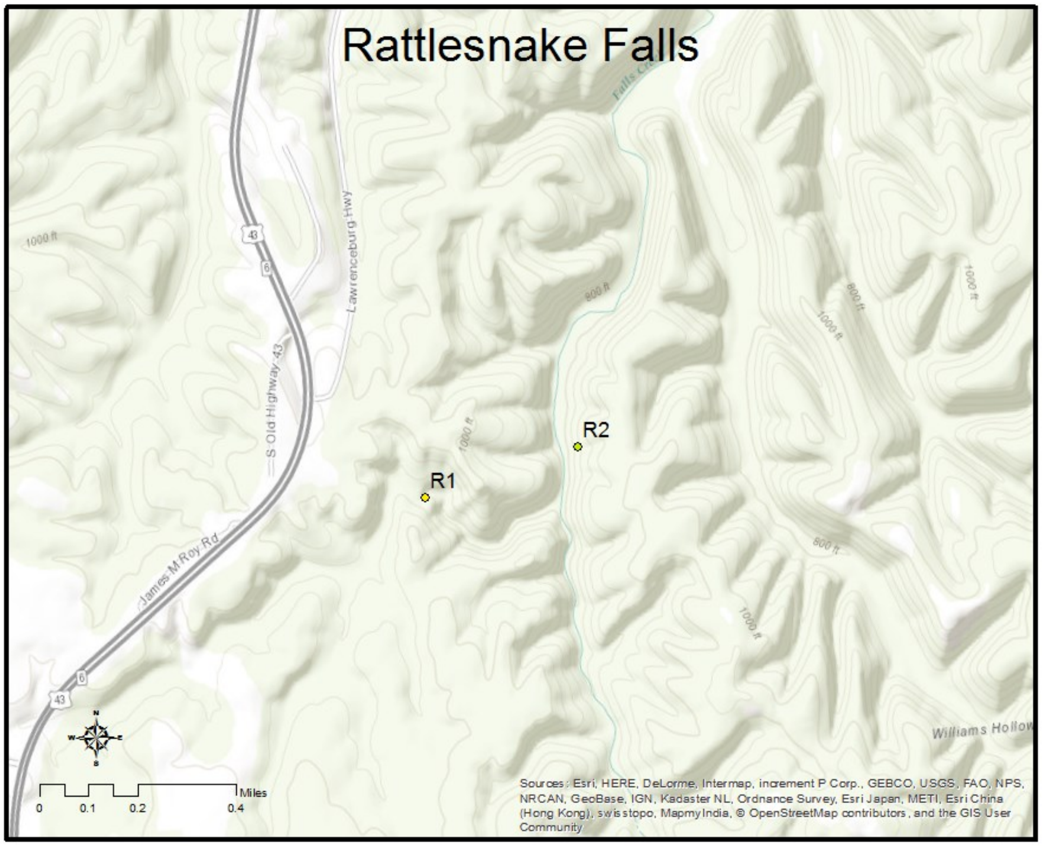


Fig. 10. Two seepage fens (R1, R2) at Rattlesnake Falls in Maury County, Tennessee.

Floristic analyses

Four hundred and thirty-one site specific species and infraspecific taxa were collected and identified from the 14 study sites. Of these, there were 160 unique species and infraspecific taxa across all sites. An annotated checklist of taxa documented in this study is provided in Appendix A and checklist by site is provided in Appendix B. A summary of the taxa by evolutionary group including a count of families, genera, and species or infraspecific taxa is found in Table 5. The eight most abundant families comprised 49% of the total number of taxa and are Poaceae (14%), Cyperaceae (11%), Asteraceae (11%), Ericaceae (4%), Fabaceae (3%), Juncaceae, (3%), Lamiaceae, (2%), and Rosaceae (2%) (Fig. 11). The remaining 51% of the total taxa the remaining taxa are distributed among 50 families.

Table 5. A summary of vascular plant specimens collected in 14 fen sites in the Western Highland Rim of Tennessee.

Evolutionary Group	Families	Genera	Species/Infraspecific Taxa
Acrogymnospermae	1	1	1
Eudicotyledonae	39	72	86
Magnoliids and Primitive Angiosperms	4	5	5
Monilophyta	5	9	10
Monocotyledonae	9	34	58
Totals	58	121	160

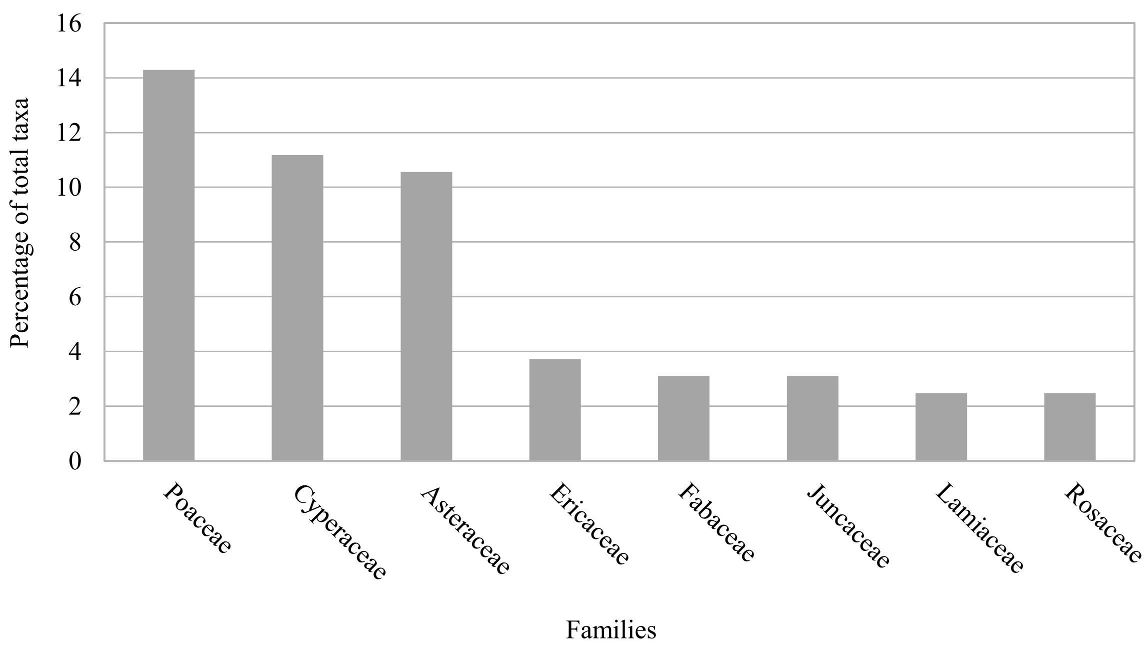


Fig. 11. Eight most taxa rich families collected from 14 seepage fens in the Western Highland Rim of Tennessee

Auntney Hollow Site 1 (A1) had the highest percentage of obligate wetland taxon (OBL, 50%), and Powdermill Branch (PM) had the least (OBL, 5%) (Fig. 12). Across all sites, the highest percentage of taxa (30%) were categorized as facultative (FAC). However, 52% of the specimens were either facultative wetland plants (FACW, 25%), or obligate wetland plants (OBL, 27%). In addition, 13% were facultative upland plants (FACU), 2% were obligate upland plants (UPL), and 3% were not classified (N/A). Non-classified taxa are listed in Table 6. Of the 431 taxa collected for all sites, forb/herbs accounted for 291 (47%) taxa; graminoids, 139 (32%) taxa; tree/shrubs, 36 (8%) taxa; trees, 30 (7%) taxa; vines, 15 (3%) taxa; shrubs, 9 (2%) taxa. (Fig. 13). Taxa richness at eleven sites (A1, A3, BC, D1, D2, D3, D4, LB, PM, R1, R2) was dominated by forb/herbs, two sites (N1, N2) were dominated by graminoids, and one site (A2) was dominated equally by forb/herbs and graminoids.

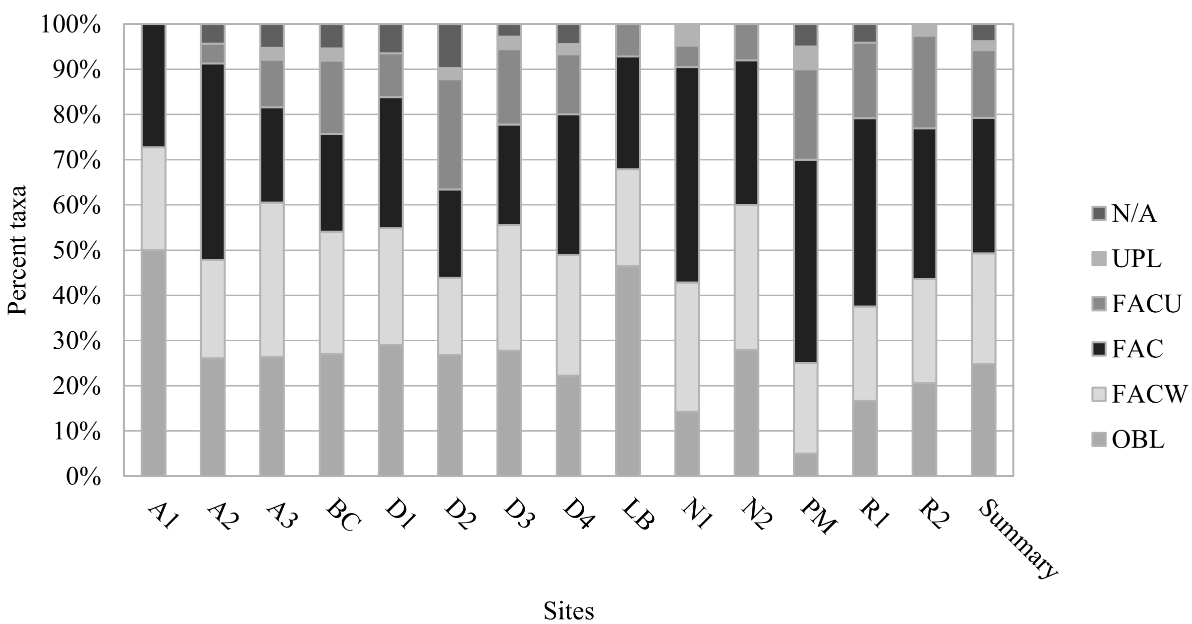


Fig. 12. Percentage of taxa for wetland delineation codes by site for vascular plants collected in 14 seepage fens in the Western Highland Rim of Tennessee. Site codes correspond to those in Table 1. OBL = Obligate Wetland Plants; FACW = Facultative Wetland Plants; FAC =

Facultative Plants; FACU = Facultative Upland; UPL = Obligate Upland Plants. Site identifiers are described in Table 1.

Table 6. Taxa from WHR seepage fens without wetland delineation codes.

Species or Infraspecific taxa
Agalinis gattingeri
Antennaria parlinii ssp. parlinii
Clinopodium glabellum
Cuscuta compacta
Danthonia spicata
Desmodium cuspidatum
Doellingeria infirma
Elephantopus tomentosus
Hydrangea cinerea
Melica mutica
Phlox amoena
Pseudognaphalium obtusifolium
Rhododendron alabamense

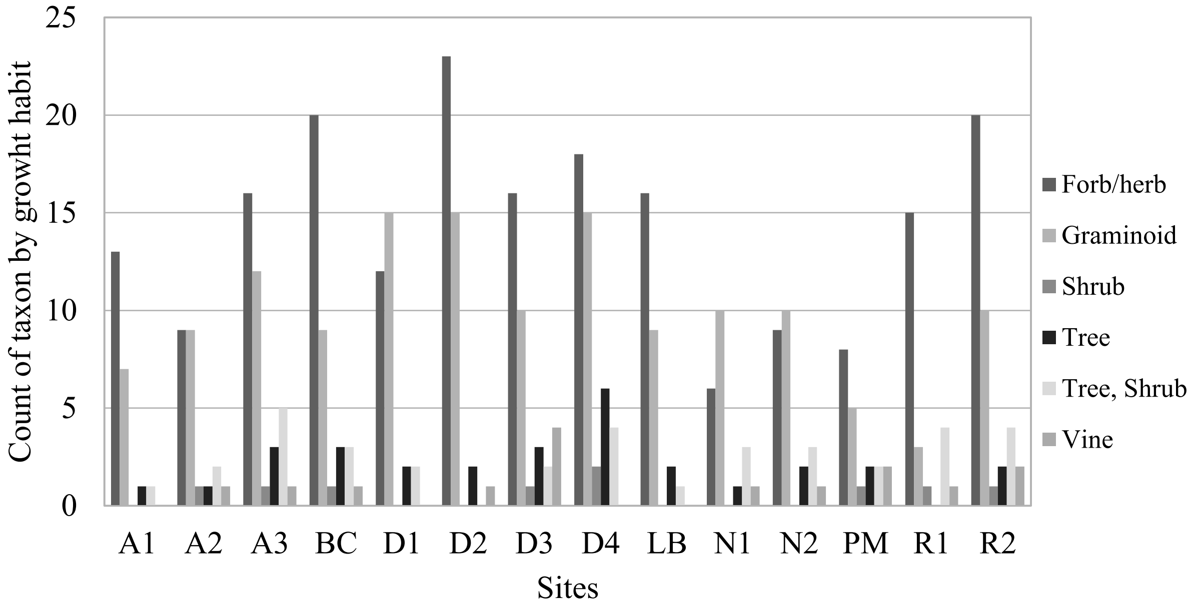


Fig. 13. Growth habit classification by count of vascular plant taxa collected in 14 seepage fens in the Western Highland Rim of Tennessee. Site identifiers are described in Table 1.

Rare and noteworthy taxa

Six of the collected taxa, listed in Table 7, had state status as special concern or endangered.

***Eleocharis tortilis* (Link) Schult., Twisted Spike-Rush (Cyperaceae):** State status is (S) and state ranked as S1. The global rank is G5 and there is no federal status for this species. This coastal Plain disjunct is known from only one other county (McNairy) in Tennessee and is a new county record for Lewis County. It was observed in one site (D1), a wooded circumneutral seep in the Dry Branch Natural Area.

***Fuirena squarrosa* Michx., Hairy Umbrella-Sedge (Cyperaceae):** State status is (S) and ranked as S1. The global rank is G4G5 and there is no federal status for this taxon. This Coastal Plain affiliated species is known from six counties (Benton, Henderson, Lewis, McNairy, White, and Polk) in Tennessee. It was collected in two sites, a circumneutral *Parnassia* glade seep (D2), and a circumneutral graminoid seep (D4) in the Dry Branch Natural Area in Lewis County.

***Juncus brachycephalus* (Engelm.) Buch., Smallhead Rush (Juncaceae):** State status is (S) and the state rank is S2. The global rank is G5 and there is no federal status for this taxon. This graminoid is known from 12 counties across Tennessee. It was collected from 4 sites (A3, BC, D1, and LB); seeps of various soil pH and plant composition.

***Lathyrus palustris* L., Marsh Pea (Fabaceae):** State status is (S) and the state rank is S1. The global rank is G5 and there is no federal status for this species. This northern disjunct is previously known from 6 counties (Anderson, Bledsoe, Coffee, Knox, Monroe, and Warren) in Tennessee and is a new county record for Williamson County (TENN 2016) and the only known specimen from the Western Highland Rim ecoregion (Kartesz 2015). It was collected from one site (BC), a sloping calcareous, stream-side seepage fen.

***Parnassia grandifolia* DC., Largeleaf Grass of Parnassus (Parnassiaceae):** State status is (S) and the state rank is S3. The global rank is G3 and there is no federal status for this taxon. This herbaceous perennial is known from 11 counties in middle and east Tennessee. It was collected from seven sites (A1, A2, A3, D1, D2, LB, R2), in various types of circumneutral seeps.

***Xyris tennesseensis* Kral, Tennessee Yellow-Eyed Grass (Xyridaceae):** State status is (E) and the state rank is S1. The global rank is G2 and the federal status is LE. This monocot endemic is known from one county in Tennessee with only 14 known populations world-wide (USFWS 1994). This species was documented at six sites (A1, A2, A3, D2, D4, LB), all Lewis County herbaceous circumneutral seeps.

In addition to rare taxa, other noteworthy observations include eight county records (Table 8). *Andropogon glomeratus* var. *pumilus,* a Coastal Plain disjunct, was previously undocumented in the Western Highland Rim of Tennessee. *Eleocharis erythropoda* is found infrequently in Tennessee and rarely in the Western Highland Rim (TFC 2015, TENN 2016, Kartesz 2015, USDA, NRCS 2016).

Table 7. Rare plant species found in 14 Western Tennessee Highland Rim seepage fens. Global rank G2 is imperiled, G3 is vulnerable, G4 is apparently secure, G5 is secure. State status S is special concern species; E is endangered species. State rank S1 is extremely rare and critically imperiled, S2 is very rare and imperiled, S3 is rare and uncommon, in Tennessee. Federal status LE is listed endangered.

Species	Common Name	Global Rank	State Status	State Rank	Federal Status	Sites
Eleocharis tortilis	Twisted Spike-Rush	G5	S	S1	--	D1
Fuirena squarrosa	Hairy Umbrella-Sedge	G4G5	S	S1	--	D4, D2
Juncus brachycephalus	Smallhead Rush	G5	S	S2	--	A3, BC, LB, D1
Lathyrus palustris	Marsh Pea	G5	S	S1	--	BC
Parnassia grandifolia	Largeleaf Grass of Parnassus	G3	S	S3	--	A1, A2, A3, D1, D2, LB, R2
Xyris tennesseensis	Tennessee Yellow-Eyed Grass	G2	E	S1	LE	D2, LB, A3, A2, A1

Table 8. New county records for taxa found in seepage fens in the Western Highland Rim in Tennessee.

Species or Infraspecific Taxon	County	Frequency (TFC 2015)
Andropogon glomeratus var. *pumilus*	Lewis	Common in the Cumberland Plateau and Mountains, unknown in the Western Highland Rim.
Antennaria parlinii	Lewis	Apparently common statewide but exact distribution in need of further documentation.
Coleataenia anceps	Lewis	Common statewide.
Eleocharis erythropoda	Lewis	Infrequent across northern half of TN but extending south throughout most of the Cumberland Plateau and Mountains.
Eleocharis tortilis	Lewis	Rare in the Coastal Plain (McNairy Co.) This is one of Tennessee's rarest species of *Eleocharis*.
Lathyrus palustris	Williamson	Rare Eastern Highland Rim and East TN.
Platanus occidentalis	Lewis	Common statewide.
Schizachyrium scoparium	Lewis	Common statewide.

Invasive species

The three non-native species, collected from eight sites, were classified as invasive by the Tennessee Exotic Pest Plant Council (TN-EPPC 2009). They comprise 1.9% of the total taxa. *Arthroxon hispidus* is ranked as a significant threat by TN-EPPC. *Lonicera japonica* and *Microstegium vimineum* are ranked as a severe threat (Table 9).

Table 9. Exotic invasive vascular plant species found in 14 Western Highland Rim fens with TN-EPPC rank.

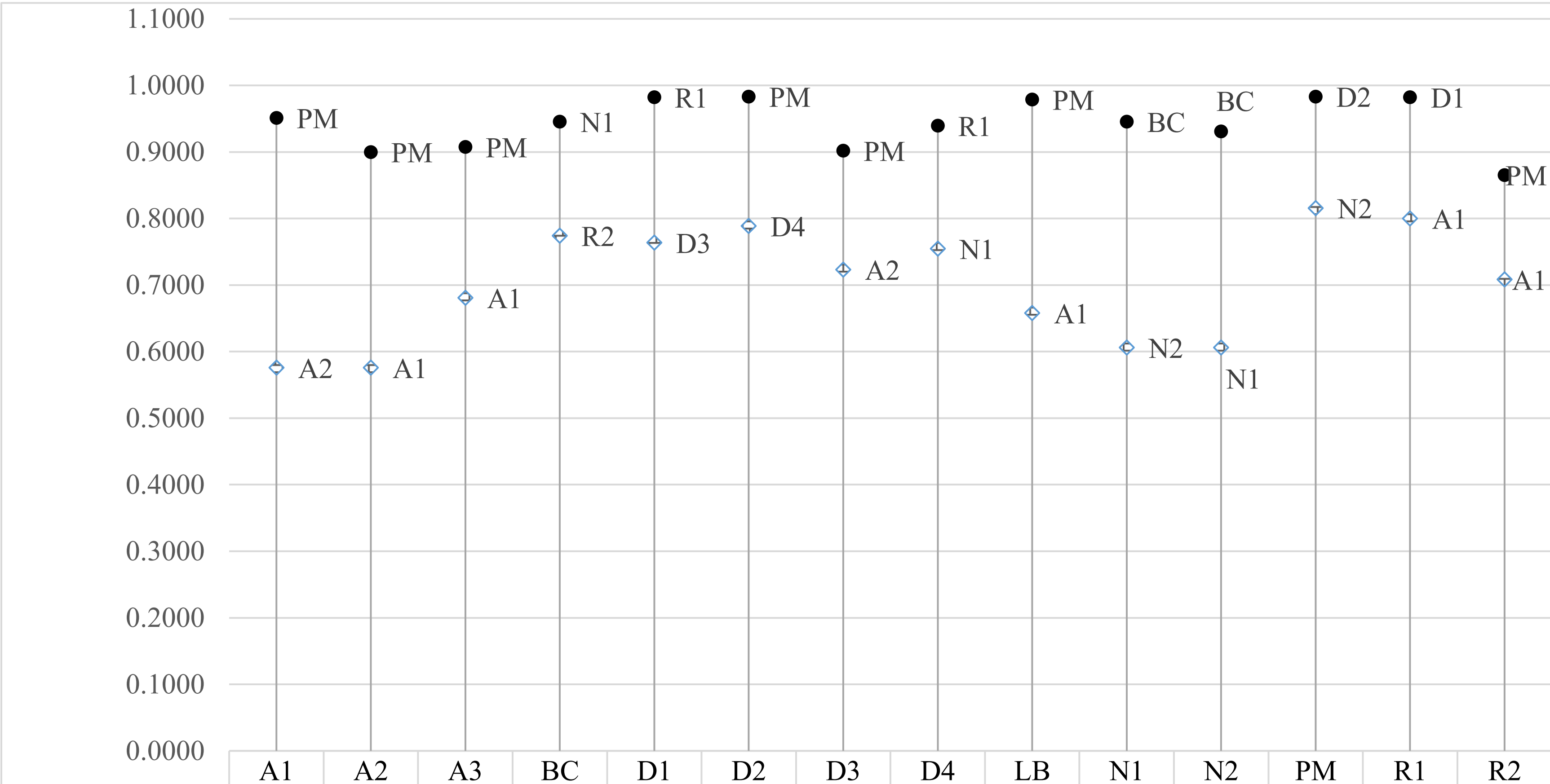
Species	Common name	Family	Sites	Invasive Rank
Arthraxon hispidus	Small Carpet-Grass	Poaceae	BC	Significant Threat
Lonicera japonica	Japanese Honeysuckle	Caprifoliaceae	D3, R1	Severe Threat
Microstegium vimineum	Nepalese Browntop	Poaceae	R2, A2, D4, LB, N1, R2	Severe Threat

Ecological indices

β-diversity, using 1-Jaccard's index, was calculated between all 14 sites for a total of 91 indices (Table 10). The highest similarity between sites, in terms of taxon composition based on estimates of β-diversity, was found for the Auntney Hollow sites A1 and A2 (0.5758) (Table 10). The most dissimilar, or the highest β-diversity, between sites was found for Powdermill Branch (PM) and a Dry Branch site (D2) (0.9833). An Auntney Hollow site (A1) had the greatest similarity to the most sites (A2, A3, LB, R1, and R2) and Powdermill Branch (PM) had the highest β-diversity for the most sites (A1, A2, A3, D2, D3, LB, and R2) (Fig. 14).

A cluster analysis of the 1-Jaccard's indices was used to demonstrate the similarity between the 14 sites. The results are plotted as a dendrogram (Fig. 15). Sites were clustered in four major distinguishable groups: (1) A1/A1/A3/LB/BC, (2) N1/N2/D3/R2/D2/D4/D1, (3) R1 and, (4) PM. Within these clusters, two of the adjacent Auntney Hollow sites are clustered, the two adjacent Natchez Trace sites are clustered, two of the Dry Branch sites, located on separate forks of the stream and separated by 1.46 km, are clustered, and a Dry Branch site is clustered with a Rattlesnake Falls site.

The Floristic Quality Index (FQI) and the mean Coefficient of Conservatism (CC) was calculated for each site. Dry Branch 4 (D4), the largest seep located on the headwaters of Dry Branch, had the highest FQI (37) and Powdermill Branch (PM) had the lowest FQI (24). All 14 sites have a CC greater than 3.5 and six of the 14 sites (A3, BC, D1, D2, D3, and D4) have a FQI of 35 or higher (Table 11).



	A1	A2	A3	BC	D1	D2	D3	D4	LB	N1	N2	PM	R1	R2
Most similar	0.5758	0.5758	0.6809	0.7742	0.7636	0.7887	0.7234	0.7547	0.6579	0.6061	0.6061	0.8158	0.8000	0.7083
Least similar	0.9512	0.9000	0.9074	0.9455	0.9821	0.9833	0.9020	0.9394	0.9787	0.9455	0.9310	0.9833	0.9821	0.8654

Fig. 14. Highest and lowest β-diversity, using 1 – Jaccard's index, for each of the 14 seepage fen sites in the Western Highland Rim of Tennessee. Horizontal axis labels are site identifiers described in Table 1.

Table 10. β-diversity, using 1 – Jaccard's index for 14 seepage fen sites in the Western Highland Rim of Tennessee shown below the diagonal. A higher number equals a higher diversity between sites and a lower number equals a greater similarity between sites. The diagonal shows in bold the total number of species from each flora. Above the diagonal shows in italics the total number of shared taxa. Site identifiers are described in Table 1.

Site	A1	A2	A3	BC	D1	D2	D3	D4	LB	N1	N2	PM	R1	R2
A1	**23**	*14*	*15*	*10*	*8*	*10*	*12*	*6*	*13*	*5*	*9*	*2*	*8*	*14*
A2	0.5758	**24**	*14*	*8*	*7*	*7*	*13*	*10*	*10*	*6*	*7*	*4*	*5*	*13*
A3	0.6809	0.7143	**39**	*10*	*9*	*11*	*12*	*10*	*14*	*10*	*12*	*5*	*8*	*16*
BC	0.8000	0.8491	0.8485	**37**	*7*	*6*	*13*	*9*	*8*	*3*	*4*	*4*	*5*	*14*
D1	0.8298	0.8571	0.8548	0.8871	**32**	*10*	*13*	*12*	*7*	*10*	*8*	*3*	*1*	*9*
D2	0.8148	0.8793	0.8406	0.9167	0.8413	**41**	*9*	*15*	*8*	*5*	*5*	*1*	*3*	*11*
D3	0.7447	0.7234	0.8095	0.7833	0.7636	0.8676	**36**	*13*	*8*	*10*	*11*	*5*	*6*	*16*
D4	0.9032	0.8305	0.8649	0.8767	0.8154	0.7887	0.8088	**45**	*9*	*13*	*8*	*6*	*4*	*12*
LB	0.6579	0.7619	0.7358	0.8596	0.8679	0.8689	0.8571	0.8594	**28**	*6*	*8*	*1*	*4*	*10*
N1	0.8718	0.8462	0.8000	0.9455	0.7674	0.9123	0.7872	0.7547	0.8605	**21**	*13*	*5*	*4*	*12*
N2	0.7692	0.8333	0.7692	0.9310	0.8367	0.9180	0.7800	0.8710	0.8222	0.6061	**25**	*7*	*7*	*12*
PM	0.9512	0.9000	0.9074	0.9245	0.9388	0.9833	0.9020	0.8983	0.9787	0.8611	0.8158	**20**	*1*	*7*
R1	0.8000	0.8864	0.8571	0.9123	0.9821	0.9524	0.8909	0.9394	0.9184	0.9048	0.8372	0.9773	**25**	*10*
R2	0.7083	0.7400	0.7419	0.7742	0.8548	0.8406	0.7288	0.8333	0.8246	0.7500	0.7692	0.8654	0.8148	**39**

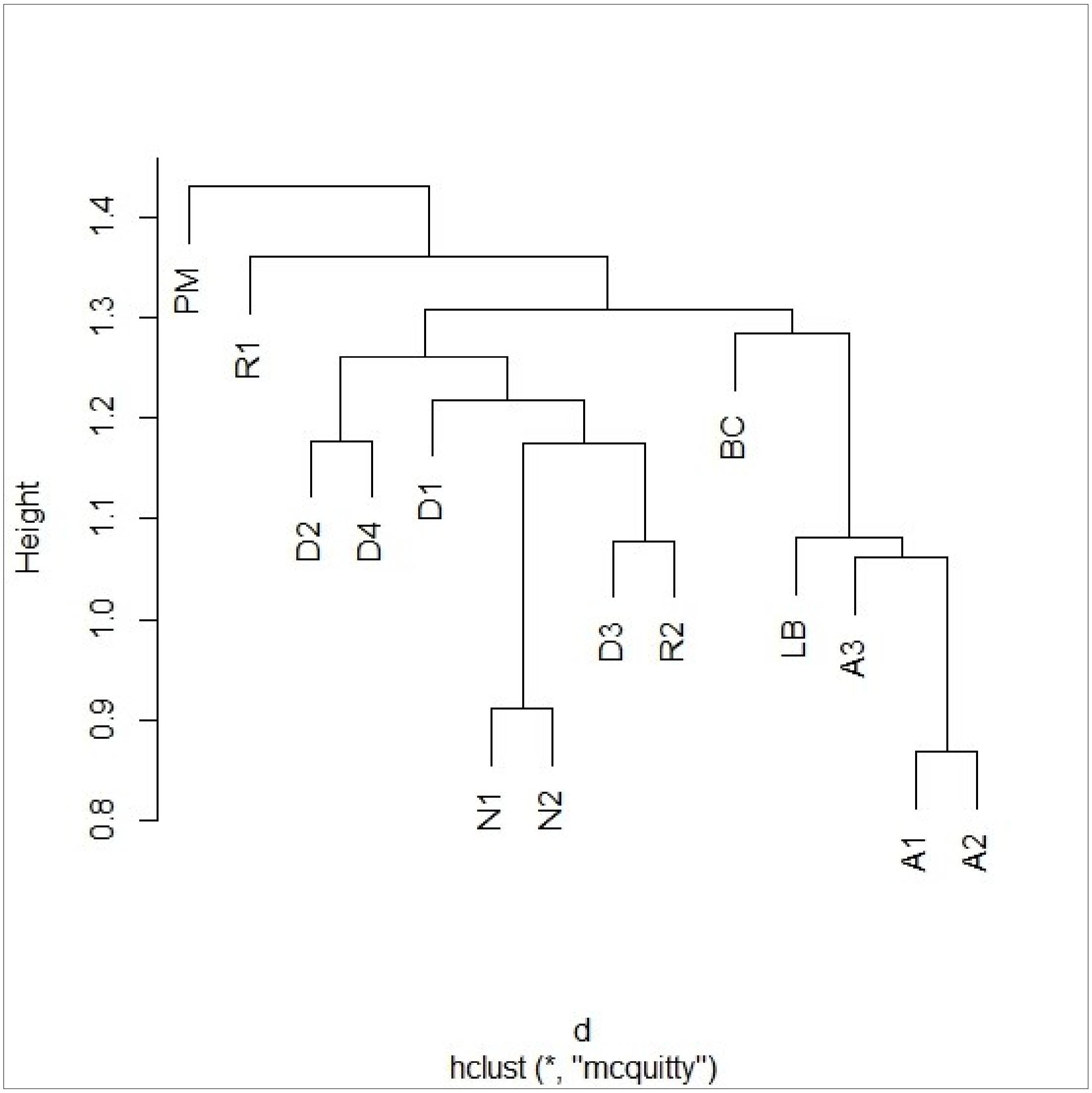


Fig. 15. Dendrogram of hierarchical cluster analysis showing the similarity of 14 seepage fens in the Western Highland Rim of Tennessee. Branch labels are site identifiers described in Table 1.

Table 11. Mean Coefficient of Conservatism (CC) as compared to Floristic Quality Index (FQI) for 14 seepage fens in the Western Highland Rim of Tennessee.

Site	CC	Taxon count	Mean CC	FQI
A1	129	22	6	27.50
A2	131	22	6	27.32
A3	227	38	6	36.82
BC	213	36	6	35.02
D1	195	31	6	35.02
D2	231	41	6	36.08
D3	212	35	6	35.33
D4	248	44	6	36.97
LB	161	27	6	30.43
N1	112	20	6	24.44
N2	144	25	6	28.80
PM	109	20	5	24.37
R1	134	23	6	27.15
R2	217	38	6	34.75

Comparison to similar floras

Families with the highest percentage of total taxa, Cyperaceae, Poaceae, and Asteraceae are compared with four fen floras from the Midwestern United States (Fig. 16) (Amon et al. 2002). The total unique taxa of WHR fens (160) was compared to three fen floras: (1) Southwestern Missouri Ozark prairie fens (Orzell & Kurz 1986), (2) Cedar Bog, Ohio (Frederick 1974), and (3) a Bog-Fen Community on Bluff Mountain, North Carolina (Tucker 1972). Common taxa from the three compared floras numbered 50 for (1) Missouri Ozarks Fens, 16 for (2) Bluff Mountain, North Carolina and 58 for the (3) Cedar Bog, Ohio (Table 12). Similarity was evaluated using Sørensen's Similarity index (Table 13).

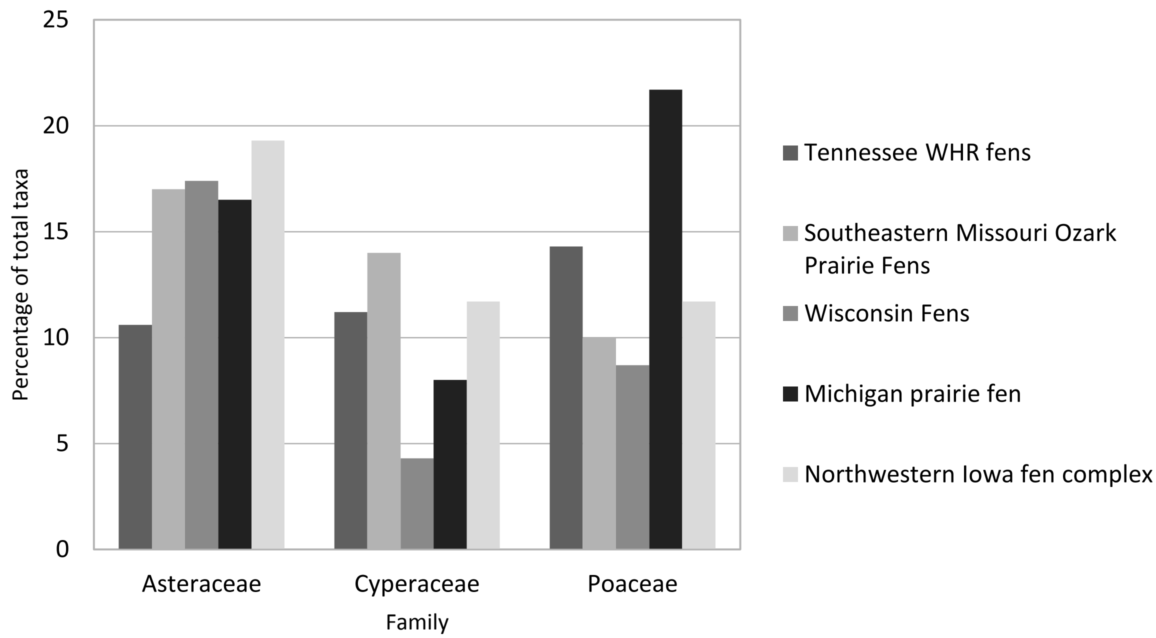


Fig. 16. A percentage comparison of three families, Asteraceae, Cyperaceae, and Poaceae, for four Midwestern fen floras (Amon et al., 2002) and a flora of Western Highland Rim of Tennessee fens.

Table 12. Plant species and infraspecific taxa in common to 14 seepage fens in the Western Highland Rim of Tennessee as compared to (1) Ozark Prairie Fens, (2) Bluff Mountain, North Carolina Bog-Fen, and (3) Cedar Bog, Ohio. A '1' indicates the presence of a taxon.

Species or Infraspecific Taxon	Ozark Prairie Fens	Bluff Mountain, North Carolina	Cedar Bog, Ohio
Acer rubrum	0	0	1
Acer saccharum ssp. *saccharum*	0	0	1
Adiantum pedatum	0	0	1
Ageratina altissima var. *altissima*	0	0	1
Alnus serrulata	0	1	0
Amphicarpaea bracteata	1	0	1
Apios americana	1	0	1
Asarum canadense	0	0	1
Cardamine bulbosa	1	0	1
Carex crinita var. *brevicrinis*	1	0	0
Carex granularis	1	0	0
Carex leptalea	1	1	0
Carex lurida	1	1	1
Carex stricta	1	1	0
Carex torta	1	0	0
Carpinus caroliniana	0	0	1
Chelone glabra	1	0	1
Cicuta maculata	1	0	1
Cinna arundinacea	0	0	1
Cirsium muticum	1	0	0
Coleataenia anceps ssp. *anceps*	1	0	0
Conoclinium coelestinum	1	0	0
Cornus alternifolia	0	0	1
Cornus amomum	0	0	1
Cornus florida	0	0	1
Corylus americana	0	0	1
Cyperus strigosus	1	0	1
Cystopteris bulbifera	0	0	1

Table 12. continued

Dioscorea villosa	1	0	1
Eleocharis erythropoda	0	0	1
Eupatorium perfoliatum	1	0	1
Fraxinus americana	0	0	1
Galium triflorum	1	0	1
Geum virginianum	0	0	1
Glyceria striata	1	0	1
Helenium autumnale	1	0	1
Houstonia caerulea	0	1	0
Ilex decidua	1	0	0
Impatiens capensis	1	0	1
Juncus brachycephalus	0	0	1
Juncus effusus	1	0	1
Juncus subcaudatus	1	0	0
Juniperus virginiana	1	0	0
Kalmia latifolia	0	1	0
Lathyrus palustris	1	0	0
Leersia virginica	0	0	1
Lindera benzoin	0	0	1
Liriodendron tulipifera	0	0	1
Lobelia puberula	0	0	1
Lobelia siphilitica	1	0	1
Mimulus ringens	1	0	1
Muhlenbergia sylvatica	0	0	1
Osmunda regalis var. *spectabilis*	1	1	1
Osmundastrum cinnamomeum	0	1	1
Oxypolis rigidior	1	1	1
Panicum flexile	0	0	1
Parnassia grandifolia	1	1	0
Pedicularis canadensis	0	0	1
Phlox divaricata var. *divaricata*	0	0	1
Phlox glaberrima	1	0	0
Pilea pumila	0	0	1

Table 12. continued

Platanus occidentalis	1	0	1
Poa sylvestris	0	0	1
Polystichum acrostichoides	0	0	1
Potentilla simplex	1	0	0
Pycnanthemum tenuifolium	1	0	0
Quercus alba	1	1	0
Rhynchospora capitellata	1	1	0
Rudbeckia laciniata	0	0	1
Rudbeckia palustris	1	0	1
Salix caroliniana	1	0	0
Salix sericea	1	0	1
Salvia lyrata	1	0	0
Schizachyrium scoparium var. *scoparium*	1	0	1
Scirpus atrovirens	1	0	1
Smilax rotundifolia	0	0	1
Solidago caesia	0	0	1
Solidago patula	1	1	1
Solidago rugosa var. *rugosa*	1	1	1
Spiranthes cernua	1	1	0
Symphyotrichum lateriflorum	1	0	0
Thelypteris palustris var. *pubescens*	1	0	0
Viola cucullata	1	0	1
Xyris torta	1	1	0
Zizia aurea	0	0	1
Totals	50	16	58

Table 13. A comparison of total taxa (160) of 14 seepage fens in the Western Highland Rim of Tennessee to similar plant communities in Missouri, Ohio, and North Carolina with a Sørensen's Similarity Index.

Flora	Total Taxa	Shared Species	Sørensen's Index
Ozark Prairie Fens	243	50	0.25
Bog-Fen Community, Bluff Mountain, North Carolina	57	16	0.15
Cedar Bog, Ohio	546	58	0.16

Phytogeography

There are seepage fen taxa with both northern and southern phytogeographic distributions from this flora (Table 14). Nine taxa (5.63% of the 160 total taxa), were identified with a northern distribution, of which *Juncus subcaudatus* and *Lathyrus palustris* were disjunct. Fifteen taxa (9.38%) were identified with a southern distribution, of which *Eleocharis tortilis, Parnassia grandifolia*, and *Xyris tennesseensis* were disjunt. A widespread distribution was attributed to 133 taxa (83.13%), and three exotic invasive species (1.9%) were observed.

Table 14. Southern and northern biogeographic distributed vascular plant taxa with wetland status from 14 Western Highland Rim of Tennessee seepage fens. Highlighted taxa are disjunct populations.

Biogeographic distribution	Species or infraspecific taxon	Wetland status
Northern	*Antennaria parlinii* ssp. *parlinii*	n/a
	Carex bromoides ssp. *bromoides*	FACW
	Cystopteris bulbifera	FAC
	Danthonia spicata	n/a
	Eleocharis erythropoda	OBL
	Juncus subcaudatus	OBL
	Lathyrus palustris	FACW
	Thelypteris noveboracensis	FAC
	Valerianella umbilicata	FAC
	Total: 9	
Southern	*Andropogon glomeratus* var. *pumilus*	FACW
	Eleocharis tortilis	FACW
	Elephantopus tomentosus	n/a
	Fuirena squarrosa	OBL
	Juncus coriaceus	FACW
	Lobelia puberula	FACW
	Melica mutica	n/a
	Parnassia grandifolia	OBL
	Phlox amoena	n/a
	Rhododendron alabamense	n/a
	Rhododendron canescens	FACW
	Rudbeckia palustris	FAC
	Saccharum alopecuroides	FAC
	Vitis rotundifolia	FAC
	Xyris tennesseensis	OBL
	Total: 15	
	Grand total: 24	

Comparison to USNVC communities

Using the USNVC (2016) ecological systems classification, the 14 study sites would fit into four ecological systems (Table 15). Eight sites (A1, A2, A3, BC, D1, D2, LB, and R2) are a good match for the Interior Low Plateau Seepage Fen ecological system. One site (R1) best fits the Highland Rim Limestone Cliff/Talus Seep ecological system. Five sites (N1, N2, PM, D3, and D4) fit equally well into two ecological systems, the Cumberland Seepage Forest or the Interior Highlands Forested Acidic Seep.

In addition, a qualitative classification for the 14 study sites is offered. This classification emphasizes landform position, pH, and physiognomy, similar to the landtype association classification of Smalley (1980). This classification fits within Estes's (2015) Vegetation of Tennessee developing scheme of community classification. Based on this system, six types of seepage fens are recognize (Table 15) and described below.

Table 15. A qualitative assessment 14 seepage fens in the Western Highland Rim of Tennessee as communities with comparison to the USNVC classification standards (Jennings et al. 2009).

Site codes	Proposed seepage fen community for the Vegetation of Tennessee (Estes 2015)	Most similar USNVC (2016) ecological system(s)	Most similar USNVC (2016) ecological association
A1, A2, A3, D1, LB, R2	Western Highland Rim Circumneutral Gravel Seepage Fen	Interior Low Plateau Seepage Fen	*Carex lurida - Carex leptalea - Parnassia grandifolia - Juncus brachycephalus - (Xyris tennesseensis)* Herbaceous Vegetation
D2	Western Highland Rim Limestone Glade Seepage Fen	Interior Low Plateau Seepage Fen	*Carex lurida - Carex leptalea - Parnassia grandifolia - Juncus brachycephalus - (Xyris tennesseensis)* Herbaceous Vegetation
R1	Western Highland Rim Seepage Cliff	Highland Rim Limestone Cliff/Talus Seep	*Hydrangea arborescens / Impatiens* (*capensis*, pallida) - *Heuchera villosa* Shrubland
N1, N2, PM	Western Highland Rim Seepage Forest	(1) Cumberland Seepage Forest (2) Interior Highlands Forested Acidic Seep	*(1) Acer rubrum var. trilobum - Nyssa sylvatica / Osmunda cinnamomea - Chasmanthium laxum - Carex intumescens / Sphagnum lescurii* Forest *(2)Acer rubrum* var. *trilobum - Liquidambar styraciflua - Magnolia tripetala / Osmunda regalis - (Cypripedium kentuckiense) Forest*
D4	Western Highland Rim Seepage Woodland	Cumberland Seepage Forest	*Acer rubrum* var. *trilobum - Nyssa sylvatica / Osmunda cinnamomea - Chasmanthium laxum - Carex intumescens / Sphagnum lescurii* Forest
BC	Western Highland Rim Stepped Seepage Fen	Interior Low Plateau Seepage Fen	*Carex lurida - Carex leptalea - Parnassia grandifolia - Juncus brachycephalus - (Xyris tennesseensis)* Herbaceous Vegetation

Western Highland Rim Circumneutral Gravel Seepage Fen: This was the proposed community for seven sites (Table 15). These communities were small-patch, circumneutral, sloping communities with a semi-open canopy located near rock-bottomed streams. The substrate contains muck and cherty gravel and is saturated by groundwater. Typical species were *Parnassia grandifolia*, *Rudbeckia palustris, Carex atlantica* var. *atlantica, Carex lurida, Carex prasina, Impatiens capensis, Oxypolis rigidior,* and *Xyris tennesseensis.*

Based on characteristic species, the USNVC Interior Low Plateau Seepage Fen association *Carex lurida - Carex leptalea - Parnassia grandifolia - Juncus brachycephalus - (Xyris tennesseensis)* Herbaceous Vegetation was a good match for these study sites (Table 16). Association taxa, *Carex lurida* occurred in five sites, *Carex leptalea* in one sites, *Parnassia grandifolia* in six sites, *Juncus brachycephalus* in three sites, and *Xyris tennesseensis* in four sites.

Western Highland Rim Limestone Glade Seepage Fen: This was the proposed community for one site (D2) (Table 15). This community was small-patch, circumneutral, near level community with a semi-open canopy located near rock-bottomed streams. The substrate, for the most part, was thin, mucky soil with limestone bedrock exposed in some areas. Typical species are *Parnassia grandifolia*, *Carex blanda, Fuirena squarrosa, Juncus coriaceus, Spiranthes cernua* and *Xyris tennesseensis.*

Based on characteristic species, the USNVC Interior Low Plateau Seepage Fen association *Carex lurida - Carex leptalea - Parnassia grandifolia - Juncus brachycephalus - (Xyris tennesseensis)* Herbaceous Vegetation was a good match for this study sites (Table 17).

Association taxa, *Carex leptalea, Parnassia grandifolia,* and *Xyris tennesseensis* occured in this site.

Table 16. A comparison of USNVC characteristic species for Interior Low Plateau Seepage Fen community to eight seepage fen sites in the Western Highland Rim of Tennessee. A '1' indicates presence of a taxon. Association taxon are highlighted.

Species or Infraspecific taxon	A1	A2	A3	BC	D1	D2	LB	R2	**Total**
Acer rubrum	0	0	0	0	1	0	1	0	4
Alnus serrulata	1	0	1	0	1	1	0	0	5
Cardamine bulbosa	1	1	1	1	0	0	1	0	6
Carex atlantica ssp. *atlantica*	1	1	1	1	1	0	0	1	9
Carex lurida	1	1	0	1	1	0	1	1	10
Carex leptalea	0	0	0	1	1	1	0	0	5
Cornus amomum	0	1	0	1	0	0	0	0	3
Impatiens capensis	1	1	1	1	0	0	1	1	8
Juncus brachycephalus	0	0	1	1	1	0	1	0	4
Juncus coriaceus	1	1	1	0	1	1	1	1	11
Juncus effusus	0	0	0	0	1	0	0	0	2
Oxypolis rigidior	1	1	1	0	0	1	1	1	10
Parnassia grandifolia	1	1	1	0	1	1	1	1	7
Phlox glaberrima	0	0	1	0	0	0	1	1	4
Rhynchospora capitellata	0	0	0	0	1	1	1	0	4
Rudbeckia palustris	1	1	1	1	0	1	1	1	8
Salix caroliniana	0	0	0	1	0	0	0	0	1
Scirpus atrovirens	0	0	0	1	0	0	1	0	2
Solidago patula	1	0	0	1	1	1	0	1	7
Thelypteris palustris var. *pubescens*	0	0	1	1	0	0	1	0	3
Xyris tennesseensis	1	1	1	0	0	1	1	0	5
Total	11	10	12	12	11	9	14	9	

Western Highland Rim Seepage Cliff. This was the proposed community for one site (R1) (Table 15). This community was a small-patch, circumneutral community with a semi-open canopy located near a rock-bottomed stream and adjacent to a waterfall. This site had a steep slope and thin, saturated soils with areas of deeper muck. Typical species were *Impatiens capensis*, *Hydrangea cinerea, Kalmia latifolia, and Cornus alternifolia.*

Based on characteristic species, the USNVC Highland Rim Limestone Cliff/Talus Seep association *Hydrangea arborescens / Impatiens (capensis, pallida) - Heuchera villosa* Shrubland was the best match for this site. The association species *Impatiens capensis* occurred in this site.

Western Highland Rim Seepage Forest. This was the proposed community for four sites (D3, N1, N2, and PM) (Table 15). These were small-patch, circumneutral to acidic communities with a closed canopy located near rock-bottomed streams. The substrate was saturated muck. Typical taxa were *Athyrium filix-femina var. asplenioides*, *Carex debilis var. debilis, Osmundastrum cinnamomeum* and *Osmunda regalis.*

The best system match for site D3 was the USNVC Interior Highlands Forested Acidic Seep located in the Ozark and Ouachita Mountains of Arkansas, a distance of at least 475 km. Site D3 matched this system for spatial pattern, pH, canopy cover, landscape position, and moisture (Table 17). Based on characteristic species, Interior Highlands Forested Acidic Seep association *Acer rubrum var. trilobum - Liquidambar styraciflua - Magnolia tripetala / Osmunda regalis - (Cypripedium kentuckiense)* Forest was the best match for this site. The association species *Osmunda regalis* occurred in this site.

Site N1 matched the USNVC Cumberland Seepage Forest system on spatial pattern, pH, canopy cover, and moisture. Site N1 matches the Interior Highlands Forested Acidic Seep located in the Ozark and Ouachita mountains of Arkansas, a distance of at least 475 km, on spatial pattern, canopy cover, landscape position, and moisture (Table 18). Site N1 matched both systems on four characteristics, however when the vegetation was compared to each system based on characteristic and dominant species, site N1 was more similar to the Interior Highlands

Forested Acidic Seep. Based on characteristic species, Interior Highlands Forested Acidic Seep system association *Acer rubrum var. trilobum - Liquidambar styraciflua - Magnolia tripetala / Osmunda regalis - (Cypripedium kentuckiense)* Forest was the best match for this site. The association species *Acer rubrum,* and *Osmunda regalis* occurred in this site.

The best USNVC system match for site N2 was the Interior Highlands Forested Acidic Seep located in the Ozark and Ouachita Mountains of Arkansas, a distance of at least 475 km (Table 18). Site N2 matched this system for spatial pattern, pH, canopy cover, landscape position, and moisture. Based on characteristic species, the Interior Highlands Forested Acidic Seep association *Acer rubrum var. trilobum - Liquidambar styraciflua - Magnolia tripetala / Osmunda regalis - (Cypripedium kentuckiense) Forest* was the best match for this site (Table 19). The association species *Osmunda regalis* occurred in this site.

Table 17. A comparison of abiotic characteristics for a seepage fen at Dry Branch in Lewis County, Tennessee (D3) to three USNVC Ecological Systems.

Site characteristics for Dry Branch (D3)		USNVC Ecological Systems		
		Cumberland Seepage Forest	Interior Highlands Forested Acidic Seep	East Gulf Coastal Plain Northern Seepage Swamp
Spatial pattern	small patch	yes	yes	no
pH	acidic	no	yes	yes
Canopy cover	open	yes	yes	yes
Position	perched on ephemeral drainage	no	yes	no
Soils	Loamy residuum weathered from cherty limestone; muck	no	n/a	no
Moisture	saturated	yes	yes	yes

Table 18. A comparison of abiotic characteristics for a seepage fen at Natchez Trace in Lewis County, Tennessee (N1) to three USNVC Ecological Systems.

Site characteristics for Natchez Trace (N1)		USNVC Ecological Systems		
		Cumberland Seepage Forest	Interior Highlands Forested Acidic Seep	East Gulf Coastal Plain Northern Seepage Swamp
Spatial pattern	small patch	yes	yes	no
pH	circumneutral	yes	no	no
Canopy cover	closed	yes	yes	yes
Position	footslope	no	yes	yes
Soils	Loamy colluvium derived from cherty limestone	no	n/a	no
Moisture	saturated	yes	yes	yes

Table 19. A comparison of abiotic characteristics for a seepage fen at Natchez Trace in Lewis County, Tennessee (N2) to three USNVC Ecological Systems.

Site characteristics for Natchez Trace (N2)		USNVC Ecological Systems		
		Cumberland Seepage Forest	Interior Highlands Forested Acidic Seep	East Gulf Coastal Plain Northern Seepage Swamp
Spatial pattern	small patch	yes	yes	no
pH	acidic	no	yes	yes
Canopy cover	closed	yes	yes	yes
Position	footslope	no	yes	yes
Soils	Loamy colluvium derived from cherty limestone	no	n/a	no
Moisture	saturated	yes	yes	yes

Site PM shared the most abiotic characteristics with the USNVC Cumberland Seepage Forest system. Site PM matched this system for spatial pattern, pH, canopy cover, soils, and moisture (Table 20). The Cumberland Seepage Forest is located in the Cumberland Plateau or Ridge and Valley ecoregion, not in the WHR. However, the WHR bounds the Cumberland Plateau on its southern boarder (Nicholson et al. 2007). Based on characteristic species, the Cumberland Seepage Forest association *Acer rubrum* var. *trilobum - Nyssa sylvatica / Osmunda cinnamomea - Chasmanthium laxum - Carex intumescens / Sphagnum lescurii* Forest is the best match for this site (Table 15). The association species *Osmundastrum cinnamomeum,* and *Carex intumescens* occur in this site.

Table 20. A comparison of abiotic characteristics for a seepage fen at Powdermill Branch in Lewis County, Tennessee (PM) to three USNVC Ecological Systems.

Site characteristics for Powdermill Branch (PM)		USNVC Ecological Systems		
		Cumberland Seepage Forest	Interior Highlands Forested Acidic Seep	East Gulf Coastal Plain Northern Seepage Swamp
Spatial pattern	small patch	yes	yes	no
pH	Circumneutral	yes	no	no
Canopy cover	open	yes	Yes	yes
Position	footslope	no	Yes	yes
Soils	Loamy alluvium derived from limestone, sandstone, and shale	yes	n/a	no
Moisture	Saturated	yes	Yes	yes

Western Highland Rim Seepage Woodland. This is the proposed community for one site (D4) (Table 15). This is a small-patch, circumneutral, gentle sloping community with a semi-open canopy located near a rock-bottomed stream. The saturated substrate is composed primarily of muck. Typical species are *Juncus subcaudatus*, *Rudbeckia palustris, Carex atlantica* var. *atlantica, Carex granularis, Carex leptalea, Carex lurida,* and *Lathyrus palustris.*

D4 share the most abiotic characteristics with the Cumberland Seepage Forest ecological system located in Cumberland Plateau or Ridge and Valley ecoregion. D3 matched this system for spatial pattern, pH, canopy cover, landscape position, and moisture (Table 21). Based on characteristic species, the Cumberland Seepage Forest association *Acer rubrum var. trilobum - Nyssa sylvatica / Osmunda cinnamomea - Chasmanthium laxum - Carex intumescens / Sphagnum lescurii Forest* is a good match for this study sites. Association taxa *Carex leptalea, Carex lurida* and *Juncus brachycephalus* occur in this site.

Table 21. A comparison of abiotic characteristics for a seepage fen at Dry Branch in Lewis County, Tennessee (D4) to three USNVC Ecological Systems.

Site characteristics for Dry Branch (D4)		USNVC Ecological Systems		
		Cumberland Seepage Forest	Cumberland Seepage Forest	Cumberland Seepage Forest
Spatial pattern	small patch	yes	yes	no
pH	circumneutral	yes	no	no
Canopy cover	open	yes	yes	yes
Position	side slope of stream	yes	yes	yes
Soils	Loamy residuum weathered from cherty limestone; muck	no	n/a	no
Moisture	saturated	yes	yes	yes

Western Highland Rim Stepped Seepage Fen. This is the proposed community for one site (BC) (Table 15). This is a small-patch, alkaline, stepped sloping community with a semi-open canopy located near a rock-bottomed stream. The saturated substrate is composed primarily of muck. Typical species are *Juncus subcaudatus*, *Rudbeckia palustris, Carex atlantica* var. *atlantica, Carex granularis, Carex leptalea, Carex lurida,* and *Lathyrus palustris. Parnassia grandifolia* is notably absent from this site.

Based on characteristic species, the Interior Low Plateau Seepage Fen association *Carex lurida - Carex leptalea - Parnassia grandifolia - Juncus brachycephalus - (Xyris tennesseensis)* Herbaceous Vegetation is a good match for this study sites. Association taxa *Carex leptalea, Carex lurida* and *Juncus brachycephalus* occur in this site.

CHAPTER V

DISCUSSION

The WHR seepage fens which range in pH from 6.4 to 7.5, fit the classification of a rich fen (Nelson 2010, Bedford & Godwin 2003, Amon et al. 2002). These fens are dominated by forbs and graminoids, with most classified as either obligate or facultative wetland taxa. They are intact communities as indicated by the (1) presence of rare and ecological endemic species, (2) high vascular plant diversity relative to area, and (3) low percentage of invasive species. Of the ten rare taxa identified as possible seepage fen taxa, five were observed. Missing from the fen flora were *Liparis loeselii, Marshallia trinervia, Minuartia muscorum, Scleria verticillata,* and *Spiranthes lucida*. These species may be absent from the fens, or may have been undetected due to small population size or their ephemeral nature. However, *Marshallia trinervia* was observed near the Auntney Hollow sites on Little Swan Creek and *Spiranthes lucida* was observed downstream from the Brush Creek site.

The WHR fens are botanically diverse as exhibited by the high number of taxa for the comparatively small area surveyed. The total area surveyed for the Tennessee WHR is 0.45 hectares comprising 160 taxa, as compared to the southwestern Missouri Ozarks prairie fens, where the smallest of the 7 sites was 0.6 hectares, comprising 242 taxa from all sites. The WHR fens are also taxonomically diverse in terms of family richness. The ratio of family to species is close to 1:2 (58 families, 160 species and infraspecific taxon), as compared to other fen floras such as the southwestern Missouri Ozarks prairie fens, which has as a ratio closer to 1:4 (60 families, 242 species and infraspecific taxon) (Orzell & Kurz 1986).

The small percentage of invasive species (1.9%) is particularly low compared to other southeastern floras. Examples of invasive percentages from other floras are 3.8% (Rodgers in prep.), 8.1% (Anderson in prep.), 13% (Estes & Walck 2005), 13.3% (Blyveis & Shaw 2011), and 16.9% (Gunn 2003). The wide range of invasive percentages for the compared floras may be explained by flora type. The Tennessee River Gorge flora (Blyveis & Shaw 2011) contained 12 communities. Gunn (2003) describe 16 communities including an agriculture community that likely included invasive agriculture weeds. Estes and Walck's (2005) flora comprised six communities. Targeting specific communities may influence the relatively low percentage of invasive species for a flora. Another influential factor could be the generally isolated nature of the WHR fen sites. With few exceptions, the sites are remote and not easily accessible by roads or trails, which would act as a corridor for invasion by non-native species.

The WHR fen study sites exhibit a wide range of β-diversity. Cluster analysis indicates that spatial scale is the most important factor in determining β-diversity. One exception is the D3/R2 cluster. The two sites are separated by 38 km. However, both sites share similar landscapes, small perched seeps surrounded by woodlands, which may contribute to similar species composition.

All sites could be categorized as high quality sites based on their high mean CC and FQI. The highest quality sites, classified as natural area quality sites, would have a CC of 3.5 or higher or a FQI or 35 or higher (Wilhelm & Masters 1999). Six sites meet this criteria (Table 11.). Five of these sites are state natural areas, while one is privately owned. The private site at Brush Creek (BC) in Williamson County, has an FQI of 35.02. *Lathyrus palustris*, a species of special concern for the state was observed here.

Western Highland Rim fens share similarities with Midwestern and northern fens including hydrology, varying soil composition, and saturation (Godwin et al. 2002). Likewise, the vascular flora of the WHR fens have similar family composition to other fen floras. The three families with the highest percentage of total taxa; Cyperaceae, Poaceae, and Asteraceae are consistent with four fen floras from the Midwestern United States (Fig. 17) (Amon et al. 2002).

The WHR fens are floristically distinct when species are compared to other floras. A Sorenson's Similarity Index comparison of species to three fen floras was quite low, with the unglaciated Ozark Prairie Fen flora being the most similar. A similar comparison between Ohio fens to fens in Indiana, Illinois, Wisconsin, and Iowa had a comparatively high Sørensen's Similarity Index (0.472 to 0.675) (Amon et al. 2002). Also noteworthy, carnivorous taxa such as *Drosera* spp., and *Utricularia* spp. observed in a Wisconsin fen, Ohio bog-fens, and North Carolina bog-fens are noticeably absent from this study. The low similarity of the WHR fen species to other fen floras may be due to the latitudinal or elevation gradient, sampling differences, or dissimilarity of fen types. Glaciation during the Pleistocene likely has played a substantial role in floristic differences.

The southeastern United States contains areas of endemism and endangerment (Estill & Cruzan 2001) in hot-spots such as those found in the Central Basin of Tennessee and areas of the Coastal Plain. The WHR is not a hot-spot of floristic endemism, but the study sites contain ecological endemics, that is, species that require a specific habitat. Two such fen species, disjunct from southern populations, are *Xyris tennesseensis,* which has a limited distribution, and *Parnassia grandifolia* which has a widespread scattered distribution.

Like the surrounding forests and woodlands, the WHR fens have probably existed since the mid-Holocene. Comparison of phytogeographic patterns for this flora is problematic. Other than DeSelm (1988), there is little information about phytogeography and regionally affiliated taxa in other WHR floras. DeSelm (1988) indicated the presence of western (2.5%), northern (5.7%), and southern (28.8%) affiliated taxa within WHR barrens. Notably absent in the WHR fen flora are western affiliated taxa. This absence can be explained by the following: (1) western affiliated species immigrated eastward during the dry Hypsithermal and are typically found in drier prairie communities (Kaul et al. 1988) and the continuously saturated fen substrate soils did not create favorable habitat for the more xeric western species, and (2) a higher percentage of western taxa occurred on loess (3.8%) versus limestone substrate (1.6%), and the fen study sites have limestone substrate.

The WHR fens are, however, influenced by northern (5.63%) and southern taxa (9.38%). The northern influence is likely aided by a substrate continuously saturated by cold groundwater and the dissected nature of the landscape. Northern taxa move south during glaciation events and then migrated northward as the glaciers retreated (Braun 1947). This back and forth continued throughout the Pleistocene glacial cycles. While there was a possibility of northern refugia during glaciation processes (Anderson et al. 2006), it is widely held that after the last glaciation event (18,000-15,000 ybp), if not during previous glaciation cycles, these northern taxa dispersed from the unglaciated south to the current northern terminus (Delcourt & Delcourt 1979, Braun 1947). Most of the WHR fen taxa demonstrate a peninsular distribution pattern indicating that the taxa are the result of dispersal, not vicariance (Kaul et al. 1988). However, two of these northern taxa are disjunct populations, *Juncus subcaudatus* and *Lathyrus palustris*, suggesting they are possible relics of glacial or early postglacial times (Kaul et al 1988).

The number of southern taxa is twice as great as the northern taxa, consistent with DeSelm (1988). There is evidence that some southern taxa experienced a south-to-north migration pattern (Liu et al. 2013), although Braun (1937) contends that the migration occurred north-to-south. Both patterns of dispersal are possible. Distribution patterns also indicate that most southern taxa are a result of dispersal except for three disjunct species. Sorrie and Weakley (2001) recognize a widespread, disjunct distribution pattern of 58 Coastal Plain taxa to central Tennessee and Kentucky including *Eleocharis tortilis*, observed in this flora. This disjunct species, as well as *Xyris tennesseensis,* and *Parnassia grandifolia* may be relictual resulting from Pleistocene glaciation events.

More phytogeographic studies based on morphology, population variability, habitat, rates of evolution, genetics, and breeding systems are needed to better understand the connection between the southern affiliated taxa of this flora and the Coastal Plain ecoregion and likewise the relationship between the northern affiliated taxa and the glaciated north (Thorne 1989).

USNVC (2016) recognizes a single fen ecological system for the WHR (Interior Low Plateau Seepage Fen). Five forested sites, not a good match for this system, were compared to three similarly forested ecological systems, the Cumberland Seepage Forest located in the Cumberland Plateau or the Ridge and Valley, the Interior Highlands Forested Acidic Seep located in Ozark and Ouachita Mountains of Arkansas, and the East Gulf Coastal Plain Northern Seepage Swamp located in the Coastal Plain. It is recommended that a similar ecological system for the Interior Low Plateaus be described for the Western Highland Rim Seepage Forest and Western Highland Rim Seepage Woodland communities (Table 15). The USNVC Interior Forested Acidic Seep ecological system also includes examples from the Shawnee Hills of Kentucky. As part of this process, consideration should be given for inclusion of the Shawnee Hills of Kentucky examples with the WHR forested seepage fens. Vegetation plot surveys would need to be conducted for determination of new ecological system associations.

Conclusions

These fens are important wetlands that recharge groundwater and improve stream quality (Amon et al. 2002, Winter 2000). Because seepage fens are so small, and are not identifiable via remote sensing, it is likely that the number of these unique communities in the WHR is underestimated. Because these sites currently have a low percentage of invasive taxa, prevention is critical and caution should be used in management practices that might contribute to invasion by non-native taxa.

Seepage fens are dependent on complex water hydrology and this may be a key component to maintaining an open fen (Amon et al. 2002). Three sites (PM, D4, and N1), had large downed trees around the perimeter of the site. One hypothesis for this phenomenon could be that the hydrology associated with seepage fens contributes to root system failure of large trees in saturated soils. Tarklin soils, as found in six sites, are subject to windthrow during wet periods (Table 1) (Soil Survey Staff 2016b).

Because these fens depend on groundwater to maintain saturation, the hydrology of the study sites may be particularly precarious if the areal extent of the ground-water-flow system is local (Winters 2000). Increases in human population could put anthropogenic pressures upon groundwater. This could result in a lower water table, and thus, eliminate the water source required for fens (Bedford & Godwin 2003). Because fen species composition can be correlated to water chemistry, and vascular herbaceous species in particular, are correlated to nutrient status, fens may be susceptible to degradation by anthropogenic eutrophication, in the form of sewage or agriculture fertilizer runoff (Godwin et al. 2002). An additional threat to these sites may be woody encroachment. Shading by trees and shrubs is suspected to be harmful to *Xyris tennesseensis* (USFWS 1994). Measuring canopy cover may help monitor this possibility. The isolated nature of fens makes them vulnerable to rare plant population loss and restoration of lost taxa could be problematic.

LITERATURE CITED

Amon, J.P. C.A. Thompson, Q.J. Carpenter & J. Mine 2002. Temperate zone fens of the glaciated Midwestern USA. Wetlands, 22: 301–317.

Anderson, K.A. Thesis in preparation. Floristics and biogeography of riverscour communities on the Locust Fork of the Black Warrior River, Blount County, Alabama. M.S. thesis, Austin Peay State University, Clarksville, Tennessee.

Anderson, L.L. F.S. Hu, D.M. Nelson, R.J. Petit & K.N. Paige. 2006. Ice-age endurance: DNA evidence of a white spruce refugium in Alaska. Proceedings of the National Academy of Sciences, 103:12447-12450.

APSC [Austin Peay State University Herbarium]. 2016. Ecoregions of Tennessee. Available at http://www.apsu.edu/herbarium/ecoregions-tennessee. Accessed December 2016.

Bebber, D.P., M.A. Carine, J.R. Wood, A.H. Wortley, D.J. Harris, G.T. Prance, G. Davidse, J. Paige, T.D. Pennington, N.K. Robson, & R.W. Scotland. 2010. Herbaria are a major frontier for species discovery. Proceedings of the National Academy of Sciences of the United States of America, 107:22169–22171.

Bedford, B.L. & K.S. Godwin. 2003. Fens of the United States: Distribution, characteristics, and scientific connection versus legal isolation. Wetlands, 23:608–629.

Blyveis, E.R. & J. Shaw. 2011. The vascular flora of the Tennessee River Gorge, Hamilton and Marion Counties. M.S. Thesis, University of Tennessee, Chattanooga, Tennessee.

Brahana, J.V. & M.W. Bradley. 1986. Preliminary delineation and description of the regional aquifers of Tennessee: The Highland Rim aquifer system (Vol. 82, No. 4054). US Geological Survey.

Braun, L. 1937. Some relationships of the flora of the Cumberland Plateau and Cumberland Mountains of Kentucky. Rhodra 39:193-208.

Braun, L. 1947. Development of the deciduous forests of eastern North America, 17:211–219.

Braun, L. 1950. Deciduous forests of eastern North America. Blakiston, Philadelphia, PA.

Carpenter, Q. J. 1995. Toward a new definition of calcareous fen for Wisconsin (USA). Ph. D. Dissertation. Institute for Environmental Studies, University of Wisconsin, Madison, WI, USA.

Carter, R., C.T. Bryson & S.J. Darbyshire. 2007. Preparation and use of voucher specimens for documenting research in weed science. Weed Technology 21:1101-1108.

Chester, E.W. 1992. An annotated catalogue of vascular plants known from Land Between the Lakes, Kentucky and Tennessee. Misc. Publ. No. 6, The Center for Field Biology, Austin Peay State University, Clarksville, TN.

Chester, E.W. 1995. An overview of forest diversity in the Interior Low Plateaus: Physiographic Province. In: Landis, T.D.; Cregg, B., tech. coords. National Proceedings, Forest and Conservation Nursery Associations. Gen. Tech. Rep. PNW-GTR-365. Portland,OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station:109-115.

Chester, E.W., B.E. Wofford, & J.M. Baskin. 1997. A floristic study of barrens on the Southwestern Pennyroyal Plain, Kentucky and Tennessee. Castanea, 62:161–172.

Chester, E.W., R.J. Jensen, & J. Schibig. 1998. Characterization of the woody strata in the xeric-site chestnut oak forest community. Journal of Kentucky Academy of Science, 59:178–184.

Clebsch, A. 1947. Bryophytes of the lower Cumberland River valley in Tennessee. The Bryologist, 50:366-376.

Costello, M.J., S. Wilson, & B. Houlding. 2012. Predicting Total Global Species Richness Using Rates of Species Description and Estimates of Taxonomic Effort. Systematic Biology, 61:871–883.

Cotterill, F.P.D. 1995. Systematics, biological knowledge and environmental conservation. Biodiversity and Conservation, 4:183–205.

Crabtree, T. 2012. Vanderbilt's Robert Kral fifth member of TNPS Hall of Fame. Newsletter of the Tennessee Native Plant Society, 36.

Crabtree, T. 2014. Tennessee Natural Heritage Program Rare Plant List. Tennessee Department of Environment and Conservation, Division of Natural Areas.

Davis, M.B. 1983. Quaternary history of deciduous forests of eastern North America and Europe. Annals of the Missouri Botanical Garden, 70:550-563.

DeSelm, H.R., 1988. The Barrens of the Western Highland Rim of Tennessee. In Proceedings of the First Annual Symposium on the Natural History of Lower Tennessee and Cumberland River Valleys. In D. Snyder, ed. The Center for Field Biology of Land Between the Lakes, Austin Peay State University, Clarksville, TN.

DeSelm, H.R. 1994. Tennessee Barrens. Castanea, 59:214–225.

Delcourt, H.R. 1979. Late Quaternary vegetation history of the Eastern Highland Rim and adjacent Cumberland Plateau of Tennessee. Ecological Monographs, 49:255–280.

Delcourt, H.R. & Delcourt, P.A. 1975. The Blufflands: Pleistocene Pathway into the Tunica Hills. The American Midland Naturalist 94:385–400.

Donoghue, M.J. & W.S. Alverson. 2012. A new age of discovery. Annals of the Missouri Botanical Garden, 87:110–126.

Drexler J. Z., B. L. Bedford, A. T. DeGaetano, and D. I. Siegel. 1999. Quantification of the water budget and nutrient loading in a small peatland. Journal of the American Water Resources Association 35:753–769.

Dyer, J.M. 2006. Revisiting the Deciduous Forests of Eastern North America. BioScience, 56:341.

Ellis, W., E. Wofford & E.W. Chester. 1971. A preliminary checklist of the flowering plants of the Land Between the Lakes. Castanea*,* 36:229-246.

Ellis, W.H. & E.W. Chester.1989. Upland swamps of the Highland Rim of Tennessee. Journal of the Tennessee Academy of Science, Vol. 64, No. 3:97-101, July 1989.

EPA [Evironmental Protection Agency]. 2014. US Level III and IV Ecoregions. National Atlas of the United States.

Estes, D. 2005. The vascular flora of Giles County, Tennessee. SIDA, 21:2343–2388.

Estes, D. 2015. Natural History and Vegetation of Tennessee. Austin Peay State University, Clarksville, Tennessee, and the Botanical Research Institute of Texas (BRIT), Fort Worth, Texas. Available http://apsu.edu/herbarium/introduction. (Accessed: September 25, 2015).

Estes, D. 2016. Personal interview December 5, 2016.

Estes, D. Unpublished. Coefficients of conservatism values for Tennessee and Alabama. Working document of the southeastern Flora Committee.

Estes, D., J. Shaw, & C. Mausert-Mooney. 2015. *Lysimachia lewisii* (Primulaceae): A new species from Tennessee and Alabama. Phytoneuron 17:1–15.

Estes, D. & J. Walck. 2005. The vascular flora of Rattlesnake Falls: A potential state natural area on the Western Highland Rim escarpment in Tennessee. SIDA, 21:1753–1780.

Estill, J.C., & M.B. Cruzan. 2001. Phytogeography of rare plant species endemic to the southeastern United States. Castanea 66:3-23.

Flora of North America Editorial Committee, eds. 1993+. Flora of North America North of Mexico. 20+ vols. New York and Oxford.

Frederick, C. 1974. A natural history study of the vascular flora. Ohio Journal of Science, 74:65–116.

Gattinger, A. 1887. The Tennessee flora: With special reference to the flora of Nashville. Phaenogams and Vascular Cryptogams. The author.

Gianopulos, K. 2013. Coefficient of conservatism database development for wetland plants occurring in the southeast United States summary document. North Carolina Dept. of Environment and Natural Resources, Division of Water Resources.

Godwin, KS, J.P. Shallenberger, D.J. Leopold, and B.L. Bedford 2002. Linking landscape properties to local hydrogeologic gradients and plant species occurrence in minerotrophic fens of New York State, USA: a hydrogeologic setting. Wetlands, 22:722–737.

Graham, A. 1999. Late Cretaceous and Cenozoic history of North American vegetation, New York, NY: Oxford University Press, Inc.

Greenberg, C.H., D.E. McLeod & D.L. Loftis. 1997. An old-growth definition for western and mixed mesophytic forests. Agriculture:14.

Gunn, S. 2003. The vascular flora of the Tennessee National Wildlife Refuge's Duck River Unit, Humpreys County, Tennessee. M.S. Thesis, Austin Peay State University, Clarksville, TN.

Hack, J.T. 1966. Interpretation of Cumberland escarpment and Highland rim, South-central Tennessee and northeast Alabama (No. 524-C).

Harrison, S., K.F. Davies, H.D. Safford & J.H. Viers. 2006. Beta diversity and the scale-dependence of the productivity-diversity relationship: A test in the Californian serpentine flora. Journal of Ecology, 94:110–117.

Harvill, A.M. 1984. On the history of Coastal Plain species on the Cumberland Plateau and Highland Rim. Sida 10:290-294.

Jaccard, P. 1912. The distribution of the flora in the alphine zone. The New Phytologist, XI(2):37–50.

Jennings, M.D., D. Faber-Langendoen, O.L. Loucks, R.K. Peet & D. Roberts. 2009. Standards for associations and alliances of the U.S. National Vegetation Classification. Ecological Monographs 79:173-199.

Joppa, L.N., D.L. Roberts, & S.L. Pimm. 2011. How many species of flowering plants are there? Proceedings of the Royal Society B, 278(July 2010):554–559.

Joyner, J.M. & E.W. Chester. 1994. The vascular flora of Cross Creeks National Wildlife Refuge, Stewart County, Tennessee. Castanea, 59:117–145.

Kartesz, J.T. 2015. The biota of North America program (BONAP). North American plant atlas. (http://bonap.net/napa). Chapel Hill, N.C.

Kaul, Robert B., G.E. Kantak & S.P. Churchill. 1988 The Niobrara River Valley, a postglacial migration corridor and refugium of forest plants and animals in the grasslands of central North America. The Botanical Review 54:44-81.

Kelly, L.A., 1989. The Vascular Flora of Williamson County, Tennessee, Vanderbilt University, Nashville, TN.

Keener, C.S. 1983. Distribution and biohistory of the endemic flora of the mid-Appalachian shale barrens. The Botanical Review, 49:65-115.

Killebrew, J.B. 1874. Introduction to the Resources of Tennessee (Vol. 2). Tavel, Eastman & Howell.

Koleff, P., K.J. Gaston & J.J. Lennon. 2003. Measuring beta diversity for presence –absence data. Journal of Animal Ecology, 72:367–382.

Kral, R. 1978. A new species of *Xyris* (sect. *Xyris*) from Tennessee and northwestern Georgia. Rhodora, 80:444-447.

Lance, R.W. & J.B. Phipps 2000. *Crataegus harbisonii* Beadle rediscovered and amplified. Castanea, 65:291-296.

Lichvar, R.W. 2016. The national wetland plant list: 2016 wetland ratings. Phytoneuron, 30:1–17.

Liu, Y., Andersen, J.J., Williams, J.W., & Jackson, S.T. 2013. Vegetation history in central Kentucky and Tennessee (USA) during the last glacial and deglacial periods. Quaternary Research, 79:189-198.

Luther, E. 1977. Our restless earth. University of Tennessee Press, Knoxville, TN.

Messina, M.G. & W.H. Conner. 1997. Southern forested wetlands: ecology and management. CRC Press.

Michaux, F.A. 1805 [1904]. Travels to the west of the Alleghany Mountains. In: R. Thwaites, eds. Early western travels, Vol. III. Reprint. Authur H. Clark Company, Cleveland, Ohio

Miller, R. 1974. The geologic history of Tennessee. State of Tennessee, Dept. of Conservation, Division of Geology, Nashville, TN.

Nelson, P.W. 2010. The terrestrial natural communities of Missouri. Missouri Department of Conservation.

Nicholson, S.W., C.L. Dicken, J.D. Horton, K.A. Labay, M.P. Foose, J.A.L. Mueller. 2007. Preliminary integrated geologic map databases of the United States: Kentucky, Ohio, Tennessee, and West Virginia (OFR 2004-1324).

Nowacki, G.J., & M.D. Abrams. 2008. The demise of fire and "mesophication" of forests in the eastern United States. BioScience 58.2:123-138.

Orzell, S. & D. Kurz. 1986. Floristic analysis of prairie fens in the southeastern Missouri Ozarks. In Fargo, North Dakota: Proceedings of the ninth North American prairie Conference. Tri-College University Center for Environmental Studies, 264.

Porter, C.L. 1959. Taxonomy of flowering plants. In: W.H. Freeman & Co., ed., San Francisco, CA.

R Core Team. 2016. R: A language and environment for statistical computing.

Redden, R. 2016. Personal interview December 4, 2016.

Richardson, C.J. & J.W. Gibbons. 1993 Pocosins, Carolina bays, and mountain bogs. Biodiversity of the southeastern United States 1:257-310.

Rodgers, D. Thesis in preparation. Vascular flora and vegetation of the Cumberland Plateau sandstone riverscour communities in Daddy's Creek Gorge, Cumberland and Morgan Counties, Tennessee. Austin Peay State University, Clarksville, Tennessee.

Safford, J.M. 1884. Report on the cotton production of the State of Tennessee with a discussion of its general agricultural features and a note on the state of cotton production in the State of Kentucky. 367-491. In: (Hilgard, E.W., Special Agent in Charge) Report on Cotton Production in the United States. Part 1. Department of Interior. Census Office, Washington, D.C.

Stambaugh, M.C., R.P. Guyette, J.M. Marschall & D.C. Dey. 2016. Scale dependence of oak woodland historical fire intervals: Contrasting the Barrens of Tennessee and Cross Timbers of Oklahoma, USA. Fire Ecology, 12:65–84.

Schafale, M.P. 2012. Guide to the natural communities of North Carolina, fourth approximation. North Carolina Natural Heritage Program, North Carolina Department of Environment and Natural Resources, Raleigh, North Carolina.

Sjors, H. 1950. On the relation between vegetation and electrolytes in north Swedish mire waters. Oikos 2:241–257.

Slack, N. G., D. H. Vitt, and D. G. Horton. 1980. Vegetation gradients of minerotrophically rich fens in western Alberta. Canadian Journal of Botany 58:330–350.

Shinners, L.H. 1962. Evolution of the Gray's and Small's manual ranges. Sida 1:1-31.

Smalley, G.W. 1980. Classification and evaluation of forest sites on the Western Highland Rim and Pennyroyal. U.S. Department of Agriculture, Forest Service, Gen. Tech Rep. S0-30, 120p. South Forest Experiment Station, New Orleans, LA.

Smith, L., E. Bridges, D. Durham, D. Eagar, A. Lovell, S. Pearsall, T. Smith, P. Somers. 1983. The Highland Rim in Tennessee development of a community classification and identification of potential natural area. Tennessee Department of Conservation Natural Heritage Program, Nashville, TN.

Soil Survey Staff 2010. Keys to Soil Taxonomy, 12th ed. USDA-Natural Resources Conservation Service, Washington, DC.

Soil Survey Staff 2016a Natural Resources Conservation Service, United States Department of Agriculture Web Soil Survey.

Soil Survey Staff 2016b Soil Survey of Lewis County, Tennessee. United States Department of Agriculture, Washington, DC.

Sørensen, T. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species and its application to analyses of the vegetation on Danish commons. Kongelinge Danske Videnskabernes Selskab 5:1-34.

Sorrie B.A., Weakley A.S. 2001. Coastal Plain vascular plant endemics: phytogeographic patterns. Castanea, 66:50-82.

Souza, K. 1987. The vascular flora of Dickson County, Tennessee, M.S. Thesis, Vanderbilt University, Nashville, TN.

Taft, J.B., G.S. Wilhelm, D.M. Ladd & L.A. Masters. 1997. Floristic quality assessment for vegetation in Illinois: A method for assessing vegetation integrity. Erigenia, 1977:3–95.

TENN [The University of Tennessee Herbarium]. 2016. Database of Tennessee vascular plants.

TDEC [Tennessee Department of Environment]. 2016. Watersheds by basin - TN.Gov.

TFC [Tennessee Flora Committee]. 2015. Guide to the vascular plants of Tennessee. University of Tennessee Press, Knoxville, TN.

Thormann, M. N., R. S. Currah, and S. E. Bayley. 1999. The mycorrhizal status of the dominant vegetation along a peatland gradient in southern boreal Alberta, Canada. Wetlands 19:438–450.

Thorne, R. 1989. Phylogeny and phytogeography. Rhodora, 91:10-24.

Thornthwaite, C.W. 1948. An approach toward a rational classification of climate. Geographical review, 38:55-94.

TN-EPPC 2009. [Tennessee Exotic Pest Plant Council] Invasive exotic pest plants in Tennessee. Available at: http://www.tneppc.org/invasive_plants.

Tu, Y. 2011. The discovery of artemisinin (qinghaosu) and gifts from Chinese medicine. Nature Medicine, 17:1217–1220.

Tucker, G.E. 1972. The vascular flora of Bluff Mountain, Ashe County, North Carolina. Castanea, 37:2–26.

USDA, NRCS. 2016. The PLANTS Database (http://plants.usda.gov, 27 October 2016). National Plant Data Team, Greensboro, NC 27401-4901 USA.

USDA, NRCS. 2000. Soil Survey of Lewis County, Tennessee. In cooperation with Tennessee Agricultural Experiment Station, Lewis County Board of Commissioners, Tennessee Department of Agriculture, and Lewis County Soil Conservation District.

USFWS [U.S. Fish and Wildlife Service]. 1994. Recovery Plan for Tennessee yellow-eyed grass (*Xyris tennesseensis* Kral), Jackson, MS.

USGS [U.S. Geological Survey]. 2016. Preliminary Conceptual Models of the Occurrence, Fate, and Transport of Chlorinated Solvents in Karst Regions of Tennessee data available on the World Wide Web (USGS Science for a changing world), accessed [Nov 18, 2016], at URL [http://pubs.usgs.gov/wri/wri974097/datatab/table3.html/].

USNVC [United States National Vegetation Classification]. 2016. United States National Vegetation Classification Database, V2.0. Federal Geographic Data Committee, Vegetation Subcommittee, Washington DC. [usnvc.org] (accessed 20-Nov-2016)

Valverde, F.H., J. Janovec & M. Tobler. 2006. Floristic diversity and composition of terra firme and seasonally inundated palm swamp forests in the Palma Real watershed in lower Madre de Dios, Peru. SIDA, 22:615–633.

Vasilas, L.M, G.W. Hurt & C.V. Noble. 2010. Field indicators of hydric soils in the United States. United States Department of Agriculture, Natural Resources Conservation Service, in cooperation with the National Technical Committee for Hydric Soils, Washington, DC.

Weakley, A.S. 2015. Flora of the Southern and Mid-Atlantic States, University of North Carolina Herbarium, North Carolina Botanical Garden, University of North Carolina, Chapel Hill.

Wilhelm, G. & L. Masters. 1999. Floristic Quality Assessment and Computer Applications Version 1.0.

Winter, T.C. 2000. The vulnerability of wetlands to climate change: a hydrologic landscape perspective. Journal of the American Water Resources Association, 36:305–311.

Witthoft, J. & W. Hunter. 1955. The Seventeenth-Century Origins of the Shawnee. Ethnohistory, 2:42–57.

Worthington, S.R.H. & J. Gunn. 2009 Hydrogeology of carbonate aquifers: A short history. Ground Water, 47:462–467.

APPENDICES

Appendix A

Annotated checklist of the vascular flora from 14 seepages fens in the Western Highland Rim of Tennessee

Annotated checklist of the vascular flora

The annotated checklist taxa are arranged per family within five major groups: Monilophyta, Acrogymnospermae, Magnoliids and Primitive Angiosperms, Monocotyledonae, and Eudicotyledonae. Nomenclature follows Tennessee Flora Committee (2015). Fields listed for each taxa are in order: scientific name, common name, wetland delineation code, Coefficient of Conservatism (CC), and the collection number(s) for voucher specimens.

* - Non-native taxa

! - Rare at the state or federal level

† - County record

Monilophyta

Dryopteridaceae

Dryopteris celsa (Wm. Palmer) Knowlt., Palmer & Pollard ex Small (Log Fern), OBL, CC=8, (1186, 1187)

Polystichum acrostichoides (Michx.) Schott (Common Christmas Fern), FACU, CC=6, (1188, 1189, 1190, 1191, 1192, 1193, 1194, 1195)

Osmundaceae

Osmunda regalis L. var. *spectabilis* (Royal Fern), CC=7, (1296, 1298, 1299, 1300, 1301, 1302, 1303, 1304, 1306, 1476, 1477, 1505)

Osmundastrum cinnamomeum L. (Cinnamon Fern), CC=7, (1297, 1307, 1308, 1309, 1310, 1312, 1313, 1314, 1478)

Pteridaceae

Adiantum pedatum L. (Northern Maidenhair), FAC, CC=7, (1396)

Thelypteridaceae

Phegopteris hexagonoptera (Michx.) Fée (Southern or Broad Beech Fern), FAC, CC=7, (1438, 1439)

Thelypteris noveboracensis (L.) Nieuwl. (Marsh Fern), FACW, CC=7, (1440, 1510, 1522)

Thelypteris palustris Schott var. *pubescens* (Marsh Fern), FACW, CC=7, (1440, 1510, 1522)

Woodsiaceae

Athyrium filix-femina (L.) Roth ssp. *asplenioides* (Southern Lady Fern), CC=6, (1447, 1448, 1449, 1450, 1451, 1452, 1512)

Cystopteris bulbifera (L.) Bernh. (Bulblet Bladder Fern), FAC, CC=8, (1524)

Acrogymnospermae

Cupressaceae

Juniperus virginiana L. (Eastern Red Cedar), FACU, CC=3, (1125, 1126, 1127, 1128)

Magnoliids and Primitive Angiosperms

Annonaceae

Asimina triloba (L.) Dunal (Pawpaw), FAC, CC=6, (1005)

Aristolochiaceae

Asarum canadense L. (Canadian Wild-Ginger), FACU, CC=6, (1023)

Lauraceae

Lindera benzoin (L.) Blume (Spicebush), FAC, CC=6, (1265, 1266, 1267, 1268, 1269, 1270, 1271, 1272, 1273, 1274, 1275)

Lauraceae

Sassafras albidum (Nutt.) Nees (Sassafras), FACU, CC=4, (1276, 1277)

Magnoliaceae

Liriodendron tulipifera L. (Tulip Poplar), FACU, CC=5, (1278, 1279, 1280, 1281)

Monocotyledonae

Cyperaceae

Carex atlantica Bailey ssp. *atlantica* (Prickly Bog Sedge), FACW, CC=7, (1129, 1130, 1131, 1132, 1133, 1134, 1135, 1171, 1503)

Carex blanda Dewey (Eastern Woodland Sedge), FAC, CC=4, (1136, 1137, 1513, 1516, 1518)

Carex bromoides Schkuhr ex Willd. ssp. *bromoides* (Broomlike Sedge), FACW, CC=8, (1526)

Carex crinita Lam. var. *brevicrinis* (Fringed Sedge), OBL, CC=6, (1138, 1158)

Carex debilis Michx. var. *debilis* (White-Edge Sedge), FAC, CC=7, (1139, 1140, 1497, 1517, 1141)

Carex granularis Muhl. ex Willd. (Limestone Meadow Sedge), FACW, CC=5, (1142, 1143, 1174)

Carex intumescens Rudge (Greater Bladder Sedge), FACW, CC=7, (1144, 1459)

Carex leptalea Wahlenb. (Bristly-Stalked Sedge), OBL, CC=8, (1145, 1146, 1147, 1148, 1149, 1172)

Carex lurida Wahlenb. (Shallow Sedge), OBL, CC=5, (1150, 1151, 1152, 1153, 1154, 1155, 1156, 1157, 1173, 1494)

Carex prasina Wahlenb. (Drooping Sedge), OBL, CC=7, (1159, 1160, 1161, 1162, 1163, 1164, 1165, 1166, 1529)

Carex stricta Lam. (Upright Sedge), OBL, CC=8, (1167, 1168)

Carex torta Boott ex Tuckerman (Twisted Sedge), FACW, CC=8, (1170)

Cyperus strigosus L. (Straw-Colored Flat-Sedge), FACW, CC=3, (1175, 1176, 1177, 1179, 1470)

†*Eleocharis erythropoda* Steud. (Red-Rooted Spike-Rush), CC=7, (1527, 1528)

!†*Eleocharis tortilis* (Link) Schult. (Twisted Spike-Rush), G5, S1, FACW, CC=8, (1499)

!*Fuirena squarrosa* Michx. (Hairy Umbrella-Sedge), G4G5, S1, OBL, CC=7, (1181, 1474)

Rhynchospora capitellata (Michx.) Vahl (Brownish Beak-Rush), OBL, CC=7, (1182, 1183, 1184, 1514)

Scirpus atrovirens Willd. (Green Bulrush), OBL, CC=5, (1185, 1493)

Dioscoreaceae

Dioscorea villosa L. (Wild Yam), FAC, CC=6, (1461)

Iridaceae

Sisyrinchium albidum Raf. (White Blue-Eyed Grass), FAC, CC=7, (1231)

Sisyrinchium angustifolium Mill. (Narrow-Leaved Blue-Eyed Grass), FACW, CC=4, (1232, 1234)

Sisyrinchium atlanticum E.P. Bicknell (Eastern Blue-Eyed Grass), FACW, CC=6, (1233)

Juncaceae

!*Juncus brachycephalus* (Engelm.) Buch. (Smallhead Rush), G5, S2, OBL, CC=9, (1238, 1239, 1240, 1464, 1491)

Juncus coriaceus Mackenzie (Leathery Rush), FACW, CC=6, (1235, 1236, 1237, 1241, 1244, 1245, 1246, 1248, 1249, 1251, 1463)

Juncus effusus L. (Common Rush), FACW, CC=4, (1242, 1500)

†*Juncus subcaudatus* (Engelm.) Coville & Blake (Woodland Rush), OBL, CC=8, (1247)

Luzula echinata (Small) F.J. Herm. (Hedgehog Wood-Rush), FACU, CC=5, (1243, 1250)

Melanthiaceae

Chamaelirium luteum (L.) Gray (Fairy-Wand), FAC, CC=8, (1282)

Stenanthium gramineum (Ker-Gawl.) Morong (Eastern Feather-Bells), FACW, CC=8, (1283, 1284)

Orchidaceae

Platanthera ciliaris (L.) Lindl. (Yellow Fringed Orchid), FACW, CC=8, (1291)

Spiranthes cernua (L.) Rich. (Nodding Ladies'-Tresses), FACW, CC=6, (1292)

Poaceae

Agrostis perennans (Walt.) Tuckerman (Upland Bent-Grass), FACU, CC=6, (1511)

†*Andropogon glomeratus* (Walt.) B.S.P. var. *pumilus* (Bushy Bluestem), FACW, CC=4, (1330, 1331, 1332, 1333)

Andropogon virginicus L. (Broomsedge Bluestem), FACU, CC=2, (1334)

**Arthraxon hispidus* (Thunb.) Makino (Small Carpet-Grass), Significant Threat, FAC, CC=0, (1335)

Chasmanthium latifolium (Michx.) Yates (Broadleaf Woodoats), FACU, CC=6, (1504)

Chasmanthium sessiliflorum (Poir.) Yates (Longleaf Woodoats), FAC, CC=6, (1336, 1337, 1338, 1340, 1498, 1504)

Cinna arundinacea L.(Sweet Woodreed), FACW, CC=5, (1341, 1342, 1343)

†*Coleataenia anceps* Michx. ssp. *anceps* (Beaked Panic-Grass), CC=4, (1344, 1367)

Coleataenia rigidula (Bosc ex Nees) LeBlond ssp. *rigidula* (Redtop Panic-Grass), CC=5, (1520)

Danthonia spicata (L.) P. Beauv. ex Roem. & Schult. (Poverty Oat-Grass), CC=5, (1345)

Dichanthelium dichotomum (L.) Gould ssp. *lucidum* (Shining Forked Panic-Grass), FAC, CC=5, (1489)

Dichanthelium dichotomum (L.) Gould ssp. *microcarpon* (Small-Fruited Forked Panic-Grass), FAC, CC=5, (1346, 1347, 1348, 1350, 1351, 1352, 1482, 1485, 1487, 1488)

Dichanthelium laxiflorum (Lam.) Gould (Soft-Tufted Panic-Grass), FACU, CC=5, (1483, 1484)

Glyceria striata (Lam.) Hitchc. (Fowl Manna-Grass), OBL, CC=5, (1353, 1354, 1355, 1458)

Leersia virginica Willd. (White Cut-Grass), FACW, CC=4, (1356, 1357)

Melica mutica Walt. (Two-Flowered Melic-Grass), CC=6, (1358)

**Microstegium vimineum* (Trin.) A. Camus (Nepalese Browntop), Severe Threat, FAC, CC=0, (1359, 1360, 1361, 1362, 1363, 1364)

Muhlenbergia sylvatica (Torr.) Torr. ex A. Gray (Woodland Muhly), FAC, CC=7, (1365, 1366, 1465)

Panicum dichotomiflorum Michx. (Fall Panic-Grass), FACW, CC=2, (1525)

Poa sylvestris Gray (Woodland Bluegrass), FACW, CC=6, (1368, 1369, 1370, 1371)

Saccharum alopecuroides (L.) Nutt. (Silver Plume-Grass), FAC, CC=4, (1372)

†*Schizachyrium scoparium* (Michx.) Nash var. *scoparium* (Little Bluestem), FACU, CC=8, (1373)

Sphenopholis pensylvanica (L.) Hitchc. (Swamp Wedge-Grass), OBL, CC=8, (1374, 1375, 1376, 1377, 1492, 1519)

Smilacaceae

Smilax bona-nox L. (Saw Greenbrier), FACU, CC=4, (1430)

Smilax rotundifolia L. (Common Round-Leaved Greenbrier), FAC, CC=4, (1432, 1433, 1434, 1435, 1436, 1437)

Xyridaceae

!*Xyris tennesseensis* Kral (Tennessee Yellow-Eyed Grass), G2, LE, S1, OBL, CC=10, (1454, 1455)

Xyris torta Sm. (Slender Yellow-Eyed Grass), OBL, CC=7, (1456)

Eudicotyledonae

Altingiaceae

Liquidambar styraciflua L. (Sweetgum), FAC, CC=4, (1001)

Anacardiaceae

Toxicodendron radicans (L.) Kuntze (Poison Ivy), FAC, CC=3, (1002, 1003, 1004)

Apiaceae

Cicuta maculata L. (Spotted Water Hemlock), OBL, CC=6, (1006)

Oxypolis rigidior (L.) Raf. (Stiff Cowbane), OBL, CC=7, (1007, 1008, 1009, 1010, 1012, 1013, 1014, 1015, 1016, 1017, 1018)

Zizia aurea (L.) W.D.J. Koch (Golden Zizia), FAC, CC=7, (1019, 1020)

Aquifoliaceae

Ilex decidua Walt. (Possum Haw), FACW, CC=6, (1021)

Araliaceae

Aralia spinosa L. (Devil's Walking Stick), FAC, CC=5, (1022)

Asteraceae

Ageratina altissima (L.) King & H. Rob. var. *altissima* (Common White Snakeroot), FACU, CC=3, (1024)

Antennaria parlinii Fernald ssp. *parlinii* (Deceitful Pussytoes), CC=7, (1025)

Cirsium muticum Michx. (Swamp Thistle), OBL, CC=7, (1026)

Conoclinium coelestinum (L.) DC. (Blue Mistflower), FAC, CC=3, (1027) *Doellingeria infirma* (Michx.) Greene (Cornel-Leaved Flat-Topped Aster), CC=7, (1028, 1029, 1030)

Elephantopus tomentosus L. (Devil's Grandmother), CC=7, (1031)

Eupatorium perfoliatum L. (Common Boneset), FACW, CC=5, (1032)

Helenium autumnale L. (Common Sneezeweed), FACW, CC=4, (1033, 1034)

Helianthus angustifolius L. (Swamp Sunflower), FACW, CC=5, (1035)

Packera anonyma (Alph. Wood) W.A. Weber & A. Löve (Small's Ragwort), UPL, CC=5, (1036)

Pseudognaphalium obtusifolium (L.) Hilliard & Burtt (Eastern Rabbit-Tobacco), CC=6, (1037)

Rudbeckia laciniata L. (Cut-Leaved Coneflower), FACW, cofc=6, (1039, 1521)

Rudbeckia palustris Eggert ex C.L. Boynt. & Beadle (Seep Orange Coneflower), CC=5, (1038, 1040, 1041, 1042, 1043, 1044, 1045, 1046, 1048, 1049, 1050)

Solidago caesia L. (Blue-Stemmed or Wreath Goldenrod), FACU, CC=6, (1052)

Solidago patula Muhl. ex Willd. (Rough-Leaved Goldenrod), OBL, CC=8, (1053, 1054, 1055, 1056, 1057, 1058, 1059, 1060, 1061, 1471)

Solidago rugosa Mill. var. *rugosa* (Wrinkle-Leaved Goldenrod), FAC, CC=4, (1062, 1063, 1064, 1065, 1066, 1509)

Symphyotrichum lateriflorum (L.) A. Löve & D. Löve (Calico), FACW, CC=5, (1067, 1068)

Balsaminaceae

Impatiens capensis Meerb. (Jewelweed), FACW, CC=4, (1069, 1070, 1071, 1072, 1073, 1074, 1075, 1076, 1077, 1078, 1079, 1080)

Betulaceae

Alnus serrulata (Ait.) Willd. (Hazel or Smooth Alder), OBL, CC=6, (1081, 1082, 1083, 1084, 1085)

Carpinus caroliniana Walt. (American Hornbeam), FAC, CC=6, (1086, 1087, 1088, 1089, 1090, 1091, 1092, 1093)

Corylus americana Walt. (American Hazelnut), FACU, CC=6, (1094)

Bignoniaceae

Campsis radicans (L.) Seem. ex Bureau (Trumpet Flower or Creeper), FAC, CC=2, (1496)

Brassicaceae

Cardamine bulbosa (Schreb. ex Muhl.) B.S.P. (Bulbous Bitter-Cress), OBL, CC=6, (1096, 1097, 1098, 1100, 1101, 1102, 1468)

Cardamine pensylvanica Muhl. ex Willd. (Pennsylvania Bitter-Cress), OBL, CC=4, (1095,1457)

Campanulaceae

Lobelia puberula Michx. (Downy Lobelia), FACW, CC=6, (1103, 1104, 1475)

Lobelia siphilitica L. (Great Blue Lobelia), FACW, CC=5, (1105, 1106, 1107, 1108, 1109, 1110, 1111)

Caprifoliaceae

**Lonicera japonica* Thunb. (Japanese Honeysuckle), Severe Threat, FAC, CC=0, (1112, 1113)

Valerianella umbilicata (Sullivant) Wood (Navel Corn Salad), FAC, CC=4, (1114)

Celastraceae

Euonymus americanus L. (Strawberry Bush), FAC, CC=6, (1115, 1116, 1117)

Convolvulaceae

Cuscuta compacta Juss. ex Choisy (Compact Dodder), CC=7, (1118)

Cornaceae

Cornus alternifolia L. f. (Alternate-Leaved Dogwood), FAC, CC=7, (1119)

Cornus amomum Mill. (Silky Dogwood), FACW, CC=6, (1120, 1121, 1122, 1124)

Cornus florida L. (Flowering Dogwood), FACU, CC=5, (1123)

Ericaceae

Kalmia latifolia L. (Mountain Laurel), FACU, CC=6, (1196, 1502)

Oxydendrum arboreum (L.) DC. (Sourwood), UPL, CC=5, (1197, 1198, 1199, 1200, 1201, 1202, 1203, 1479)

Rhododendron alabamense Rehd. (Alabama Azalea), CC=7, (1204, 1205, 1207, 1460)

Rhododendron canescens (Michx.) Sweet (Southern Pinxter Azalea), FACW, CC=7, (1206)

Vaccinium arboreum Marsh. (Farkleberry), FACU, CC=7, (1208, 1209)

Vaccinium corymbosum L. (Highbush Blueberry), FACW, CC=7, (1210, 1211, 1212)

Fabaceae

Amphicarpaea bracteata (L.) Fern. (American Hog Peanut), FAC, CC=5, (1213, 1214, 1215, 1216, 1217)

Apios americana Medik. (American Groundnut), FACW, CC=5, (1218, 1219, 1220)

Desmodium paniculatum (L.) DC. (Panicled Tick-Trefoil), FACU, CC=5, (1221)

!†*Lathyrus palustris* L. (Marsh Pea),G5, --, S1, FACW, CC=9, (1222)

Vicia caroliniana Walt. (Carolina Vetch), FACU, CC=7, (1223)

Fagaceae

Quercus alba L. (White Oak), FACU, CC=5, (1224, 1225, 1226, 1227)

Hydrangeaceae

Hydrangea cinerea Small (Ashy Hydrangea), CC=6, (1229)

Hypericaceae

Hypericum prolificum L. (Shrubby St. Johnswort), FACU, CC=5, (1230)

Lamiaceae

Clinopodium glabellum (Michx.) Kuntze (Ozark Calamint), CC=9, (1252)

Lycopus virginicus L. (Virginia Water Horehound), OBL, CC=5, (1253, 1254, 1255, 1256)

Pycnanthemum tenuifolium Schrad. (Narrowleaf Mountain Mint), FACW, CC=5, (1258, 1259, 1480)

Salvia lyrata L. (Lyreleaf Sage), FACU, CC=3, (1260, 1261, 1262, 1263, 1264)

Nyssaceae

Nyssa sylvatica Marsh. var. *sylvatica* (Black Gum), FAC, CC=6, (1285, 1286, 1287)

Oleaceae

Fraxinus americana L. (White or American Ash), FACU, CC=6, (1288, 1289, 1290)

Orobanchaceae

Agalinis gattingeri (Small) Small (Roundstem False Foxglove), CC=7, (1293)

Pedicularis canadensis L. (Canadian Lousewort), FACU, CC=7, (1294, 1295)

Parnassiaceae

!*Parnassia grandifolia* DC. (Largeleaf Grass of Parnassus), G3, S3, OBL, CC=9, (1315, 1316, 1317, 1318, 1319, 1320, 1321, 1322, 1323, 1324, 1325, 1508)

Phrymaceae

Mimulus ringens L. (Allegheny Monkey-Flower), OBL, CC=6, (1515)

Plantaginaceae

Chelone glabra L. (White Turtlehead), OBL, CC=7, (1327, 1328)

Platanaceae

†*Platanus occidentalis* L. (Sycamore), FACW, CC=4, (1329)

Polemoniaceae

Phlox amoena Sims (Hairy Phlox), CC=7, (1378)

Phlox divaricata L. var. *divaricata* (Sweet William), FACU, CC=7, (1379) *Phlox glaberrima* L. (Smooth Phlox), FAC, cofc=7, (1380, 1381, 1382, 1383, 1462)

Polygonaceae

Persicaria sagittata (L.) Gross. (Arrow-Leaved Tearthumb), OBL, CC=6, (1384, 1385, 1386, 1387)

Persicaria virginiana (L.) Gaertn. (Jumpseed), FAC, CC=5, (1388, 1389, 1391, 1392, 1393, 1395, 1506)

Ranunculaceae

Ranunculus abortivus L. (Early-Spring Buttercup), FACW, CC=2, (1394)

Trautvetteria caroliniensis (Walt.) Vail (Carolina False Bugbane), FACW, CC=8, (1397, 1398, 1399, 1400, 1401, 1472)

Rosaceae

Amelanchier arborea (Michx. f.) Fernald (Common Serviceberry), FAC, CC=6, (1402, 1467)

Geum virginianum L. (Cream Avens), FAC, CC=6, (1403)

Potentilla simplex Michx. var. *simplex* (Common Cinquefoil), FACU, CC=6, (1404, 1405, 1406)

Rubiaceae

Galium triflorum Michx. (Fragrant Bedstraw), FACU, CC=6, (1407, 1408, 1409, 1410, 1411, 1412)

Houstonia caerulea L. (Azure Bluet), FACU, CC=4, (1413, 1414, 1416, 1417)

Salicaceae

Salix caroliniana Michx. (Carolina Willow), OBL, CC=6, (1418)

Salix sericea Marsh. (Silky Willow), OBL, CC=7, (1419, 1420)

Sapindaceae

Acer rubrum L. (Red Maple), FAC, CC=4, (1507)

Acer saccharum Marsh. ssp. *saccharum* (Sugar Maple), FACU, CC=4, (1425, 1426)

Saxifragaceae

Tiarella cordifolia L. (Allegheny Foamflower), FAC, CC=7, (1427, 1428, 1429)

Urticaceae

Pilea pumila (L.) Gray (Canadian Clearweed), FACW, CC=4, (1441)

Violaceae

Viola cucullata Ait. (Marsh Blue Violet), FACW, CC=6, (1442, 1443)

Vitaceae

Vitis rotundifolia Michx. (Muscadine Grape), FAC, CC=5, (1444, 1445)

Appendix B

Checklist by site for 14 seepage fens in the Western Highland Rim of Tennessee

All vascular plant species and infraspecific taxon identified are listed. Presence of a taxon for a specific site is indicated by a 1 in that site's column.

Species or Infraspecific taxon	**A1**	**A2**	**A3**	**BC**	**D1**	**D2**	**D3**	**D4**	**LB**	**N1**	**N2**	**PM**	**R1**	**R2**	**Totals**
Acer rubrum	0	0	0	0	1	0	0	1	1	1	0	0	0	0	4
Acer saccharum* var. *saccharum	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Adiantum pedatum	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Agalinis gattingeri	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Ageratina altissima* var. *altissima	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Agrostis perennans	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Alnus serrulata	1	0	1	0	1	1	0	0	0	0	1	0	0	0	5
Amelanchier arborea	0	1	0	0	0	0	0	1	0	0	0	0	0	0	2
Amphicarpaea bracteata	1	0	0	1	0	0	1	0	1	0	0	0	1	0	5
Andropogon glomeratus* var. *pumilus	0	0	0	0	0	1	0	1	0	0	0	0	0	0	2
Andropogon virginicus	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Antennaria parlinii* var. *parlinii	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Apios americana	0	0	0	0	0	0	0	0	1	0	1	0	0	0	2
Aralia spinosa	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Arthraxon hispidus	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Asarum canadense	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Asimina triloba	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Athyrium filix-femina* var. *asplenioides	0	0	0	0	0	0	0	1	0	1	1	1	1	1	6
Campsis radicans	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Cardamine bulbosa	1	1	1	1	0	0	1	0	1	0	0	0	0	0	6
Cardamine pensylvanica	1	0	0	0	0	0	0	0	0	0	0	0	1	0	2
Carex atlantica* var. *atlantica	1	1	1	1	1	0	1	0	0	1	1	0	0	1	9
Carex blanda	0	0	0	0	1	1	1	0	0	1	0	0	0	1	5
Carex bromoides* var. *bromoides	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Carex crinita brevicrinis	0	0	0	0	0	0	0	0	1	0	1	0	0	0	2
Carex debilis debilis	0	1	0	0	1	0	0	0	0	1	1	1	0	0	5
Carex granularis	0	0	1	1	0	0	0	0	0	0	0	0	0	1	3
Carex intumescens	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2
Carex leptalea	0	0	0	1	1	1	1	1	0	0	0	0	0	0	5
Carex lurida	1	1	0	1	1	0	1	1	1	1	1	0	0	1	10
Carex prasina	1	0	1	0	1	1	1	0	0	1	1	0	0	1	8
Carex stricta	0	0	0	0	1	0	0	1	0	0	0	0	0	0	2
Carex torta	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Carpinus caroliniana	0	0	1	0	0	0	0	1	0	1	1	0	1	1	6

Species or Infraspecific taxon	A1	A2	A3	BC	D1	D2	D3	D4	LB	N1	N2	PM	R1	R2	Totals
Chamaelirium luteum	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Chasmanthium latifolium	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Chasmanthium sessiliflorum	0	1	0	0	0	0	1	1	0	0	0	1	0	0	4
Chelone glabra	0	0	0	1	0	0	0	0	0	0	0	0	0	1	2
Cicuta maculata	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Cinna arundinacea	0	0	0	0	0	0	0	1	0	1	1	0	0	0	3
Cirsium muticum	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Clinopodium glabellum	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Coleataenia anceps* var. *anceps	0	0	0	0	0	1	0	1	0	0	0	0	0	0	2
Coleataenia rigidula* var. *rigidula	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Conoclinium coelestinum	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Cornus alternifolia	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Cornus amomum	0	1	0	1	0	0	1	0	0	0	0	0	0	0	3
Cornus florida	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Corylus americana	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Cuscuta compacta	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Cyperus strigosus	1	0	1	0	0	1	0	0	1	0	0	0	0	0	4
Cystopteris bulbifera	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Danthonia spicata	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Desmodium paniculatum	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Dichanthelium dichotomum* var. *lucidum	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Dichanthelium dichotomum* var. *microcarpon	0	1	1	0	1	1	1	1	0	1	0	0	0	0	7
Dichanthelium laxiflorum	0	0	0	0	0	1	0	0	0	0	0	1	0	0	2
Dioscorea villosa	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Doellingeria infirma	0	0	0	0	1	0	0	1	0	0	0	0	0	0	2
Dryopteris celsa	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Eleocharis erythropoda	0	0	1	0	0	1	0	0	0	0	0	0	0	0	2
Eleocharis tortilis	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Elephantopus tomentosus	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Euonymus americanus	1	0	0	1	0	0	0	0	0	0	0	1	0	0	3
Eupatorium perfoliatum	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Fraxinus americana	0	0	1	0	0	0	1	0	0	0	1	0	0	0	3
Fuirena squarrosa	0	0	0	0	0	1	0	1	0	0	0	0	0	0	2
Galium triflorum	0	0	0	1	0	0	1	0	0	0	0	0	1	1	4
Geum virginianum	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Glyceria striata	1	1	1	0	0	0	0	0	0	0	0	0	1	0	4
Helenium autumnale	0	0	0	0	0	1	0	1	0	0	0	0	0	0	2

Species or Infraspecific taxon	A1	A2	A3	BC	D1	D2	D3	D4	LB	N1	N2	PM	R1	R2	Totals
Helianthus angustifolius	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Houstonia caerulea	0	0	0	0	1	1	1	1	0	0	0	0	0	0	4
Hydrangea cinerea	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Hypericum prolificum	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Ilex decidua	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Impatiens capensis	1	1	1	1	0	0	1	0	1	0	0	0	1	1	8
Juncus brachycephalus	0	0	1	1	1	0	0	0	1	0	0	0	0	0	4
Juncus coriaceus	1	1	1	0	1	1	1	1	1	1	1	0	0	1	11
Juncus effusus	0	0	0	0	1	0	0	0	0	0	0	1	0	0	2
Juncus subcaudatus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Juniperus virginiana	0	0	0	0	0	1	1	1	0	0	0	0	0	0	3
Kalmia latifolia	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
Lathyrus palustris	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Leersia virginica	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2
Lindera benzoin	1	1	1	1	1	0	1	0	0	0	1	0	1	1	9
Liquidambar styraciflua	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Liriodendron tulipifera	0	0	1	0	0	0	0	1	0	0	0	1	0	0	3
Lobelia puberula	0	0	0	1	0	1	0	1	0	0	0	0	0	0	3
Lobelia siphilitica	1	1	1	1	0	0	0	1	0	0	0	0	1	1	7
Lonicera japonica	0	0	0	0	0	0	1	0	0	0	0	0	1	0	2
Luzula echinata	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2
Lycopus virginicus	0	0	0	0	0	0	1	1	0	1	1	0	0	0	4
Melica mutica	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Microstegium vimineum	0	1	0	0	0	0	0	1	1	1	0	0	0	1	5
Mimulus ringens	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Muhlenbergia sylvatica	1	1	0	0	0	0	0	0	0	0	0	0	0	1	3
Nyssa sylvatica sylvatica	0	0	0	0	0	0	0	1	0	0	0	0	0	1	2
Osmunda regalis* var. *spectabilis	1	1	1	0	0	0	1	0	1	0	1	1	0	1	8
Osmundastrum cinnamomeum	0	0	1	0	0	0	1	0	0	1	1	1	0	1	6
Oxydendrum arboreum	0	0	1	1	0	0	1	1	0	1	0	1	0	1	7
Oxypolis rigidior	1	1	1	0	0	1	1	1	1	0	1	0	1	1	10
Packera anonyma	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Panicum flexile	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Parnassia grandifolia	1	1	1	0	1	1	0	0	1	0	0	0	0	1	7
Pedicularis canadensis	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2
Persicaria sagittata	1	0	0	0	0	0	1	0	1	0	0	0	0	0	3
Persicaria virginiana	1	0	0	0	0	1	0	0	1	1	1	0	1	1	7
Phegopteris hexagonoptera	0	1	0	0	0	0	1	0	0	0	0	0	0	0	2
Phlox amoena	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1

Species or Infraspecific taxon	A1	A2	A3	BC	D1	D2	D3	D4	LB	N1	N2	PM	R1	R2	Totals
Phlox divaricata* var. *divaricata	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Phlox glaberrima	0	0	1	0	0	0	0	1	1	0	0	0	0	1	4
Pilea pumila	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Platanthera ciliaris	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Platanus occidentalis	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Poa sylvestris	0	0	1	0	0	0	0	0	0	1	1	0	1	0	4
Polystichum acrostichoides	0	0	0	1	0	0	1	0	0	0	1	1	0	1	5
Potentilla simplex simplex	0	1	1	0	0	1	0	0	0	0	0	0	0	0	3
Pseudognaphalium obtusifolium	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Pycnanthemum tenuifolium	0	0	0	1	0	1	0	1	0	0	0	0	0	0	3
Quercus alba	0	0	0	1	0	0	0	1	0	0	0	1	0	0	3
Ranunculus abortivus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Rhododendron alabamense	0	1	0	0	0	0	0	1	0	0	0	1	0	0	3
Rhododendron canescens	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Rhynchospora capitellata	0	0	0	0	1	1	0	1	1	0	0	0	0	0	4
Rudbeckia laciniata	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Rudbeckia palustris	1	1	1	1	0	1	0	1	1	0	0	0	0	1	8
Saccharum alopecuroides	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Salix caroliniana	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Salix sericea	0	0	1	0	0	0	0	0	1	0	0	0	0	0	2
Salvia lyrata	0	0	0	0	0	1	0	0	0	0	0	0	1	1	3
Sassafras albidum	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Schizachyrium scoparium* var. *divergens	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Scirpus atrovirens	0	0	0	1	0	0	0	0	1	0	0	0	0	0	2
Sisyrinchium albidum	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Sisyrinchium angustifolium	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2
Sisyrinchium atlanticum	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Smilax bona-nox	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Smilax rotundifolia	0	0	1	0	0	0	0	0	0	1	0	1	0	1	4
Solidago caesia	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Solidago patula	1	0	0	1	1	1	1	1	0	0	0	0	0	1	7
Solidago rugosa rugosa	0	0	1	0	1	0	0	1	1	1	1	0	0	0	6
Sphenopholis pensylvanica	0	0	0	1	0	0	1	0	0	0	0	0	0	1	3
Spiranthes cernua	0	0	0	0	0	1	0	1	0	0	0	0	0	0	2
Stenanthium gramineum	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Symphyotrichum lateriflorum	0	0	0	1	0	0	0	0	0	0	0	0	0	1	2
Thelypteris noveboracensis	0	0	0	0	1	0	0	0	0	0	0	1	0	0	2
Thelypteris palustris* var. *pubescens	0	0	1	1	0	0	0	0	1	0	0	0	0	0	3

Species or Infraspecific taxon	A1	A2	A3	BC	D1	D2	D3	D4	LB	N1	N2	PM	R1	R2	Totals
Tiarella cordifolia	0	0	1	0	0	0	0	0	0	0	0	0	1	0	2
Toxicodendron radicans	0	1	0	0	0	0	1	0	0	0	0	0	0	1	3
Trautvetteria caroliniensis	0	0	0	0	1	0	1	1	0	1	0	0	0	0	4
Vaccinium arboreum	0	0	0	0	0	0	0	1	0	1	0	0	0	0	2
Vaccinium corymbosum	0	0	0	0	0	0	1	1	0	0	0	0	0	0	2
Valerianella umbilicata	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Vicia caroliniana	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Viola cucullata	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2
Vitis rotundifolia	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2
Xyris tennesseensis	1	1	1	0	0	1	0	0	1	0	0	0	0	0	5
Xyris torta	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Zizia aurea	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2
Totals	22	23	38	37	31	41	36	46	28	21	25	20	24	39	431

Appendix C

Photographs of study sites

STUDY SITE PHOTOGRAPHS

Auntney Hollow stream side seep 1 (A1), 6-May-2015

Auntney Hollow stream side seep 2 (A2), 6-May-2015

Auntney Hollow stream side seep 3 (A3), 6-May-2015

Brush Creek stream side sloping seep (BC), 12-May-2014

Dry Branch woodland circumneutral seep (D1), 29-Sep-2014

Dry Branch *Parnassia* seep (D2), 11-May-2015

Dry Branch perched woodland seep (D3)., 11-May-2015

Dry Branch graminoid seep (D4), 11-May-2015

Natchez Trace seep 1 (N1), 11-May-2015

Natchez Trace acid seep 2 (N2), 11-May-2015

Powdermill Branch woodland seep (PM), 21-Jul-2014

Rattlesnake Falls *Impatiens* cliff seep (R1), 6-May-2015

Rattlesnake Falls perched seep (R2), 6-May-2015

VITA

Judy Annette Redden was born in Dickson, Tennessee. Judy graduated from Hickman County High School in 1980, where she received a scholarship from her high school as the outstanding senior athlete. In the fall of 1980, she enrolled as a freshman at The University of Tennessee at Martin. She was a pre-Forestry major and a member of the Natural Resource Management Club. The following year she left UTM and enrolled at Columbia State Community College as a Computer Science major where she was a member of the Lady Chargers basketball team. She graduated from Columbia State Community College, Columbia, Tennessee in the spring of 1983, obtaining an Associate of Science with high honors. She worked for more than 20 years as an Information Technology professional until returning to the University of Tennessee at Martin in the fall of 2010. She was a charter member of the University of Tennessee at Martin Ecology Club. Her undergraduate research project was a study of oak masting in the Beach Ridge Unit of the Obion River Wildlife Management Area in Weakley County, Tennessee. She graduated from the University of Tennessee at Martin in December 2012, obtaining a Bachelor of Science in Ecology and Environmental Biology. In January 2014, she entered the Graduate School of Austin Peay State University in Clarksville, Tennessee. Judy attributes her interested in plants and the natural world to her childhood spent roaming the hills and hollows of middle Tennessee.