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The Center for Transportation and the Environment
North Carolina State University

Final Report

Ecological Assessment of a Wetlands Mitigation Bank (Phase I: Baseline Ecological Conditions and Initial Restoration Efforts)

CTE is funded by USDOT and NCDOT through The Institute for Transportation Research and Education at North Carolina State University.

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16. Abstract

The Tulula Wetlands Mitigation Bank, the first wetlands mitigation bank in the Blue Ridge Province of North Carolina, was created to compensate for losses resulting from highway projects in western North Carolina. The overall objective for the Tulula Wetlands Mitigation Bank has been to restore the functional and structural characteristics of the wetlands. Specific ecological restoration objectives of this Phase I study included: 1) reestablishing site hydrology by realigning the stream channel and filling drainage ditches; 2) recontouring the floodplain by removing spoil that resulted from creation of the golf ponds and dredging of the creek; 3) improving breeding habitat for amphibians by constructing vernal ponds; and 4) reestablishing floodplain and fen plant communities. Efforts to restore Tulula have focused on the altered hydrology of the site, particularly on the re-meandering of Tulula Creek, which had been previously been dredged into a gully-like channel. The footprint of the new meandering channel has been completed, and the contractor will join the separate segments of the new channel together in fall of 2001. Former golf course ponds were filled or partially filled to create shallow ponds, thus creating thirteen new breeding sites for amphibians. The site currently contains 23 constructed ponds and about 10 smaller amphibian breeding sites. Overall, constructed ponds contained a significantly greater number of breeding species than natural breeding habitats of Tulula. The majority of the floodplain has been mapped and classified as Nikwasi loam. Disturbance of the soil profiles was limited to the surface layer over most of the site, allowing the presence of a remnant seedbank in the soil to enhance development of the plant community. Thirteen vegetation communities are described in the report, including four disturbed and nine natural communities. Over 400 vascular and nonvascular plant species have been identified; many of these species are new records for Graham County. Red maple saplings and shrub saplings were planted in two disturbed fairways adjacent to the fen in 1996. At the end of this study, approximately one-half of the planted shrub saplings were alive. The red maple saplings survived reasonably well, but were outperformed by the extensive natural regeneration of red maple on the site, resulting in the conclusion that large-scale planting of canopy trees is unnecessary at Tulula. The database on hydrology, soils, flora, and fauna that has resulted from these efforts will provide the framework for documenting the long-term success of wetland restoration activities at Tulula. After the Tulula Wetlands Mitigation Bank is restored, the site is expected to support 40 ha of wetlands, 38 ha of upland buffers, and 11 ha of surrounding upland protection areas. The proposed mitigation credit for Tulula is based on restored surface water and groundwater flow gradients in wetland areas, coupled with spoil removal from the floodplain. The report offers several recommendations for approaching wetland restoration both general and specific to Tulula. A key recommendation is to maintain flexibility in the regulatory components of restoration; rather than trying to use a "cookbook" approach, federal and state agencies that work cooperatively on wetland restoration activities should use site-specific baseline ecological conditions to develop restoration strategies that are appropriate for each site.

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TABLE OF CONTENTS

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LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The Tulula Wetlands Mitigation Bank was created to compensate for losses resulting from highway projects in western North Carolina, particularly in the 468,817-ha Little Tennessee River basin located in Macon, Swain, Graham, Jackson, Clay, and Transylvania Counties. Large wetlands are uncommon in this region, and in the past a piecemeal approach was used to mitigate wetland losses to highway projects. Impacted areas were replaced with small wetlands, with little regard to the overall quality of the surrounding landscape. Tulula was an ideal site for a mitigation bank, due to its relatively large size (95 ha) and need for large-scale restoration.

The floodplain of Tulula Creek was disturbed in the mid-1980s during development of a golf course. During construction, the bed of Tulula Creek was dredged and channelized and several drainage ditches were dug. Spoil from the drainage ditches and from 11 small ponds that were created on the golf course was spread over portions of the floodplain. A large portion of the floodplain forest was removed during the construction of the fairways. About 40% of the wetlands were disturbed by drainage and timber harvest during construction of the golf course. In 1994 the North Carolina Department of Transportation (NCDOT) purchased Tulula to develop a wetlands mitigation bank. Since then, faculty and students of the University of North Carolina at Asheville (UNCA) have collected information on baseline ecological conditions (hydrology, soils, flora, and fauna) and have evaluated restoration activities at the site.

The overall objective for Tulula is to restore the functional and structural characteristics of the wetlands. Specific ecological restoration objectives include: 1) reestablishing site hydrology by realigning the stream channel and filling drainage ditches; 2) recontouring the floodplain by removing spoil that resulted from creation of the golf ponds and dredging of the creek; 3) improving breeding habitat for amphibians by constructing vernal ponds; and 4) reestablishing floodplain and fen plant communities.

Baseline Conditions

The hydrology of Tulula exhibited distinct and regular seasonal fluctuations. The water table was highly variable in the floodplain but typically greater than 60 cm below the surface during summer and fall, and within 40 cm of the surface during winter and spring. The water table in the fen remained at or near the surface from late November until May. The water table gradually declined in late May or June and dropped 20 to 80 cm during the summer between precipitation events, probably due to increased plant transpiration.

The Tulula site has about 40 ha of hydric soils. The majority of the floodplain has been mapped and classified as Nikwasi loam, a Typic Fluvaquent (unpublished data, United States Department of Agriculture 1995). Organic matter content varies from about 8% in the floodplain to 18% in the fens. Soil pH is generally between 4.3 and 4.9. The soil texture is classified as a sandy loam or loam in the surface horizon, changing to a silt/clay loam horizon at 50 to 90 cm below the surface. Disturbance of

the soil profiles has been limited to the surface layer over most of the site except for two fairways carved out of the hilly slopes adjacent to the floodplain.

We have described 13 vegetation communities at Tulula, including four disturbed and nine natural communities. The natural communities, which include upland forest, a red maple/white pine alluvial forest, fens, and a transitional mixed mesophytic hardwood forest, serve as reference areas for research and restoration activities. The disturbed communities are mostly in fairways that were bushhogged in 1995 and are now in various stages of natural succession. Depending on hydroperiod, landscape position, and the degree of disturbance, fairways are dominated by sedges (*Carex* spp.), soft rush (*Juncus effusus*), grasses (including *Calamagrostis cinnoides*, and *Panicum dichotomum*), and forbs such as goldenrods (*Solidago* spp.) and asters (*Aster* spp.) (Rossell and Wells 1999).

We have identified over 400 vascular and nonvascular plant species at Tulula. Many of the plant species are new records for Graham County and several are considered rare in North Carolina. The high level of species richness at Tulula is related to site disturbance and will probably decline as a forest canopy develops. Species of special interest include the red Canada lily (*Lilium canadense* spp. *editorum*) (Rossell 1996), bog goldenrod (*Solidago uliginosa*), ten-angled pipewort (*Eriocaulon decangulare*), and the zigzag bladderwort (*Utricularia subulata*).

We have documented 17 species of amphibians and 13 species of reptiles at Tulula. Amphibians of interest are those species that use vernal pools to deposit their egg masses, including the spotted salamander (*Ambystoma maculatum*), wood frog (*Rana sylvatica*), four-toed salamander (*Hemidactylium scutatum*), and gray treefrog (*Hyla chrysoscelis*). The altered hydrology at Tulula had resulted in reproductive failure for many vernal pond species because the depressional areas on the floodplain that collect and hold water dried out before larval forms of salamanders and frogs could metamorphose. Reptiles of particular interest include the bog turtle (*Clemmys muhlenbergii*) and the eastern ribbon snake (*Thamnophis s. sauritis*). The bog turtle is currently listed as federally threatened. Only one specimen has been found at Tulula to date and the status of this population is unknown. The eastern ribbon snake is rare in southwestern NC, with only one other confirmed record in nearby Macon County (Palmer and Braswell 1995).

We have observed 94 species of birds at Tulula, including 20 neotropical migrants (Rossell et al. 1999). At least 47 species probably breed on site. The most notable species at Tulula is the golden-winged warbler (*Vermivora chrysoptera*). This species breeds in relatively large numbers on site and are considered rare in North Carolina. The most abundant species include the indigo bunting (*Passerina cyanea*), red-eyed vireo (*Vireo divaceus*), white-eyed vireo (*Vireo griseus*), and yellow-breasted chat (*Icteria virens*). The majority of species at Tulula prefer early-successional habitats with edges for nesting.

We have recorded 32 species of mammals at Tulula. With the exception of the meadow jumping mouse (*Zapus hudsonius*) and the little brown bat (*Myotis lucifugus*), all are common in western North Carolina. The meadow jumping mouse occurs primarily in wet areas with little canopy closure in the disturbed portions of the site (Rossell and Rossell 1999).

Restoration at Tulula

Efforts to restore Tulula have focused on the altered hydrology of the site. Tulula Creek originally had a meandering, slightly entrenched channel with a low width-to-depth ratio and would have been classified as an E5 stream type (Rosgen 1996). Since dredging, the channel is classified as a G6c stream, a gully-type channel that is highly entrenched with a sinuosity less than 1.1 (North Carolina Department of Transportation 1997). The NCDOT hired a contractor to construct a meandering channel (1.9 km in length) across the floodplain to recreate an E5 stream type. The design of the new channel was partially based on the physical characteristics of a relic channel found mainly at the lower end of the site. The contractor used the relic channel, wherever practical, as part of the new meandering channel. The footprint of the new channel has been completed, and the contractor will join the separate segments of the new channel together by crossing the existing Tulula Creek in 2001.

Ten vernal ponds were constructed between October 1995 and January 1996 to replace natural breeding habitats for amphibians that were destroyed during golf course construction. Thirteen new breeding sites were also created in the fall of 1999 when golf course ponds were either filled or partially filled to create shallow ponds. Most of the golf ponds were stream-fed, and now exist as shallow, permanent sites that contain small fish. In others, fish were eliminated and the sites were converted into temporary ponds. Sections of the restored stream channel also were temporarily blocked with check dams to allow the channel to revegetate prior to restoring stream flow. Small pools formed in the deepest sections of these channel segments and were used as breeding sites by resident amphibians. The site currently contains 23 constructed ponds and about 10 smaller amphibian breeding sites.

Resident amphibians rapidly colonized constructed ponds that first filled in 1996. Eight species of amphibians bred in the constructed ponds within a year of construction and 10 species have used the ponds through 2001. Overall, constructed ponds contained a significantly greater number of breeding species than natural breeding habitats of Tulula during the 6-year period.

In March 1995, we planted 231 red maple saplings and 132 shrub saplings in two disturbed fairways adjacent to the fen. Shrub species included silky dogwood, black chokeberry, red chokeberry, and elderberry, all of which are abundant throughout the fen, and were available locally at moderate cost. All plants were bare-root stock, purchased from a wholesale plant nursery in Tennessee. Although the red maple saplings that we planted survived reasonably well, even after 6 years of growth they were not as tall or as vigorous as many of the naturally-regenerated maples. Given the extensive natural regeneration of red maple on site, we are convinced that large-scale planting of canopy trees is unnecessary at Tulula, unless the specific restoration goal is to increase the diversity of canopy trees. Of the shrubs, elderberry fared the worst, with only 25% surviving after 6 years. Silky dogwood survived extremely well, with 30 out of 32 stems (94%) alive after 6 years. Black chokeberry also survived well, with 73% survival after 2 years. Red chokeberry fared less well. After 6 years, only about half of the planted shrub saplings were alive.

The likelihood for long-term success of the wetlands restoration at Tulula is enhanced by three important factors (Moorhead et al. 2001). First, the site is nearly surrounded by the Nantahala National Forest, so that external pressures on the site are limited. Second, in many areas of the Tulula floodplain, the profile of the floodplain soils was not radically disrupted during golf course construction. This suggests that long-term pedogenic processes required for developing mature soil profiles will not be required for ecosystem development at Tulula. Third, there is a remnant seed bank associated with the intact soils of the floodplain, which should enhance development of the plant community. In areas of disturbance, a herbaceous community has developed quickly from the seed bank, and naturally regenerating woody species are found throughout the disturbed fairways.

Tulula is the first wetlands mitigation bank in the Blue Ridge Province of North Carolina. Most of the mitigation banks of North Carolina are located in the Coastal Plain, and differ considerably from Tulula in hydrology and ecology. Our database on hydrology, soils, flora, and fauna will provide the framework for documenting the long-term success of wetland restoration activities at Tulula. Cooperation among members of the Mitigation Bank Review Team has been enhanced by a thorough understanding of the unique ecological conditions at this site. The data have been useful for designing restoration activities, and have facilitated plans for long-term management of the site.

I. INTRODUCTION

Wetland losses associated with transportation projects have historically been mitigated by creating or restoring small wetlands near the project on a case-by-case basis. Increasingly, wetland losses are being mitigated by the creation of larger "banks" of restored or natural wetlands that are protected from future disturbance. These mitigation banks provide a way of consolidating funds and other resources acquired to compensate for the loss of wetlands, facilitating advanced planning and enhancing the monitoring and evaluation of mitigation projects (Short 1988). The Tulula Wetlands Mitigation Bank was created to compensate for losses resulting from highway projects in western North Carolina, particularly in the 468,817-ha Little Tennessee River basin located in Macon, Swain, Graham, Jackson, Clay, and Transylvania counties. Large wetlands are uncommon in this region, and in the past a piecemeal approach was used to mitigate wetland losses to highway projects. Impacted areas were replaced with small wetlands, with little regard to the overall quality of the surrounding landscape. Tulula was an ideal site for a mitigation bank, due to its relatively large size (95 ha) and need for large-scale restoration.

The Tulula Wetlands Mitigation Bank is located in Graham County, in the floodplain of Tulula Creek, 4.8 km west of Topton, at an elevation ranging from 784 to 800 m. It is characterized by a relatively large, level floodplain along Tulula Creek, bordered by forested uplands and infrequent seepage communities on adjacent slopes. The floodplain includes scattered, small depressions where *Sphagnum* spp. accumulate. These "boggy" areas led to the classification of the site as a swamp forest-bog complex, a rare community type in the mountains of North Carolina (Weakley and Schafale 1994). However, the term "bog" is a misnomer for the depressional areas, since they receive groundwater inputs from surrounding mineral soils and support vegetation more characteristic of minerotrophic than ombrotrophic conditions (Moorhead and Rossell 1998). We will refer to these areas as fens.

Until the mid-1980s Tulula was part of the Nantahala National Forest and owned by the U.S. Forest Service. At that time, Tulula was considered to have regional significance due to the scattered depressional fens located throughout the floodplain of Tulula Creek. The dominant floodplain canopy trees were red maple (*Acer rubrum*) and white pine (*Pinus strobus*). A survey of bogs in western North Carolina highlighted Tulula as the last wetland complex of its type in this part of the state (Gaddy 1981). In 1984 the North Carolina Natural Heritage Program, recommended that the site be protected and registered as a Natural Heritage Area (Roe 1984). Stressing that the site represented an important refuge for wetland species, they cautioned that any water level manipulations or timber cutting would adversely affect the wetlands.

The U.S. Forest Service subsequently traded Tulula to a group of developers who planned to build a golf course that would fuel economic growth in Graham County. During construction of an 18-hole golf course, the bed of Tulula Creek was dredged and channelized and several drainage ditches were dug. Spoil from the drainage ditches and from 11 small ponds that were created on the golf course was spread over portions of the floodplain. A large portion of the floodplain forest was removed during the construction of the fairways. Development plans also included lots for 60 single-family homes on the adjacent, sloping land, and much of the understory was removed in forested areas designated for housing. About 40% of the wetlands was disturbed by drainage and timber harvest during construction of the golf course. Despite all this, the golf course failed as a commercial project for a variety of reasons, including the failure of the developers to secure the appropriate 404 wetland permits.

In 1994 the North Carolina Department of Transportation (NCDOT) purchased Tulula to develop a wetlands mitigation bank. Since then, faculty and students of the University of North Carolina at Asheville (UNCA) have collected information on baseline ecological conditions (soils, hydrology, flora, and fauna) and have evaluated restoration activities at the site. (See www.unca.edu/tulula)

The overall objective for Tulula is to restore the functional and structural characteristics of the floodplain/fen complex. Specific ecological restoration objectives include: 1) reestablishing site hydrology by realigning the stream channel and filling drainage ditches; 2) recontouring the floodplain by removing spoil that resulted from creation of the golf ponds and dredging of the creek; 3) improving breeding habitat for amphibians by constructing vernal ponds; and 4) reestablishing floodplain and fen plant communities.

II. ECOLOGICAL ASSESSMENT

Our initial efforts at Tulula were focused on establishing the baseline ecological conditions of the site before restoration began. We used a holistic approach for evaluating ecological conditions, including hydrology, soils, vegetation composition and structure, and surveys of various faunal groups. We then conducted a more intensive evaluation of several of these components, using this information to document changes associated with restoration. Unfortunately, full restoration of the Tulula wetlands complex was not completed by the end of CTE-funded research. Restoration of the stream channel was delayed for a variety of reasons, including potential conflicts with the Indiana bat, the brook trout spawning season, the lack of an appropriate 404 permit, and incorrect engineering of the constructed channel. UNCA will continue to evaluate changing ecological conditions at Tulula over the next year through support of the NCDOT. The following sections highlight the ecological data collected at Tulula thus far.

A. Hydrology

A standard assessment of wetland hydrology for regulatory purposes involves documenting the location of the water table relative to the surface elevation. Wetlands that meet regulatory requirements have a water table within 30 cm of the surface for five percent of the growing season in five or more years out of ten. A network of water table gauges was installed at Tulula to document the temporal and spatial patterns of the water table. Most of these gauges were installed in permanent vegetation plots to couple the assessment of hydrology with soils and vegetation. Piezometers also were installed to determine groundwater recharge and discharge patterns in the Tulula floodplain and fen.

1. Water Table Dynamics of Tulula Fen and Floodplain

Southern mountain fens are thought to receive substantial groundwater inputs (Wieder 1985, Walbridge 1994, Weakley and Schafale 1994). Despite this generalization of hydrologic inputs, limited information is available on the hydrology of these wetlands. Part of the hydrology assessment of Tulula was to address the hydrologic linkage between Tulula Fen, the surrounding floodplain, and the adjacent hillslopes. Specific objectives were to determine: 1) the patterns of seasonal variation in water table level in floodplain and fen areas of the site; 2) the direction of vertical water flow (vertical hydraulic gradient) of the floodplain and fen; 3) if shallow aquifers or soil interflow from adjacent hillslopes contribute to the hydrology of the fen; and 4) if soil texture influences the water table of the floodplain, fen, or hillslopes.

Methods

Twelve shallow water table gauges were installed within the four-ha floodplain/fen wetland complex in May 1994 (Fig. 1). The gauges were constructed from 3.8 and 5.1 cm diameter PVC pipe with horizontal slits spaced at 2 cm over the entire length (Bridgham and Richardson 1993). The gauges were installed at a depth of 84 cm using a 7.6-cm diameter dutch auger. The annular space between the pipe and augered hole was filled with river gravel and the surface was sealed with subsurface clayey sediments and mounded to enhance runoff away from the well. Ten additional water table gauges were installed in May 1995 to establish two transects across an elevational gradient from adjacent slopes into the fen (Fig. 2). Transect A has nine gauges, including four in the fen; Transect B has five gauges, including two in the fen.

Piezometers (six in the depressional fen and three in the floodplain) were installed in June 1994. Each piezometer was installed with 1 m of a water table gauge. Piezometers were made by cutting horizontal slits every 2 cm in the bottom 20 cm of 3.8-cm diameter PVC pipe. The pipes were installed to a depth of 137 cm using a 7.6-cm diameter dutch auger. The space between the pipe and augered hole was filled with river gravel in the bottom 20 cm, and the remaining area was filled with a mixture of soil and bentonite. Vertical hydraulic gradient (VHG) was calculated as the difference between hydraulic head (piezometer - water table gauge) divided by the depth to the piezometer screen (Lee and Cherry 1978). A positive VHG would indicate upwelling of water (aquifer discharge) and a negative VHG would indicate downwelling of water (aquifer recharge) (Jones et al. 1995).

Water levels in the gauges and piezometers were measured weekly or bi-weekly using a steel tape that was marked with a washable marker that readily dissolved in water. Precipitation was measured during the same time period using a standard rain gauge. The water table, piezometer, and precipitation data were averaged on a monthly basis. Soil samples were collected by horizon with a dutch auger during installation of the gauges or piezometers. Horizons were differentiated by changes in color or texture. The soils were air-dried, sieved through a 2-mm sieve and analyzed for particle size distribution with a hydrometer (Gee and Bauder 1986) after treatment with 10% hydrogen peroxide to remove organic matter and physical dispersion using 0.5 g L^{-1} Na-hexametaphosphate.

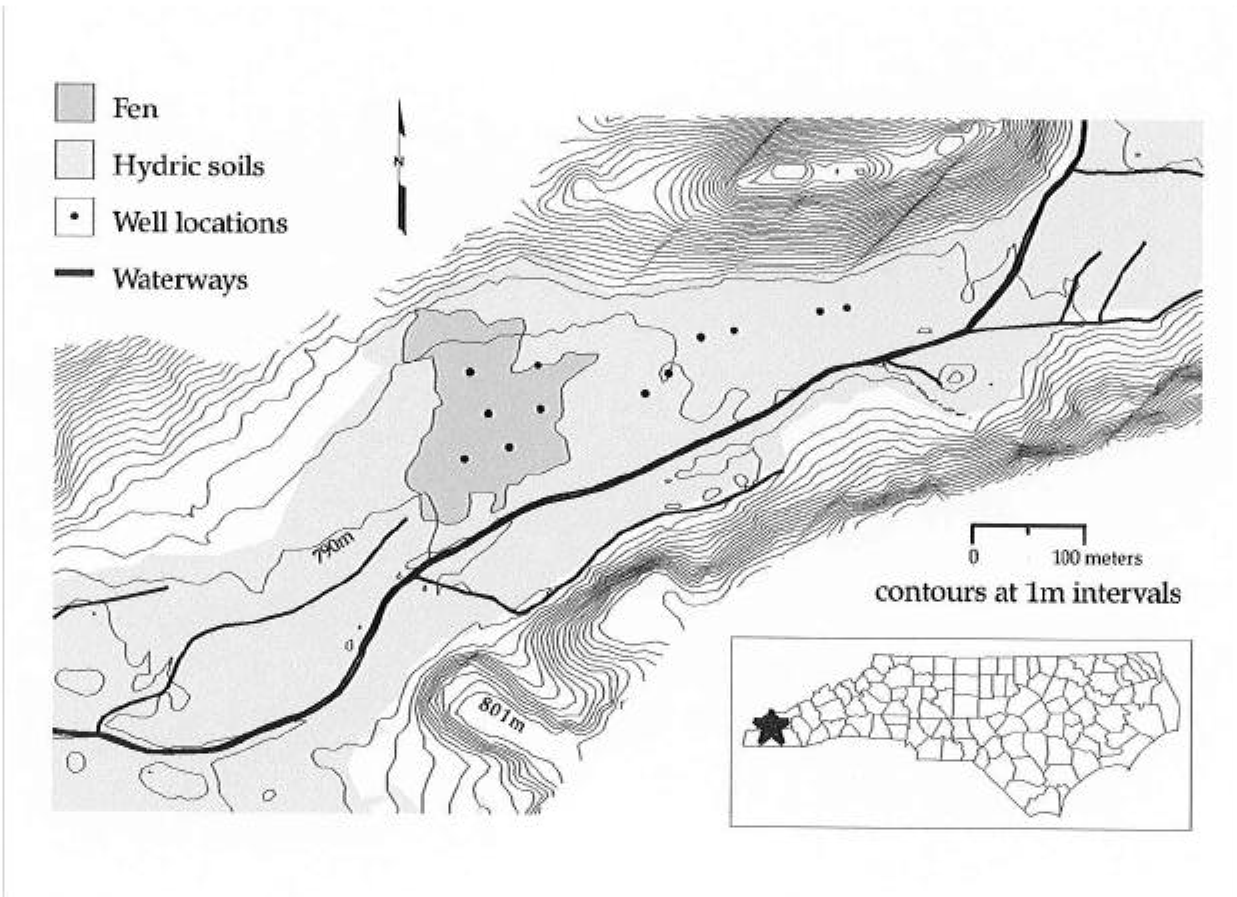

Fig. 1. Locations of water table gauges in Tulula Fen and adjacent floodplain.

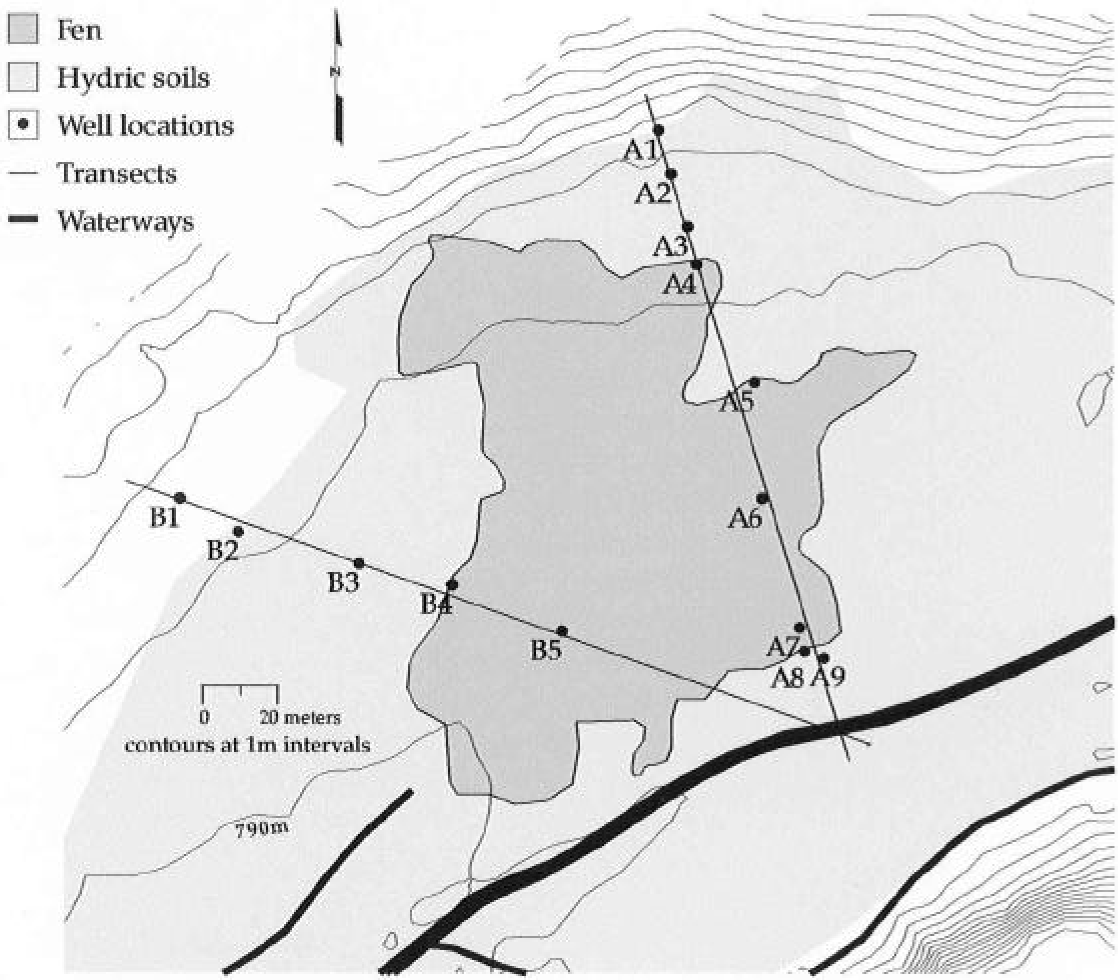

Fig. 2. Transects of water table gauges to determine the contribution of hillslopes to the hydrology of Tulula Fen.

Results and Discussion

The annual variation of precipitation and its effects on the water table of the fen and floodplain are shown in Fig. 3. Average annual precipitation was roughly 150 cm. Precipitation was slightly higher at Tulula during the winter and spring months although there was substantial variation in the monthly totals among years. August was typically the driest month of the year, resulting in lower water tables in September. The hydrology of Tulula exhibited distinct and regular seasonal fluctuations. The water table was highly variable in the floodplain but typically greater than 60 cm below the surface during summer and fall, and within 40 cm of the surface during winter and spring. The water table in the fen remained at or near the surface from late November until May. The water table gradually declined in late May or June and dropped 20 to 80 cm during the summer between precipitation events, probably due to increased plant transpiration.

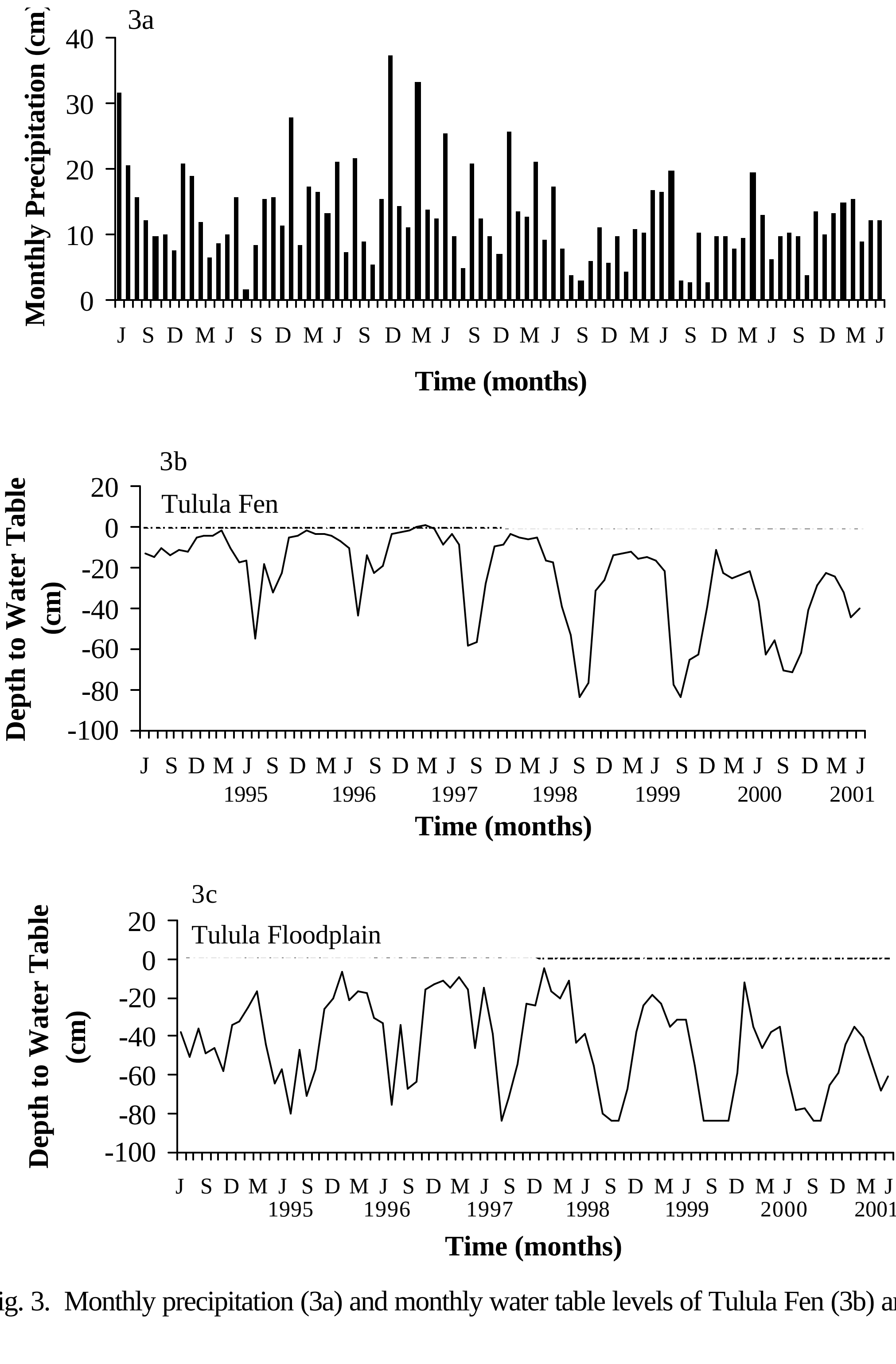

Fig. 3. Monthly precipitation (3a) and monthly water table levels of Tulula Fen (3b) and floodplain (3c).

The VHG of the floodplain was highly variable although seasonal patterns of upwelling (aquifer discharge) in fall and downwelling (aquifer recharge) in winter were common (Fig. 4). The VHG of the fen showed a consistent downwelling of water and suggested that the fen serves as a recharge area for an aquifer. The depressional fens should serve as groundwater discharge areas for the floodplain of Tulula. Water discharged into the fen could be stored, transpired, evaporated, flow downward and recharge an aquifer, or flow horizontally and discharge into Tulula Creek.

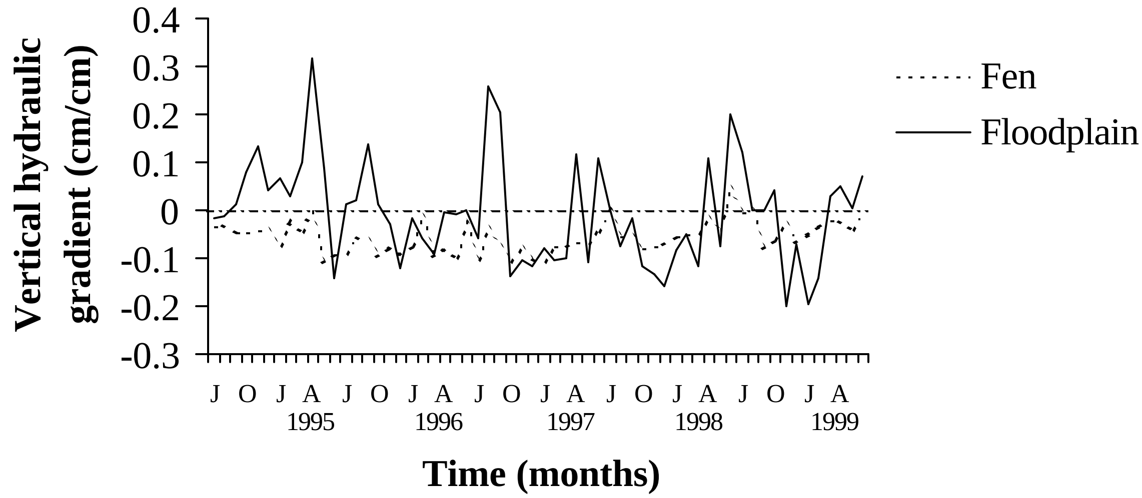

Fig. 4. Vertical hydraulic gradient of the floodplain and fen.

The higher water tables in the fen or floodplain following precipitation events cannot be attributed entirely to direct input from precipitation. Transects of water table gauges (Fig. 2) were established to determine if the elevation of the water table within the fen was influenced by increased interflow from soils from adjacent slopes associated with precipitation or if there was constant shallow ground water flow to the fen. The data suggested that there was a constant source of ground water to the fen from one sloping area (Transect A) and increased interflow after precipitation events from another sloping area (Transect B) (Moorhead 2001).

2. Effects of Drought on the Water Table Dynamics at Tulula

A hydrologic assessment of Tulula has been challenging because western North Carolina has fluctuated between conditions of moderate to severe drought since July 1998. Average rainfall at Tulula is about 150 cm (60 in), based on 30-year records available on the Internet for Andrews, NC. Annual rainfall at Tulula has been 10 to 25% below average rainfall over the past three years. We have had one year of average rainfall at Tulula over the past seven years. The sequence of three years of above average rainfall followed by three years of drought at Tulula allowed for an additional investigation on the impacts of drought on the water table of the Tulula fen and floodplain. The drought conditions can be shown with the Palmer Drought Severity Index (PDI).

Methods

The PDI was developed by the National Weather Service and is a meteorological drought index calculated from precipitation and temperature data and the local available water content of soils. The PDI is available on the Internet; Fig. 5 shows the PDI for the southwestern corner of North Carolina for January 1994 through June 2001. The long-term precipitation data used to calculate the precipitation index came from 30 years of records (1961 to 1990) posted on the Internet for Andrews, NC (24 km from Tulula).

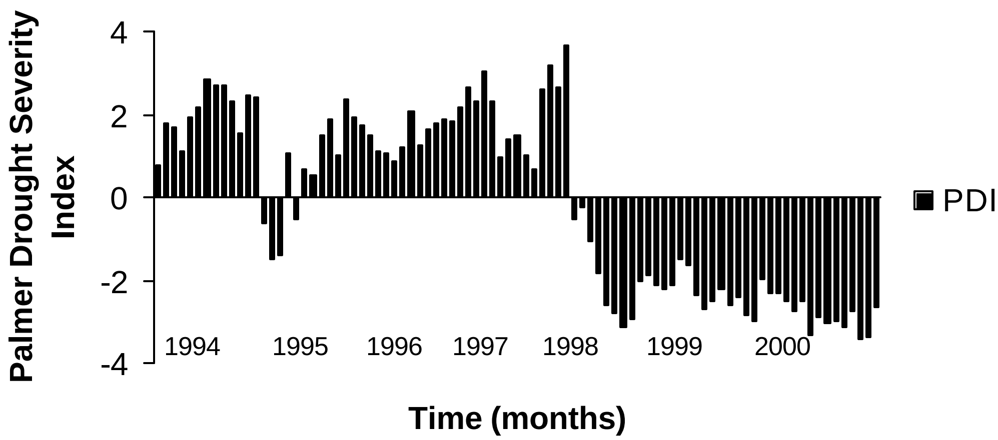

Fig. 5. The PDI for the southwestern corner of North Carolina, January 1994 to June 2001.

The PDI varies roughly between -6.0 and +6.0 with 0.49 to -0.49 representing normal conditions. A negative value indicates drier conditions with -2.0 to -2.99 indicating moderate drought and -3.0 to -3.99 severe drought. For the most part, Tulula fluctuated between conditions of moderate and severe drought from August 1998 through June 2001. The precipitation index also indicates that the majority of months for the same period had less than average precipitation.

Results and Discussion

The drought lowered the water table in the fen (Fig. 6) and floodplain (Fig. 7) throughout the year, although the greatest differences occurred during months of active plant transpiration. The impact of the drought was more pronounced in the fen with a maximum difference of 50 cm occurring during the months of September and October. Tulula Fen would still be classified as a jurisdictional wetland during the drought period, because of the high water table through May. The floodplain, however, would not have met the criteria of jurisdictional wetlands during the drought period. The floodplain would be considered a jurisdictional wetland only during periods of normal or above normal rainfall.

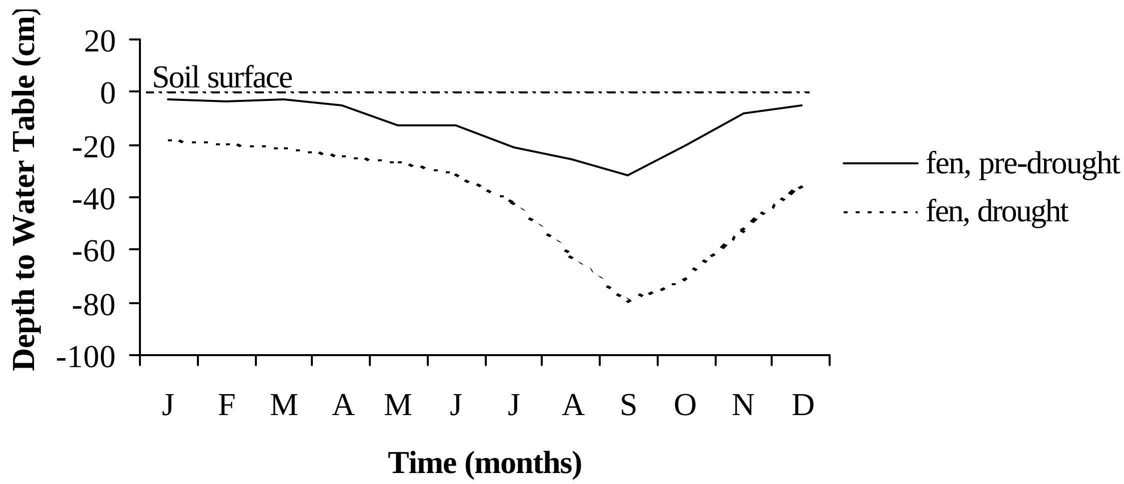

Fig. 6. Effects of drought on the average monthly water table level in the fen.

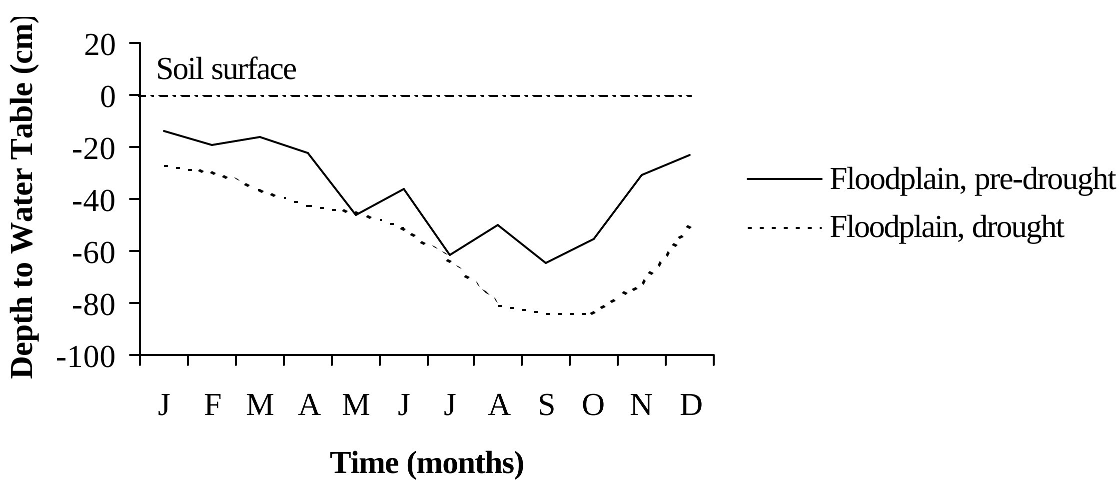

Fig. 7. Effects of drought on the average monthly water table level in the floodplain.

The drought did not appear to impact the vertical hydraulic gradient of the floodplain or fen (Fig. 4). The drought did impact the water table in gauges located along the two transects on elevational gradients into the fen (Fig. 2) and it disrupted the constant flow associated with the shallow ground water aquifer (Transect A).

Restoration of the site hydrology should result in a general raising of the water table throughout the floodplain of Tulula. The precipitation data, coupled with the water table data, illustrates the need for a thorough understanding the role of precipitation in overall water table dynamics for Tulula. The challenge for assessing the hydrological impacts of restoration will be to determine how the water table shifts in relationship to the restoration of site hydrology and to changes in precipitation patterns.

B. Soils

A standard assessment of wetland soils for regulatory purposes includes a site delineation of hydric soils. Morphological indicators of hydric soils (e.g., accumulation of carbon, redoximorphic features, gleyed soil colors) are used during field delineation to establish the boundaries of hydric soils (US Department of Agriculture 1996). For restoration projects, the delineated areas represent potential areas for restoring wetland plant communities.

Soil physical and chemical characteristics are directly related to site hydrology and geomorphology and influence overall plant community development and productivity. Documenting soil properties such as particle size distribution (texture), organic carbon content, pH, and cation exchange capacity provide the basis for a structural assessment of wetland soils.

1. Delineation of Hydric Soils

Methods

The hydric soils of Tulula were identified and delineated in the summer of 1994. Hydric soils were identified primarily by the presence of redoximorphic features (mottles) or gleyed soil colors within 30 cm of the soil surface. The parameter boundary of hydric soils was flagged for the site. Soils expertise provided by the North Carolina Department of Environment and Natural Resources and the NCDOT facilitated the work. The delineated boundary was converted to digital formal by using GPS to record locational coordinates of each flag, then converting the coordinates to GIS format.

Results and Discussion

The Tulula site has about 40 ha of hydric soils (Fig. 8). The hydric soils in the Tulula floodplain were mapped as Nikwasi silt loam (Typic Fluvaquent) by the Natural Resources Conservation Service (unpublished data). In most cases, the boundaries of hydric soils followed the broad floodplain of Tulula Creek, although they extended into the gentle sloping areas of the northwestern side of the site.

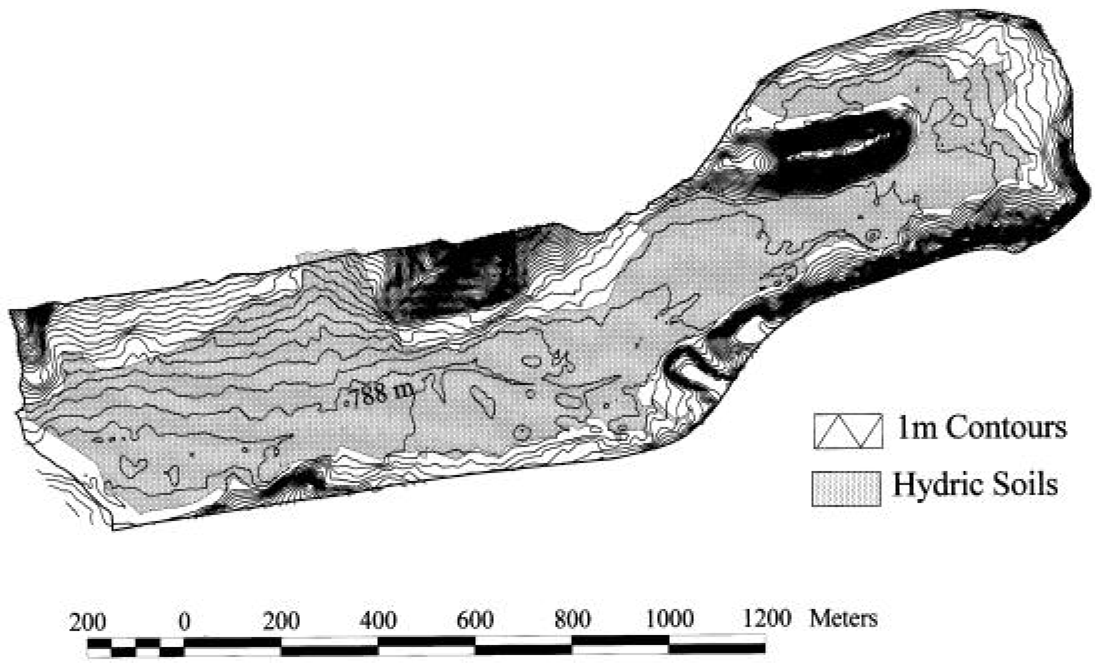

Fig. 8. Extent of hydric soils at Tulula.

2. Soil Physical and Chemical Characteristics

Methods

Two approaches were used to collect soils. The first approach was to collect soils from the surface 0-20 and 20-40 cm layers to determine soil properties of the plant root zone for the vegetation plots established in the fen and floodplain areas. These soils were randomly collected from 15 to 20 locations within each plot, using a standard soil probe. The second approach was to collect soils by horizons to a maximum depth of 150 cm during installation of water table gauges, using a dutch auger. These data were used to determine characteristics of soil profiles and for a secondary study based on plant community types. The analyses of physical or chemical properties of soils (particle size distribution, organic matter, cation exchange capacity, exchangeable cations, and pH) were conducted using standard procedures (see Page et al. 1982)

Results and Discussion

Physical and chemical properties of soils in the vegetation plots of the fen and floodplain are listed in Table 1. Soil properties in the vegetation plots of both areas were fairly uniform in the surface 0-20 cm and lower 20-40 cm layers. The pH ranged from 4.63 to 4.90, with a general pattern of increasing pH in the 20-40 cm layer. Organic matter content ranged from 12.1 to 15.9% in the 0-20 cm layer and was higher in the fen. The cation exchange capacity ranged from about 45 cmol/kg in the surface layer of the fen to 35 cmol/kg in the floodplain. Exchangeable cations were low for the fen and floodplain but higher levels of exchangeable magnesium and potassium were noted in the fen.

Table 1. Soil properties of the fen and floodplain wetlands.

Soil Property	depth (cm)	Tulula Fen Closed canopy	Open canopy	Floodplain
sand (%)	0-20	49.9[a]*	56.6[a]	50.3[a]
	20-40	49.3[b]	56.0[a]	44.2[c]
silt (%)	0-20	40.2[a]	31.9[a]	41.2[a]
	20-40	39.4[a]	30.5[b]	44.5[a]
clay (%)	0-20	9.9[b]	11.9[a]	8.4[b]
	20-40	11.3[a]	13.5[a]	11.4[a]
pH	0-20	4.63[b]	4.62[b]	4.81[a]
	20-40	4.74[a]	4.79[a]	4.89[a]
organic matter (%)				
	0-20	14.5[a]	15.9[a]	12.1[a]
	20-40	8.9[b]	12.0[a]	5.6[c]
cation exchange capacity ($cmol_c$/kg)				
	0-20	42.8[a]	48.1[a]	33.2[b]
	20-40	31.2[b]	39.3[a]	27.2[b]
exchangeable cations ($cmol_c$/kg)				
Ca	0-20	0.43[a]	0.75[a]	0.73[a]
	20-40	0.21[a]	0.35[a]	0.21[a]
K	0-20	0.29[a]	0.31[a]	0.19[b]
	20-40	0.20[a]	0.19[a]	0.10[a]
Mg	0-20	0.44[a]	0.44[a]	0.29[a]
	20-40	0.17[b]	0.29[a]	0.11[b]

* Values in rows followed by the same letters are not significantly different at $P < 0.05$.

The surface layers in the fen and floodplain are sandy loams or loams. Sand ranged from 50 to 57% in the surface 0-20 cm layer and from 45 to 56% in the lower layer. Silt ranged from 31 to 43%. The variations in sand and silt were not significant. Clay ranged from 8 to 12% in the surface layer and from 11 to 18% in the lower layer.

Although subtle differences were noted in the 0 to 20 and 20 to 40 cm layers of soil in the fen and floodplain, there were more notable differences in the soil profile. The average depth of the A horizon of the open-canopy area of the fen was 59 cm, compared to 79 cm in the closed area. The clay content of the A horizon ranged from 9 to 16%. Below the A horizon, the clay content increased to about 30% and changed the textural class from a sandy loam (open canopy) or loam (closed canopy) to a clay loam. A buried A horizon was found below the clay loam horizon in both areas of the fen. The organic matter content of the buried A horizon was higher than that of the surface A horizon. A clay loam horizon was also observed in the floodplain at about 90 cm. The clay content of this layer ranged from 19 to 26%. Below the clay loam horizon, clay decreased, ranging from 4 to 13%.

Soil properties on the floodplain were highly variable, but a few trends were notable. We found that soil texture and organic matter content did not vary appreciably across the floodplain based on plant community type. The surface soils had a high silt content (30 to 50%) and most would be classified as sandy loams or loams. A subsurface clayey layer (18 to 30% clay) was located across the floodplain at various depths. The presence of a clayey subsurface soil layer would suggest that the floodplain and fen soils are not Nikwasi soils (as mapped by the NRCS). The soil profile of Nikwasi soils is described as having a sandy loam A horizon (0 - 66 cm) over a gravely coarse sand C horizon. The subsurface B or C clay loam horizon does not fit this description.

Most of the soils on the floodplain had a surface A horizon that varied in depth from 0.5 to 1 m. Depending on location, these surface horizons were underlain by well-defined horizons of either clayey or sandy substrates, indicating intensive development of soils. Some locations had a more typical soil stratification based on sediment deposition events. Major depositional events are clearly obvious in many locations, based on buried A horizons and organic debris located deep within the soil profile. Despite substantial disturbance at the site, the disruption of soil profiles was limited to surface layers for most of the floodplain.

Mountain fens are found in depressions of floodplains, on slopes intercepting the water table and subject to constant seepage from groundwater, and as isolated systems over resistant rock strata (Walbridge 1994, Weakley and Schafale 1994). Tulula Fen is a depressional fen in the floodplain of Tulula Creek. We compared the soil characteristics of three mountain depressional fens (Tulula, Cold Prong, and McClure) with a seepage fen (Deep Gap) and determined that geomorphic location influences a variety of soil characteristics, including particle size distribution, pH, organic carbon content, and exchangeable cations (Moorhead et al. 2000). The depressional fens found in floodplains tend to accumulate more carbon, have higher silt content, lower pH, and lower concentrations of exchangeable cations.

C. Vegetation

1. Plant survey

When NCDOT purchased Tulula in 1994, the landscape had been recently disturbed, and was highly fragmented. Natural and disturbed habitats were interspersed throughout the site, along with human-created features such as logging roads, powerlines, and an abandoned railroad. One of our first goals was to survey the plant communities across the site, and identify as many species as possible. Of particular interest were rare species and species unique to mountain wetlands.

Methods

Beginning in April 1994 and continuing throughout the next several years, the entire site was searched regularly for flowering and fruiting plants. Specimens of each woody and herbaceous taxon encountered were pressed, identified, and stored in a herbarium case. Collection of additional plants continued each year. During the summer of 1994, we were fortunate to have a UNCA student in our employment who was knowledgeable about the lichen flora in western North Carolina, and had worked with a lichenologist at the Smithsonian Institute. She undertook a lichen survey in the fen, and collected specimens for our herbarium.

Results and Discussion

To date, more than 400 vascular and nonvascular plants have been identified at Tulula (nomenclature follows that of Radford et al. 1968) (Appendix A). Although many of the species we encountered are common throughout the region, several are of particular interest. Approximately 30 red Canada lilies (*Lilium canadense* ssp. *editorum*) were located at various locations around the site (Rossell 1996). Prior to this sighting, the red Canada lily had not been documented in North Carolina for over 20 years, and it is currently a candidate for listing as an endangered species in North Carolina. The Canada lily inhabits open, sunny meadows, where it grows and reproduces slowly. As natural succession at Tulula has progressed, the optimal habitat for the Canada lily has declined. A UNCA student collected seeds from Canada lilies during the fall of 1994. She was able to break dormancy of the seeds, and force germination by applying gibberellic acid. The resulting bulbs were planted in several areas at Tulula where mature lilies are found. However, none of the bulbs produced plants. This reinforces the need to protect the existing population, and maintain open areas where they will thrive.

The bog goldenrod (*Solidago uliginosa*) is classified by the NC Natural Heritage Program as Significantly Rare in North Carolina. A small population was found at Tulula in the open canopy fen. Two other noteworthy species documented at Tulula include the ten-angled pipewort (*Eriocaulon decangulare*) and the zigzag bladderwort (*Utricularia subulata*). The bladderwort is the only carnivorous plant that we found growing at Tulula. Both species inhabit open, wet habitats in the fen and an adjacent fairway. Additionally, since both species are small in stature, they are limited to areas where the surrounding vegetation is short (i.e., early successional or disturbed habitats). By 2001, natural succession in the fairways, combined with a herbicide application by Duke Power Company underneath the major powerline crossing Tulula, resulted in a significant decrease in the population of zigzag bladderwort at the site.

In 1996, a UNCA student who was studying the ecology of carnivorous pitcher plants in the mountains of western North Carolina received permission from Highlands Biological Station (HBS) to transplant northern pitcher plants (*Sarracenia purpurea*) from HBS to the fen at Tulula. He transplanted 6 clumps of pitcher plants into the open and closed canopy regions of the fen. Several of the clumps have grown well, and in 2001, were flowering and producing new pitchers. These plants have added to the educational value of Tulula when students interested in wetland ecology visit the site.

2. Vegetation inventory

Within the mosaic of disturbance at Tulula is an approximately 2.5-ha mountain fen. Although it is clear that some trees were cut within the fen (as evidenced by coppiced trees), and there are traces of drainage ditches, much of the fen appears to have been relatively undisturbed by the golf course construction. Fens are uncommon communities in the southern Appalachians, and little is known about them beyond cursory lists of species (Murdock 1994). Our objective was to quantify the composition of the plant community in the fen, as well as in a disturbed fairway adjacent to the fen. The data that we collected would provide a baseline against which to evaluate the effects of restoration on the ecosystem.

Methods

A grid of 80, 10x10m plots was established throughout the fen in the early summer of 1994. Approximately half of the plots were located in a forested area of the fen (the Aclosed canopy≅ area), and the other half were in an open, sunnier area (the Aopen canopy≅ area). In July 1994, a species-area curve indicated that approximately 40 plots would be sufficient to characterize the herbaceous vegetation in this area. Twenty plots in each of the closed and open canopy areas were chosen at random, and inventoried using a series of nested plots. Overstory trees (>10 cm dbh) in each 10x10m plot were identified, counted, and their dbh measured. Understory trees (2-10 cm dbh) in a 4x4m subplot were identified, counted, and their dbh measured. The number and dbh of dead overstory and understory trees were also recorded. Herbaceous plants and woody seedlings were identified in a 1x1m quadrat placed near the center of each 10x10m plot, and the percent cover of each species was visually estimated. The number of woody seedlings was also counted in the 1x1m quadrats.

In the adjacent disturbed floodplain, 4, 1x1m quadrats were randomly established in each of the 6, 20x30m plots to evaluate planted red maple saplings (see section III.B). Since there were no overstory or understory trees in the floodplain, only herbaceous species and woody seedlings were inventoried, as previously described.

Importance values (IV) were calculated for each taxon (Barbour et al. 1999). For overstory and understory trees, importance values were based on density, basal area, and frequency of occurrence [IV = (relative density + relative basal area + relative frequency) / 3]. For herbaceous plants and woody seedlings, importance values were based on percent cover and frequency of occurrence [IV =(relative cover + relative frequency) / 2].

Results and Discussion

Four overstory species were documented in the closed canopy region (Table 2). Red maple was the most important species (IV = 73.1), followed by white pine (IV = 16.7). There were no overstory trees in the open canopy region.

Table 2. Importance values of overstory trees in 20, 10x10m plots in closed canopy region of fen.

Family	Species	Importance Value
Aceraceae	*Acer rubrum*	73.1
Aquifoliaceae	*Ilex opaca*	5.0
Pinaceae	*Pinus strobus*	16.7
Rosaceae	*Amelanchier arborea* var. *laevis*	5.3

Species richness was greater in the understory (9 species) than in the overstory (4 species) (Table 3). All 9 understory species occurred in the closed canopy region, while only 3 occurred in the open canopy region. Red maple was the most important understory tree in both canopy areas (IV = 42.2 in closed canopy, and 69.0 in open canopy), followed by white pine in the closed canopy area (IV = 17.8) and tag alder in the open canopy area (IV = 18.9). Nine out of twenty plots in the open canopy area lacked any understory trees. Where they occurred, most were coppice growth.

Dead overstory and understory trees were inventoried, in order to provide a baseline for evaluating the impacts of a rising water table on tree growth and survival. In the closed canopy area, there were 4 dead overstory trees (mean dbh = 17.1 cm), and 7 dead understory trees (mean dbh = 5.1 cm). There were no dead trees in the open canopy area.

The taxonomic richness of herbaceous plants and woody seedlings was similar among the three areas: 36, 34, and 36 for the closed canopy, open canopy, and disturbed floodplain, respectively (Table 4). Since many taxa occurred infrequently, and covered less than 1% of some quadrats, taxa were grouped according to growth form (ferns, forbs, sedges, rushes, grasses, woody plants) in order to interpret the results more meaningfully.

Table 3. Importance values of understory trees in 4x4m plots in open and closed canopy regions of fen.

Family	Species	Importance value Closed canopy (n = 20)	 Open canopy (n = 20)
Aceraceae	*Acer rubrum*	42.2	69.0
Aquifoliaceae	*Ilex verticillata*	4.7	-
Betulaceae	*Alnus serrulata*	4.8	18.9
Caprifoliaceae	*Sambucus canadensis*	2.5	-
Caprifoliaceae	*Viburnum cassinoides*	9.4	-
Ericaceae	*Oxydendrum arboreum*	3.2	-
Nyssaceae	*Nyssa sylvatica*	7.0	-
Pinaceae	*Pinus strobus*	17.8	12.1
Rosaceae	*Malus angustifolia*	8.4	-

Table 4. Importance values of plants in 1x1m quadrats in open and closed canopy regions of fen, and in adjacent disturbed floodplain.

Family	Taxon	Closed canopy (n = 20)	Importance values Open canopy (n = 20)	 Floodplain (n = 24)
Sedges				
Cyperaceae	*Carex debilis*	0.38	-	-
Cyperaceae	*Carex incomperta*	0.37	1.13	-
Cyperaceae	*Carex intumescens*	-	0.37	-
Cyperaceae	*Carex* spp.	-	1.55	3.55
Cyperaceae	*Carex stricta*	17.40	25.12	0.25
Cyperaceae	*Cyperus* spp.	-	-	0.43
Cyperaceae	*Eleocharis* spp.	-	0.67	-
Cyperaceae	*Rhynchospora glomerata*	-	0.35	4.42
Cyperaceae	*Scirpus* spp.	-	0.99	-
Total for all sedges		18.15	30.18	8.65
Rushes				
Juncaceae	*Juncus effusus*	0.80	6.44	8.35
Juncaceae	*Juncus* spp.	-	0.95	0.22
Total for all rushes		0.80	7.39	8.57
Grasses				
Poaceae	Pan*icum dichotomum*	0.34	-	-
Poaceae	Pan*icum* spp.	1.97	12.93	-
Poaceae	Unknown	-	-	20.05
Total for all grasses		2.31	12.93	20.05

Woody plants				
Aceraceae	*Acer rubrum*	1.03	1.18	1.58
Caprifoliaceae	*Sambucus canadensis*	0.86	1.01	0.25
Caprifoliaceae	*Viburnum cassinoides*	0.65	-	-
Celastraceae	*Euonymous americanus*	0.37	-	-
Cornaceae	*Cornus amomum*	0.37	-	0.30
Ericacecae	*Kalmia latifolia*	0.43	-	-
Ericaceae	*Lyonia ligustrina*	0.70	1.25	-
Ericaceae	*Vaccinium* sp.	0.75	0.88	-
Fagaceae	*Quercus* sp.	0.68	-	-
Liliaceae	*Smilax glauca*	1.38	-	-
Pinaceae	*Pinus strobus*	0.68	0.29	-
Ranunculaceae	*Xanthorhiza simplicissima*	0.36	-	-
Rosaceae	*Amelanchier arborea* var. *laevis*	0.34	-	-
Rosaceae	*Prunus serotina*	0.68	-	-
Rosaceae	*Rosa palustris*	2.29	2.04	-
Rosaceae	*Rubus hispidus*	19.65	12.04	5.07
Rosaceae	*Rubus* sp.	-	2.02	1.60
Rosaceae	*Sorbus arbutifolia*	3.91	2.00	-
Rosaceae	*Sorbus melanocarpa*	6.03	1.80	-
Vitaceae	*Vitis aestivalis*	1.30	-	0.46
Unknown	Unknown	0.34	-	-
Total for all woody plants		42.80	24.51	9.26
Forbs				
Alismataceae	*Sagittaria latifolia*	-	0.32	-
Asteraceae	*Ambrosia artemisiifolia*	-	-	0.21
Asteraceae	*Aster puniceus*	-	-	6.39
Asteraceae	*Eupatorium* sp.	-	0.63	1.69
Asteraceae	Unknown	1.56	1.59	11.15
Asteraceae	*Vernonia noveboracensis*	-	-	0.36
Balsaminaceae	*Impatiens* sp.	0.76	-	-
Convolvulaceae	*Cuscuta* sp.	-	-	0.23
Eriocaulaceae	*Eriocaulon decangulare*	-	0.56	-
Fabaceae	*Apios americana*	1.17	-	0.24
Gentianaceae	*Sabatia campanulata*	-	-	0.21
Hypericaceae	*Hypericum mutilum*	-	0.57	1.53
Iridaceae	*Sysrinchium* sp.	-	-	1.45
Lamiaceae	*Prunella vulgaris*	-	-	0.38
Melastomataceae	*Rhexia mariana*	-	-	3.66
Onagraceae	*Ludwigia alternifolia*	-	0.86	0.24
Oxalidaceae	*Oxalis stricta*	-	-	0.22
Polygonaceae	*Polygonum* sp.	-	-	0.43
Poygonaceae	*Polygonum sagittatum*	1.73	5.01	0.99
Primulaceae	*Lysimachia lanceolata*	-	-	1.61
Rosaceae	*Potentilla simplex*	0.41	-	17.61
Rubiaceae	*Galium asprellum*	1.87	4.22	0.21
Acrophulariaceae	*Agalinis purpurea*	-	-	0.51
Violaceae	*Viola* sp.	0.68	0.82	2.72
Violaceae	*Viola primulifolia*	-	0.58	-
Xyridaceae	*Xyris torta*	-	-	0.43

Total for all forbs		8.18	5.16	52.47
Ferns				
Aspidiaceae	*Thelyptris noveboracensis*	-	1.26	-
Osmundaceae	*Osmunda cinnamomea*	24.64	5.69	1.02
Osmundaceae	*Osmunda regalis*	1.94	2.60	-
Unknown	Unknown fern	0.88	0.29	-
Total for all ferns		27.46	9.84	1.02

In the 1x1m quadrats in the closed canopy area, the most important groups were woody seedlings (IV = 42.8), ferns (IV = 27.5), and sedges (IV = 18.2). Dominant species included swamp dewberry, cinnamon fern, and tussock sedge. In the open canopy area, sedges (IV = 30.2) and woody seedlings (IV = 24.5) dominated. As in the closed canopy area, important species here included tussock sedge and swamp dewberry. The disturbed floodplain was dominated by forbs (IV = 52.5) and grasses (IV = 20.1). Important species included members of the Asteraceae, and common cinquefoil.

The density of woody seedlings in the closed canopy area was higher than in the other two areas. There were 17 species of woody seedlings in this area. Black chokeberry seedlings were the most numerous (20/m^2), followed by red chokeberry (8/m^2), and swamp rose and strawberry bush (both = 6/m^2). In the open canopy area, there were only half as many species as in the closed canopy area. The most abundant species here were swamp rose (9/m^2) and black chokeberry (3/m^2). In the disturbed floodplain, there were only two woody species: red maple (4/m^2) and elderberry (0.5/m^2). Further analysis of the herbaceous layer in the fen can be found in the next section, where we compare the composition of the seed bank in the fen with the standing vegetation.

3. Seed bank study

Soil seed banks, which represent the viable reserves of seeds in soil, may provide clues to the vegetational history of a site and may help predict future vegetational communities. Seed banks have been studied in a variety of wetland types, but virtually no work has investigated seed banks in bogs or fens. We found only three published studies: one of a Canadian bog (Moore and Wein 1977), one of a quaking fen in the Netherlands (van der Valk and Verhoeven 1988), and one of a southern Appalachian bog (McGraw 1987). Clearly, additional studies on the species composition of wetland seed banks are needed to help assess the contribution that seed banks can make to wetland restoration projects (van der Valk et al. 1992).

We used the seedling emergence technique (Brown 1992) to examine the seed banks of the closed and open canopy regions of the fen, as well as the seed bank in the adjacent disturbed fairway. We also compared the composition of the seed bank to the composition of the standing vegetation in these three areas.

Methods

We collected seed bank samples 2-4 June 1994 from the open and closed canopy regions of the fen and from the adjacent fairway. We took samples from the same 40, 10x10m plots that were inventoried for the vegetational analysis of the fen (section II.C.2). In the floodplain, where the vegetation and hydrology were more uniform than in the fen, a smaller area was sampled (twelve 10x10m plots). In each plot, a soil probe was used to collect 45 soil cores (2.5-cm diameter x 5.0-cm depth). Loose surface litter was brushed aside before sampling to ensure that samples were collected from a uniform depth, and the soil probe was wiped clean between plots. The 45 soil cores from each plot were composited, placed on ice in a cooler in the field, then refrigerated in the lab.

Samples from each plot were potted in triplicate between 16 and 18 June 1994. Each sample was thoroughly mixed and divided into three equal portions. One-third of each sample was placed on top of sterile potting soil in square plastic pots (10.5 cm-wide x 9.5-cm deep). The depth of the seed bank soil was approximately 2.5 cm. Pots were arranged randomly on a shelf in a greenhouse with no supplemental light, heat, or air-conditioning, kept moist, and monitored daily for seedling emergence. As seedlings emerged, they were identified (nomenclature follows Radford et al. 1968) and removed from the pots. On 14 October 1994, pots were moved to a greenhouse with supplemental heat (mean temperature = 21^{o}C) but no supplemental light. Some seedlings never matured or flowered but were identified to family, when possible. The study was terminated after 7 months, when emergence of new seedlings had ceased. The numbers of seedlings of each taxon in the triplicate samples were summed for each plot. Because seedling numbers were low for some taxa, plants were grouped as woody plants, grasses, sedges, rushes, or forbs for data analysis.

The composition of the standing vegetation in the herbaceous layer of each of the three study areas was documented in July 1994 by randomly locating a 1.0-m^2 quadrat within each 10x 10m plot (see section II.C.2). The quadrat frame was held at knee height, and the percent cover of all species occurring within the quadrat was visually estimated. Species were subsequently classified as woody plants, forbs, grasses, sedges, or rushes for data analysis.

Analysis of variance (ANOVA) was used for the seed bank study to determine whether the total number of seedlings of each of the five plant types differed among the three areas (open canopy fen, closed canopy fen, floodplain). ANOVAs were also used to determine whether the mean cover of each of the five plant types in the standing vegetation differed among the three areas. In each case, Bonferroni-type adjustments of the alpha level were used because multiple comparisons were made (Tabachnik and Fidell 1989). The experimentwise error rates were set at 0.1, with comparisonwise error rates (alpha levels) of 0.0067. Differences among areas within each plant type were tested with Tukey's multiple comparison procedure. Statistical Analysis System programs (SAS Institute, Inc. 1990) were used for all analyses.

A discriminant function analysis was used for the seed bank study to determine which plant type best distinguished the floodplain, open canopy fen, and closed canopy fen. Because discriminant function analysis is sensitive to the inclusion of outliers (Tabachnick and Fidell 1989), eight outliers (one forb, one grass, one woody, three sedge, and two rush entries) were eliminated from the data set prior to conducting the analyses. Boxplots and stem-and-leaf plots generated with the PROC UNIVARIATE procedure were used to identify outliers.

Results and Discussion

Thirty-two taxa of seedlings emerged in the seed bank study (Table 5): 26 in closed canopy fen soils, 19 in open canopy fen soils, and 22 in floodplain soils. Graminoids (well represented by *Juncus*) represented 85%, 77%, and 69% of the total number of seedlings in open canopy fen, floodplain, and closed canopy fen soils, respectively. Leck (1989) noted that the dominant species in wetland seed banks are usually monocots and often graminoids. Only five woody taxa emerged in our study: *Acer rubrum*, *Rosa palustris*, *Rubus hispidus*, *Vitis aestivalis*, and one unknown taxon. In each case except *R. hispidus* (which was represented by 31 seedlings), fewer than four seedlings of each taxon emerged. Other wetland seed bank studies have shown woody plants to be absent or poorly represented, likely because most have short-lived seeds (Leck 1989). No noxious species emerged from any of our samples.

Table 5. Total number of seedlings of each taxon emerging in seed bank study.

Family	Taxon	Closed canopy (n = 20)	Open canopy (n = 20)	Floodplain (n = 12)
Sedges				
Cyperaceae	*Carex* spp.	325	420	399
Cyperaceae	*Cyperus retrorsus* Chapman	0	1	0
Cyperaceae	*Cyperus strigosus* L.	2	0	27
Cyperaceae	*Eleocharis obtusa* (Willd.) Schultes	2	5	1
Total sedges		329	426	427
Rushes				
Juncaceae	*Juncus* spp.	107	780	141
Grasses				
Poaceae	*Panicum dichotomum* L.	129	91	151
Poaceae	Unknown	28	145	76
Total grasses		157	236	227
Woody plants				
Aceraceae	*Acer rubrum* L.	1	0	0
Rosaceae	*Rosa palustris* Marshall	0	0	1
Rosaceae	*Rubus hispidus* L.	29	0	2

Vitaceae	*Vitis aestivalis* Michx.	4	0	0
Unknown	Unknown	4	0	2
Total woody plants		38	0	5
<u>Forbs</u>				
Asteraceae	*Erechtites hieracifolia* (L.) Raf.	4	1	2
Asteraceae	*Eupatorium perfoliatum* L.	19	1	2
Euphorbiaceae	*Acalypha rhomboidea* Raf.	0	0	7
Hypericaceae	*Hypericum mutilum* L.	83	72	74
Lamiaceae	*Lycopus virginicus* L.	2	0	0
Melastomataceae	*Rhexia mariana* L.	1	1	24
Onagraceae	*Ludwigia palustris* (L.) Ell.	8	11	0
Oxalidaceae	*Oxalis stricta* L.	0	0	2
Plantaginaceae	*Plantago* sp.	1	0	0
Polygonaceae	*Polygonum pensylvanicum* L.	0	1	0
Polygonaceae	*Polygonum punctatum* Ell.	1	1	5
Poygonaceae	*Polygonum sagittatum* L.	7	5	1
Rosaceae	*Potentilla* sp.	0	0	3
Rubiaceae	*Galium tinctorium* L.	7	16	0
Scrophulariaceae	*Lindernia dubia* (L.) Pennell	1	0	0
Scrophulariaceae	*Verbascum thapsus* L.	1	0	0
Violaceae	*Viola blanda* Willd.	19	6	23
Violaceae	*Viola primulifolia* L.	18	3	70
Unknown	Unknown dicots	32	11	10
Unknown	Unknown monocots	21	118	8
Total forbs		225	247	231
Grand totals (all taxa)		856	1689	1031

The number of seedlings of each of the five plant types differed significantly between the three areas (Table 6). Most of the woody seedlings emerged in closed canopy fen soils, most rushes emerged in open canopy fen soils, and significantly more sedges and forbs emerged in floodplain soils than in soils from either of the other sites. More grasses emerged in floodplain soils than closed canopy fen soils, but grass emergence did not differ between the floodplain and the open canopy region of the fen.

Two canonical variables resulted from the linear discriminant function analysis. These accounted for 59.1% (Can1) and 40.9% (Can2) of the total variability. Can1 had a high positive loading for woody taxa and a high negative loading for rushes, and separated the open canopy fen from the closed canopy fen and the floodplain along the x-axis (Table 7, Fig. 9). Can2 had high positive loadings for sedges and grasses, and separated the floodplain from the fen along the y-axis. These patterns of emerged seedlings may correspond to differences in hydrologic regime but bear little similarity to the standing vegetation. For example, the open canopy fen was the wettest of the three areas, with the water table remaining within 10 cm of the surface during most of 1994-1995 (Rossell et al. 1999). The seed bank in this area produced the greatest number of rush seedlings but was lowest in overall taxonomic richness. The standing vegetation, however, was characterized by a low cover of rushes and a greater proportion of sedges than the other areas (Table 8).

Table 6. Mean (± S.E.) number of emerged seedlings per plot of five plant types in three study areas. Across rows, values followed by the same letter are not significantly different at $P > 0.0067$.

Plant type	Closed canopy	Open canopy	Floodplain
Woody	1.9 ± 0.4a	0 ± 0b	0.4 ± 0.2b
Grasses	7.9 ± 1.7b	12.4 ± 1.2ab	18.9 ± 2.3a
Sedges	19.4 ± 1.2b	21.3 ± 1.8b	35.6 ± 3.7a
Rushes	5.9 ± 1.4b	39.0 ± 5.4a	11.8 ± 2.8b
Forbs	11.3 ± 1.5b	12.4 ± 1.2b	21.0 ± 2.9a

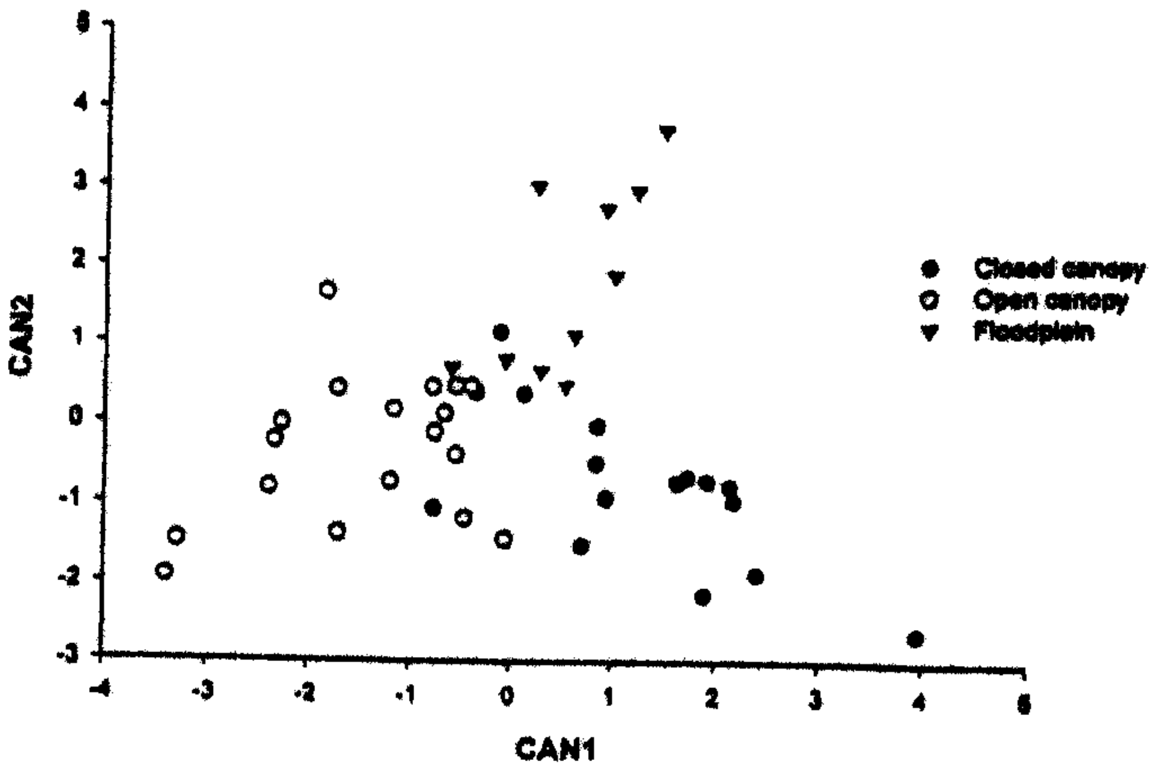

Fig. 9. Discriminant function analysis of three study areas, based on the number of emerged seedlings of five plant types (woody plants, grasses, sedges, rushes, and forbs).

Table 7. Canonical coefficients for number of emerged seedlings of five plant types.

Plant type	Can1	Can2
Woody	0.710	-0.214
Grasses	0.009	0.531
Sedges	0.160	0.621
Rushes	-0.744	-0.272
Forbs	0.308	0.377

Table 8. Mean (± S.E.) cover of five plant types in herbaceous layer of $1x1m^2$ plots in three study areas. Across rows, values followed by the same letter are not significantly different at *P* > 0.0067.

Plant type	Closed canopy	Open canopy	Floodplain
Woody	5.7 ± 1.0 a	5.7± 1.2 a	3.0 ± 0.6 a
Grasses	1.4 ± 0.6 b	13.3 ± 1.7 ab	25.6 ± 4.5 a
Sedges	10.8 ± 2.0 b	25.0 ± 3.9 a	2.0 ± 0.6 b
Rushes	1.6 ± 1.1 a	5.9 ± 1.5 a	8.8 ± 4.4 a
Forbs	0.9 ± 0.2 b	2.2 ± 0.3 ab	8.1 ± 2.6 a

In the closed canopy fen, where transpiration losses are greater, the water table dropped more then 30 cm below the surface on several occasions during the growing season. The seed bank in this area produced the most woody seedlings and the greatest overall taxonomic richness. The closed canopy fen is dominated by mature trees and other woody species that would continually drop seeds into the seed bank. However, the presence of woody plants in its herbaceous layer did not differ from the other areas. The floodplain, which is drained by numerous ditches, was the driest of the three areas, with the water table frequently dropping more than 60 cm below the surface. The seed bank in this area produced the most sedge and forb seedlings and was intermediate in taxonomic richness. The standing vegetation had a greater cover of forbs and grasses than the closed canopy fen but only differed from the open canopy fen in having less sedge cover.

In other studies, the species composition of wetland seed banks has sometimes resembled the standing vegetation but often has not (Leck 1989, Poiani and Dixon 1995, Hanlon et al. 1998). At Tulula, the seed bank and the standing vegetation in all three study areas were both characterized by a large proportion of graminoids. Although the open canopy fen had woody seedlings in its standing vegetation, no woody seedlings germinated from its seed bank. In contrast, rushes constituted less than

10% cover in any of the study areas, but the open canopy seed bank produced an abundance of rush seedlings. Similarly, sedges contributed only 2% cover in the floodplain vegetation, but the floodplain seed bank produced the most sedge seedlings.

One of the wetland restoration goals for Tulula is to restore the original plant communities in the floodplain. It is not known whether restoration activities in the floodplain will influence the hydrology and vegetation dynamics in the adjoining closed and open canopy regions of the fen. Historical aerial photographs show that the floodplain was forested prior to disturbance, and it is likely that the vegetation resembled that in the closed canopy fen. Current restoration plans include planting some trees and shrubs in the floodplain, allowing others to regenerate on their own, and monitoring the herbaceous assemblages that develop. Since few woody seedlings emerged from floodplain soils in our study, most woody species that establish in this area will probably be contributed by the seed rain from surrounding forested areas. The seed bank in the floodplain will most likely lead to the establishment of graminoids and forbs. Later in succession, the composition of the restored plant communities might be influenced more by vegetative reproduction of shade-tolerant species (Bierzychudek 1982, Hanlon et al. 1998).

The actual contribution that the seed bank makes to the plant communities that become established in the floodplain will depend on the hydrologic regime after restoration, the germination requirements of individual species (Leck 1989, van der Valk et al. 1992), and the depth that soil is disturbed, which could result in burial of some species (McGee and Feller 1993). It will also be influenced by the extent of additions to the seed bank from the local seed rain (Schneider and Sharitz 1986, Titus 1991) and on the microtopographical relief that is established (Golet 1969, Paratley and Fahey 1986). Virtually all of the microtopographical relief in the floodplain was obliterated when this area was graded during the attempted golf course construction, and the extent to which restoration can recreate microtopographic heterogeneity may exert a strong influence on the nature of the communities that develop.

4. Red maple survey

Red maple is the dominant canopy tree in the fen, as well as in other forested areas across Tulula. Although there is only one species of red maple (*Acer rubrum*), genetically distinct ecotypes may have evolved in response to specific environmental conditions, including soil saturation (Tiner 1991). For example, in wet soils, red maple develops shallow lateral roots, while it forms a taproot in dry soils (Kramer 1949). Consequently, red maples derived from the seed rain at Tulula are adapted to the prevailing conditions at the site, unlike those purchased from nurseries. There is an abundant supply of red maple seeds at Tulula, as evidenced by the large numbers observed in litter traps across the site. The seeds of red maple are disseminated in the early spring, and germinate readily upon contact with soil, with no dormancy requirements (Clinton and Vose 1996). Many recently germinated seedlings are routinely observed, with cotyledons still intact. Our objective was to evaluate the natural regeneration of red maples at the site, in order to determine whether large-scale planting would be necessary.

Methods

Red maple seedlings were inventoried in 1996 and 2001, in the fairways adjacent to the fen. Transects were established across the fairways at 20-m intervals. A 0.25-m^2 quadrat was centered along the transect at 2-m intervals. Within each quadrat, all red maple seedlings were counted, and their heights were measured. One seedling in each quadrat was marked with a colored plastic band, in the hopes that we might be able to monitor the survival of individual trees.

Results and Discussion

A total of 379, 0.25-m^2 quadrats were inventoried across the disturbed floodplain (Table 9). The number of red maple seedlings increased slightly between 1996 (145 seedlings) and 2001 (161 seedlings), and the number of quadrats containing at least one seedling increased from 18% in 1996, to 22% in 2001. The most noteworthy change was the height of the seedlings. The overall mean seedling height more than doubled, from 21 cm in 1996, to 52 cm in 2001. Very few tagged seedlings were relocated in 2001, so that we were unable to document the growth of individual plants.

Table 9. Summary of red maple seedling inventory in disturbed fairway, 1996 and 2001.

	1996	2001
Number of 0.25 m^2 quadrats	379	379
Total number of seedlings	145	161
Density of seedlings (no/m^2)	1.5	1.7
Minimum no. seedlings per plot	0	0
Maximum no. seedlings per plot	8	6
Plots with 0 seedlings (%)	82	78
Plots with 1-4 seedlings (%)	17	21
Plots with 5+ seedlings (%)	1	1
Shortest seedling height (cm)	2	5
Tallest seedling height (cm)	146	280
Mean seedling height (cm)	21	52

The distribution of seedling heights each year (using 25-cm height classes) is shown in Fig. 10. In 1996, only 5 height classes were represented. Seventy-five percent of seedlings were less than 25 cm tall, and 90% were less than 50 cm tall. Only one seedling was taller than one meter. By 2001, there were nine height classes, and only 62% of seedlings were under 50 cm. There were 12 seedlings taller than one meter, and two seedlings taller than two meters.

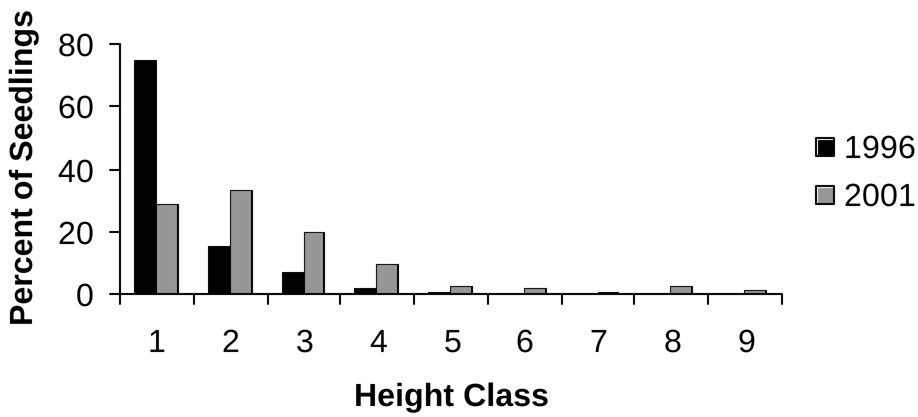

Fig. 10. Height classes of red maple seedlings in disturbed fairway adjacent to Tulula Fen, 1996 and 2001. Height classes: Class 1 = ≤ 25 cm, Class 2 = 26-50 cm, Class 3 = 51-75 cm, Class 4 = 76-100 cm, Class 5 = 101-125 cm, Class 6 = 126-150 cm, Class 7 = 151-175 cm, Class 8 = 176-200 cm, Class 9 = > 200 cm.

Our results show clearly that red maples are successfully reproducing and growing in the floodplain at Tulula. Many of the naturally regenerated red maples are taller and more vigorous than the nursery-stock saplings that we planted in 1995 (see section III.C).

D. Amphibians and Reptiles

1. Amphibian and Reptile Surveys

Methods

A major goal during 1993-1995 was to inventory the resident amphibians and reptiles at Tulula. Resident species were identified by searching ponds for amphibian egg masses, censusing calling male frogs, seining ponds and streams, conducting night and day searches of plots for salamanders, turning logs and rocks during daylight searches for amphibians and reptiles, and using drift fences with pitfall traps.

Results and Discussion

Seventeen species of amphibians and 13 species of reptiles were documented at Tulula between 1993 and 2001(Appendix B). The cumulative total was 25 species through 1994, 27 species through 1995, 29 species through 1996, and 30 species since 1998. Overall, the herpetofaunal diversity at

Tulula is exceptionally rich relative to other areas of similar size that have been surveyed in western North Carolina (J. W. Petranka, unpublished data). This high diversity reflects the diversity of habitats and community types that occur at the site.

Reptiles of particular interest include the bog turtle and the eastern ribbon snake. The bog turtle is currently listed as federally threatened. Only one specimen has been found at Tulula to date and the status of this population is unknown. The eastern ribbon snake is rare in southwestern NC, with only one other confirmed record in nearby Macon County (Palmer and Braswell 1995). Amphibians of note include the four-toed salamander, spotted salamander, spring peeper, wood frog, and gray treefrog. These species are strongly affiliated with small, fish-free wetlands and are spottily distributed in the western mountains.

2. Eastern Box Turtles

The eastern box turtle (*Terrapene carolina*) is a relatively common reptile in the eastern United States, but virtually no studies have investigated how these animals utilize wetlands. In recent years, box turtle populations have been declining (Wilson 1995). Habitat loss and degradation, and collection for the pet trade have been blamed (Ernst et al. 1994). As a result, all species of *Terrapene* have been listed as Appendix II species of CITES (Convention on International Trade in Endangered Species of Wild Flora and Fauna). Disease also may be causing declines in populations of box turtles (e.g., Tangredi and Evans 1997, Rossell et al. in press).

At Tulula, maintaining a buffer zone around the restored wetlands has been proposed as a way to help protect the integrity of the site. Preliminary studies of box turtles at Tulula documented the movement of turtles from the wetlands into the drier, upland forests surrounding the site on a regular basis. Several turtles dug their hibernacula on the upland slopes. Our objectives were to monitor box turtle movements in the floodplain and surrounding area, develop a GIS map of home ranges and macrohabitats, quantify the type of microhabitats that the turtles were using, and investigate the nature of disease that was causing death in the population.

Methods

Box turtles were monitored from 1997-2000. A maximum of 10-15 turtles was radiotagged at any one time, depending on the number of transmitters that was available. As turtles were encountered, identification notches were filed in one or two scutes on the outer shell, following the system of Cagle (1939). The age of each turtle was estimated by the mean number of annual growth rings on four scutes (Ewing 1939). Sex was determined by external characteristics (males with red eyes and a deeper plastron depression than females; Stuart and Miller 1987).

A radiotransmitter engineered to fit the curvature of box turtle shells (Wildlife Materials, Inc.) was attached to each turtle by drilling two small holes in the edge of the turtle's carapace, and attaching the transmitter with galvanized wire. Transmitters were removed from turtles that died, moved far from the floodplain, or were attempting to cross roads. Once a transmitter became available, it was placed on the next turtle that was encountered. Once turtles were radiotagged, they were tracked with a TRX-1000s pll tracking receiver and a model F151-5FB antenna (Wildlife Materials, Inc.). Turtles were located at least once a week during the summer, and once every two weeks in the fall, until they entered their hibernacula.

In 1997 and 1998, microhabitat data were collected each time a turtle was located. Using the turtle location as the center of a 0.25-m^2 quadrat, data were collected on air temperature, ground surface temperature, and relative humidity (using a Protimeter PLC digital hygrometer), soil temperature (using a Weksler soil thermometer inserted 5 cm into the soil), canopy coverage (using a spherical densiometer held 0.5 m above the turtle, with readings taken in the four cardinal directions), and the proportions of bare soil, leaf litter, woody debris, and plant cover within the 0.25-m^2 quadrat (using visual estimates). Corresponding data were taken at a random point located within 25 m of every turtle location (random points were generated with a random number table). Data were analyzed using SAS. A series of paired t-tests were performed to determine whether the microhabitat variables used at actual turtle locations differed from the corresponding random locations.

In 1999, a Trimble TDIC 3300 GPS unit was used to record the coordinates of each turtle location. Coordinates were downloaded into a GIS system that overlaid the turtle locations onto a map of the site to produce maps of the home range of each turtle. The area and perimeter of each turtle home range were calculated using GIS, along with the proportion of habitat cover types within each home range (habitat cover types had been catalogued previously). An ANOVA was performed to determine whether home range area or perimeter, or habitat cover types differed for males and females.

When turtles showed signs of disease (e.g., ocular or nasal discharge), or died, notes were taken of the circumstances surrounding the symptoms or death. In 1997 and 1998, one recently deceased turtle each year was taken to the Western Disease Diagnostic Laboratory in Arden, NC, for necropsy. In August 1999, blood samples were taken from seven turtles with no clinical signs of disease, and sent to the Mycoplasma Research laboratory in Gainesville, FL, where they were tested for the presence of antibodies to *Mycoplasma agassizii*. *M. agassizii* is the organism known to cause the highly contagious and often fatal upper respiratory tract disease (URTD) in tortoises (Smith et al. 1998).

Results and Discussion

A total of 34 turtles (20 M, 12 F, 2 sex unknown) were monitored from 1997-2000. Twenty-two turtles (64%) were monitored < 1 yr, 8 turtles (24%) were monitored 1-2 yr, and 4 turtles (12%) were monitored 2-3 yr. The mean age was 22 years (Table 10).

Table 10. Sex and mean ages of eastern box turtles monitored from 1997-2000.

Variable	1997	1998	1999	2000
Number				
Male	12	12	4	3
Female	6	5	5	3
Mean age (yrs)				
Male	21	26	18	NA
Female	21	22	21	NA

When data from 1997 and 1998 were combined, ground surface temperature was significantly lower (P = 0.03) and canopy coverage was significantly higher (P < 0.001) at turtle-locations than at corresponding random points (Table 11), suggesting that turtles were seeking areas that were cool and shady. Overall, turtles were located in areas with moderate canopy cover (56%) and leaf litter (55%), little exposed soil (8%) and woody debris (6%), and low herbaceous plant cover (24%).

Table 11. Means (± SD) of microhabitat variables of actual and corresponding random locations (n = 64) of radio-tagged eastern box turtles during the summers of 1997 and 1998.

	Location	
Variable	Actual	Random
Air temp. (^{o}C)	26.4 (2.1)	26.6 (2.5)
Relative humidity (%)	8.5 (8.2)	47.5 (8.9)
Ground surface temp. (^{o}C)	25.2 (2.4)*	25.5 (2.5)
Soil temp. (^{o}C)	7.5 (2.2)	17.6 (2.3)
Canopy cover (%)	55.6 (31.7)**	46.6 (31.5)
Exposed soil (%)	8.2 (12.7)	5.1 (8.7)
Leaf litter (%)	55.3 (19.5)	58.3 (21.7)
Woody debris (%)	6.0 (8.1)	6.1 (12.4)
Herbaceous cover (%)	24.4 (14.5)	27.3 (15.2)

Note: * means differ at P < 0.05, ** means differ at P < 0.0001.

The home ranges of nine turtles monitored during 1999 are illustrated in Fig. 11. There were no differences in home range characteristics between male and female turtles for any of the parameters examined (all P > 0.05; Table 12). Forested habitats included montane oak-hickory forest, mesic hardwood forest, pine-oak forest, acidic cove forest, and fen forest. Open canopy habitats included grassy fields, shrub thickets, stream corridor, and road corridor. In general, turtle home ranges were dominated by forested habitats (66% of male home ranges, and 87% of female home ranges), with limited use of grassy fields and other open habitats.

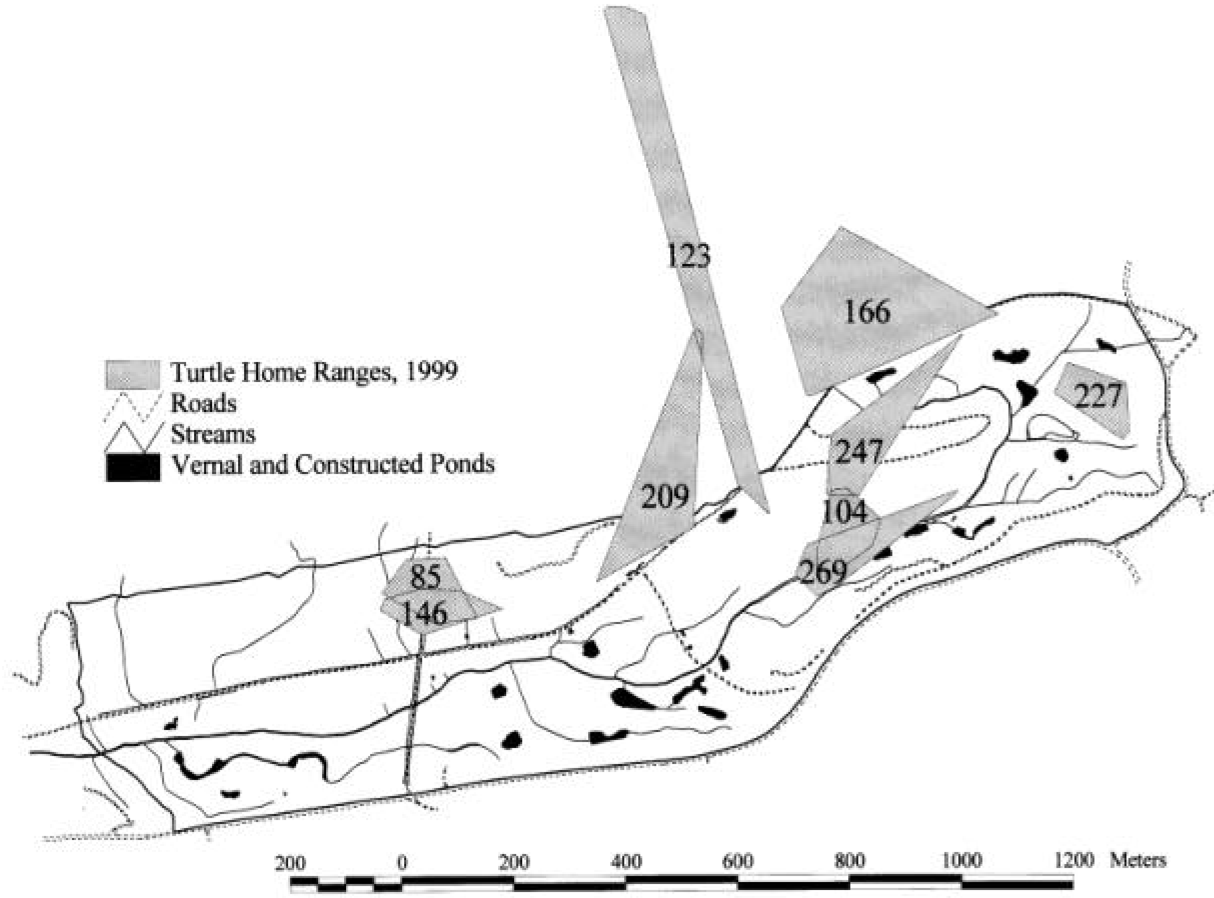

Fig. 11. Home ranges of nine eastern box turtles monitored during summer 1999. Numbers inside home ranges identify individual turtles.

During 1997-2000, 7 of 34 turtles (21%) died while being monitored. Five turtles (2 M, 2 F, 1 unknown) died in 1997, one turtle (1 M) died in 1998, and one turtle (1 M) died in 2000. Turtles that died in 1997 and 1998 all exhibited clear ocular and nasal discharge, and swollen eyelids prior to death. Clear ocular and nasal discharge also were observed in ca. 50% (n = 14) of turtles that did not die during 1997 and 1998. These signs generally manifested during the summer and disappeared within 1 to 4 weeks after the initial observation prior to hibernation. The turtle that died in 2000 exhibited labored breathing, coughing, and discharge of a large amount of yellowish exudate. This turtle also appeared listless and moved very little 1 to 2 d prior to death.

Table 12. Mean size of home ranges and proportion of habitat types used by nine radio-tagged eastern box turtles during summer 1999.

Variable	Male (n = 4)	Female (n = 5)
Total Area (m^2)	11,332	32,231
Perimeter (m)	506	1,076
Forest habitat types (%)		
Montane Oak-Hickory	18.2	83.2
Mesic Hardwoods	36.3	3.9
Fen Forest	1.4	0
Cove Forest	3.6	< 1
Pine-Oak Forest	6.8	0
Total (%)	66.3	87.1
Open habitat types (%)		
Grassy field	26.3	7.8
Shrub thicket	5.4	2.9
Stream corridor	0	1.8
Road corridor	1.9	0.4
Total (%)	33.6	12.9

Laboratory results from the two necropsied turtles indicated hemorrhaging and necrosis of internal organs, as well as bacterial cultures recovered from some organs. Results of the blood tests taken from turtles with no clinical signs of disease indicated that three turtles were seropositive, three were seronegative, and one was suspect for antibodies to *Mycoplasma* sp.

The disease that caused high mortality in this population of turtles is unknown. Necropsy results suggest that septicemia possibly caused the death of the two individuals examined. Septicemia is a major disease syndrome in reptiles and may be caused by a variety of gram-negative bacteria (Marcus 1981). Animals usually become infected through skin abrasions from contaminated soil or water (Marcus 1981). In snakes, clinical signs of this disease include respiratory distress and clear to purulent nasal discharge (Heywood 1968).

Another disease that may have caused mortality is URTD. Six of the seven turtles that died exhibited clear ocular and nasal discharge prior to death. These signs are the most common clinical signs of URTD in tortoises (Jacobson et al. 1991, Brown et al. 1994). Results of the blood tests also support the possibility that URTD may have been a factor in the deaths of turtles in this study. However, this could not be confirmed because the nasal cavities of the turtles were not swabbed and examined for *M. agassizii*.

Iridoviruses are another potential causal agent. Members of the genus *Ranavirus* are known to cause systemic disease in infected fish and amphibians and are associated with high morbidity and mortality (Mao et al. 1997). Recently, Mao et al. (1997) identified a *Ranavirus* sp. in an eastern box turtle and they expressed concern that local outbreaks of iridoviruses in fish or amphibians could quickly spread to neighboring reptile populations. From 1997-2000, mass mortality of wood frog (*Rana sylvatica*) and spotted salamander (*Ambystoma maculatum*) larvae was documented in ponds at Tulula. Necropsies of diseased larvae confirmed *Ranavirus* as the etiological agent of the mass mortality (D. Greene and K. Converse, USGS, National Wildlife Health Center, pers. comm.). However, samples from turtles have yet to be analyzed for viral infections.

E. Birds

Birds are the most commonly used animal indicator of environmental change, because they are relatively conspicuous and easy to monitor and quantify (Morrison 1986). The southern Appalachians support some of the highest diversities of breeding birds in the United States (Franzreb and Rosenberg 1997). Neotropical migrants comprise approximately 48% of the breeding species in the southern Appalachians (Franzreb and Phillips 1996). Many of these species (55-70%) are declining, particularly those that require early-successional habitats (Franzreb and Rosenberg 1997).

Mountain wetlands are important to bird conservation in the southern Appalachians because they provide early-successional habitats (Franzreb and Rosenberg 1997). These systems attract birds because their habitats are often unique and structurally complex (Boynton 1994). However, little is known about the avian faunas that inhabit mountain wetlands, because few comprehensive surveys have been conducted (Boynton 1994).

This section documents the avian fauna during pre-restoration conditions at Tulula. It provides a baseline for using birds and habitat in a long-term monitoring program to help evaluate restoration efforts at the site. Specifically, this section documents birds that utilized Tulula from 1994 to 2000; it quantifies the richness and abundance of breeding birds during 1994, 1998, and 2000; it explores the relationships between habitat structure and bird richness and abundance; and it characterizes the attributes of song perches used by Golden-Winged Warblers.

1. Bird Surveys

Methods

All birds heard or seen during field visits to Tulula were recorded from spring 1994 to fall 2000. In addition, breeding bird surveys were conducted during the springs of 1994, 1998, and 2000. In 1994, 12 transects were established at 50-m intervals across the study site. Along each transect 4-12 plots were located at 50-m intervals (N = 111). Plot centers were georeferenced using a global positioning system (GPS).

Surveys were conducted from sunrise until 1000 hrs. After a 1-min quiet time, all birds heard or seen within 25 m of the plot center were recorded during a 3-min period. Birds that flushed within 25 m of the plot center during the approach also were recorded. Plots were surveyed three times during each breeding season.

One hundred eleven plots were surveyed in 1994 to obtain a complete breeding bird list. In 1998 and 2000, 65 plots were surveyed (Fig. 12). Thirty-two plots were selected across the site, with each plot separated by at least 100 m. This greater distance between plots provided greater sample independence among plots by reducing the likelihood of double-counting birds (Pendelton 1995). An additional 33 plots were sampled where habitat data were collected in 1994 (see Bird-Habitat Relations below). Bird richness and relative bird abundance were calculated for 1994, 1998, and 2000 using the subset of 65 plots. Bird richness was defined as the total number of species, and relative bird abundance was defined as the total number of individuals of a species.

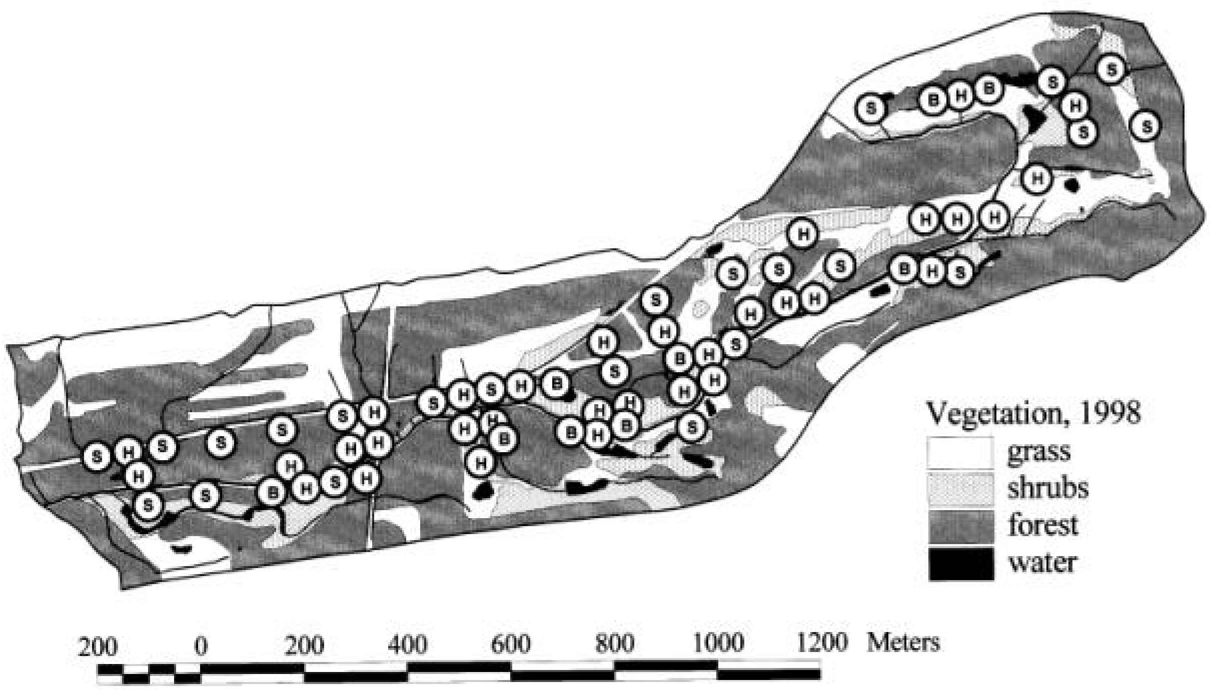

Fig. 12. Location of bird survey and habitat plots (25-m radius) used during 1994, 1998, and 2000. S = survey plots, H = habitat plots, and B = survey and habitat plots.

Results and Discussion

Appendix C lists the bird species observed at Tulula between 1994 and 2000. A total of 94 species, representing 33 families, were recorded. At least 47 species used Tulula as a breeding ground. Twenty-four species used Tulula as a foraging site and probably nested in the surrounding forests or residential areas. Twenty-three species were either spring or fall migrants or winter residents.

Results of the breeding bird surveys for 1994, 1998, and 2000 are presented in Table 13. Species richness increased 16% from 1994 to 1998 (31 to 36 species), and decreased 24% from 1998 to 2000 (36 to 29 species). There was an overall decline of 6% during the study period. Of the 41 species recorded during surveys, 54% (22 species) were neotropical migrants.

Three species (Belted Kingfisher, Northern Rough-winged Swallow, and Yellow Warbler) recorded during surveys were not breeding, but used Tulula for foraging or as a stopover during migration. Belted Kingfishers and Northern Rough-winged Swallows were commonly observed feeding on fish and insects, respectively, at Tulula. The Yellow Warbler recorded in 1998 was observed on only one day and was likely a late migrant.

Brown-headed Cowbirds probably bred for the first time at Tulula in 2000, but were not recorded during surveys. At least 1-2 pairs were observed during the 2000 breeding season. This was the only year during the 6-year study period that Brown-headed Cowbirds used Tulula as a breeding site. Brown-headed Cowbirds are an edge species that lay their eggs in the nests of other species and are regarded as a major culprit in the decline of neotropical migrants (Franzreb and Phillips 1996). Although cowbirds are not yet considered a problem in the southern Appalachians, their numbers are increasing throughout the region (Franzreb and Phillips 1996).

The number of birds recorded during surveys steadily declined during the study period. Overall, the relative abundance of birds decreased 43% from 1994 to 2000 (378 to 215 birds). Species showing the greatest decrease were neotropical migrants. Of the 11 most abundant neotropical migrants in 1994, 8 decreased, 2 increased, and 1 remained relatively constant during the study period. Of particular concern, was the 74% decrease in Golden-winged Warblers. Golden-winged Warblers are an edge species, with an affinity for hard edges which determine their territory boundaries (C.R. Rossell, Jr., pers. obs.). During the study period, natural succession has softened the edges between the fairways and forests, with the once grassy fairways now dominated by brambles and shrubs (Table 14). This natural succession may have diminished the habitat quality for Golden-winged Warblers.

Table 13. Relative abundance and migratory status of birds recorded during breeding bird surveys in 65, 25-m radius (0.2 ha) plots during 1994, 1998, and 2000.

Species	1994 Number	1998 Number	2000 Number	% Change 1994-2000	Migratory Status
Acadian Flycatcher	2	14	3	+ 50	N
American Robin	0	1	0	0	D
Belted Kingfisher	0	1	0	0	Y
Blue-gray Gnatcatcher	11	13	10	- 9	N
Brown Thrasher	1	0	0	- 100	D
Black-and-White Warbler	1	3	1	0	N
Blue Jay	0	2	0	0	Y
Carolina Chickadee	15	4	7	- 53	Y
Carolina Wren	3	6	3	0	Y
Common Flicker	1	0	0	- 100	Y
Common Yellowthroat	7	1	0	- 700	N
Chestnut-sided Warbler	23	2	7	- 70	N
Cedar Waxwing	9	10	4	- 56	D
Downy Woodpecker	6	1	2	- 67	Y
American Goldfinch	19	13	7	- 63	Y
Golden-winged Warbler	31	21	8	- 74	N
Gray Catbird	4	0	0	- 400	Y
Hooded Warbler	11	21	6	- 45	N
Indigo Bunting	83	55	15	- 82	N
Kentucky Warbler	17	9	9	- 47	N
Mourning Dove	0	2	0	0	Y
Northern Bobwhite Quail	0	0	2	+ 200	Y
Northern Cardinal	8	3	4	- 50	Y
Northern Parula	17	24	10	- 41	N
Northern Rough-winged Swallow	0	2	0	0	N
Ovenbird	2	6	2	0	N
Pileated Woodpecker	0	2	1	+ 100	Y
Red-eyed Vireo	21	28	28	+ 33	N
Ruby-throated Hummingbird	6	5	6	0	N
Rufous-sided Towhee	22	24	14	- 36	Y
Scarlet Tanager	0	1	1	+ 100	N
Song Sparrow	4	11	11	+ 175	Y
Swainson's Warbler	1	4	0	- 100	N
Tufted Titmouse	3	5	8	+ 167	Y
White-breasted Nuthatch	1	0	1	0	Y
White-eyed Vireo	22	26	29	+ 32	N
Wood Thrush	0	1	0	0	N
Yellow-breasted Chat	18	23	12	- 33	N
Yellow-throated Vireo	4	1	3	- 25	N
Yellow-throated Warbler	3	4	1	- 67	N
Yellow Warbler	0	1	0	0	N
Total Species	31	36	29	- 6	
Total Individuals	378	350	215	- 43	

Note: Migratory status from Hamel (1992).
N = Neotropical migrant, D = Short-distance migrant, Y = Year-round resident.

Table 14. Proportion (m^2) and percent change of four habitat classes during 1994, 1998, and 2000. Data were generated from digitized aerial photos for each respective year of study. See Section V for methods.

Variable	1994	Year 1998	2000	% Change 1994-98	1998-00
Grass	303,600	241,096	268,772	- 21	+ 11
Shrub	88,506	108,509	124,233	+ 23	+ 14
Forest	397, 754	434,958	391,530	+ 9	- 10
Water	33,184	38,480	38,528	+ 16	0

Swainson's Warbler, another species of high conservation concern (Franzreb and Phillips 1996), also declined during the study period, and was not observed at all in 2000. In the mountains, this species is associated with rhododendron (*Rhododendron* spp.) and mountain laurel (*Kalmia latifolia*) thickets (Hammel 1992). One to 4 pairs were thought to regularly nest at Tulula. The loss of this species coincided with stream restoration activities. Substantial amounts of relatively old-growth rhododendron were cut throughout the interior of Tulula in 1998 to survey and construct the new stream channel. These interior stands of rhododendron encompassed the majority of habitat used by Swainson's Warblers.

2. Bird-Habitat Relations

Methods

Habitat data were collected from 41 plots during the late spring and early summer of 1994, 1998, and 2000. Bird-habitat plots were selected in 1994 based on the criterion that they had at least one species recorded in two out of three surveys. Within each plot, herbaceous cover, shrub thickness, and canopy cover were estimated at 16 points along two perpendicular transects. Understory (2.5-10 cm dbh) and overstory (> 10 cm dbh) tree densities also were estimated in each plot using the closest individual method (Bonham 1989). Herbaceous cover was estimated for vegetation < 0.5 m in height using a 0.25-m^2 quadrat. Shrub thickness was estimated for vegetation 0.5-2 m tall using a shrub profile board (Hays et al. 1981). Canopy cover was estimated using a spherical densiometer (Hays et al. 1981). Areal amounts of grass, shrub, forest, and water for each of the 41 plots also were estimated using digitized aerial photos and a geographic information system (see Section IV. GIS SUPPORT for methods).

Bird richness and relative bird abundance were calculated for each plot for 1994, 1998, and 2000. Cedar Waxwings and American Goldfinches were excluded from the analysis because their flocking behavior tended to inflate estimates. Correlation analysis was used to examine associations between the habitat variables and bird richness and relative bird abundance. Analysis of variance tests were used to compare differences among years for bird diversity, relative bird abundance, and the habitat variables.

Results and Discussion

Means of bird richness, relative bird abundance, and habitat variables for the 41 habitat plots are summarized in Table 15. Both bird richness and relative bird abundance were significantly lower in 2000 than in 1994 and 1998 ($P < 0.0003$ and $P < 0.0001$). In addition, shrub thickness and canopy cover were significantly lower in 1998 than in 1994 and 2000 ($P < 0.014$ and $P < 0.033$). All other habitat variables were similar among the three years of study (all $P > 0.05$). Correlations between bird richness or relative bird abundance and the habitat variables were extremely low (all Pearson r, between -0.09 and 0.06).

The trends in bird richness and relative bird abundance found in the habitat plots were similar to and support the results of the breeding bird surveys. Reasons for the declines in the avian fauna at Tulula are unclear. The extremely low associations between bird richness and abundance and the habitat variables may reflect the highly diverse structure of the habitat among sample plots. This diverse structure is indicated by the large standard deviations of the habitat variables in Table 15. Unfortunately, the heterogeneity of the habitat makes interpreting the habitat data difficult.

Table 15. Means (± SD) of bird richness, relative bird abundance, and habitat variables for 41, 25-m radius (0.2 ha) plots during 1994, 1998, and 2000.

Variable	Year 1994	1998	2000
Bird Diversity	4.6 ± 2.1a	4.0 ± 1.8a	2.8 ± 1.9b
Relative Bird Abundance	6.6 ± 3.0a	5.2 ± 2.8a	3.4 ± 2.3b
Herbaceous Cover (%)	60.0 ± 17.5	53.9 ± 20.6	52.4 ± 17.9
Shrub Thickness (%)	35.2 ± 15.9a	28.5 ± 14.7b	38.9 ± 17.7a
Canopy Cover (%)	59.2 ± 23.8a	45.4 ± 21.8b	51.7 ± 25.0a
Understory Tree Density (no./0.2 ha)	11.5 ± 15.3	6.3 ± 18.8	21.7 ± 27.1
Overstory Tree Density (no./0.2 ha)	7.1 ± 13.9	7.6 ± 13.8	10.8 ± 20.5
Grass (m^2)	716.1 ± 716.2	560.8 ± 487.0	763.5 ± 537.1
Shrub (m^2)	437.4 ± 540.7	526.5 ± 508.8	402.1 ± 390.6
Forest (m^2)	697.1 ± 662.9	740.0 ± 655.8	653.6 ± 594.7
Water (m^2)	127.5 ± 147.6	151.6 ±154.2	158.9 ± 179.3

Note: Values followed by the same or no letters are not significantly different across rows at $P > 0.05$.

Overall, the majority of succession at Tulula has been from grass to shrubs. The proportion of forested habitats on site has remained relatively constant throughout the study period, while there has been an 11% decrease in grassy habitats and a 9% increase in shrubby habitats (Table 14). Most of the bird species that breed at Tulula are neotropical migrants that require a diversity of edge and early-successional habitats for nesting. The succession of grass to shrubs at Tulula may have reduced the quality and quantity of edge habitat, as well as diminished the diversity of early-successional habitats. This loss of habitat diversity may have impacted the carrying capacity of the habitat for early-successional breeding birds.

In 1998, stream restoration activities included cutting trees and shrubs along the new and existing stream corridors in the interior of the floodplain. This loss of mature habitat structure may have reduced the quality of habitat to the point where bird species richness and abundance were negatively affected. The reduction of trees and shrubs is reflected in the significant decrease in shrub thickness and canopy closure in the habitat plots during 1998 (Table 15). The increase in grass and decrease in shrub and forest in the habitat plots in 2000 also reflect restoration activities (Table 15). The 1998 data derived from aerial photography do not reflect restoration activities, because the photos were taken during the winter, prior to the start of restoration.

Natural population fluctuations of individual species also may have influenced the trends in bird numbers. Thus, long-term monitoring is required to minimize the possible biases associated with the natural variability of the avian fauna. Breeding bird surveys are planned for 2002. This additional year of data will help to evaluate the apparent decline in birds and the effects of succession and restoration.

3. Golden-winged Warbler Song Perches

Golden-winged Warblers are a species of high conservation concern and are listed as "significantly rare" in North Carolina (LeGrand and Hall 1999). Golden-winged Warblers are one of the most abundant species breeding at Tulula (Rossell et al. 1999). Few studies have investigated the habitat features that are important to Golden-winged Warblers. Song perches are known to be important because they act as stimuli to females when selecting a mate (Ficken and Ficken 1968). Field observations at Tulula suggest that Golden-winged Warblers select song perches with specific characteristics, such as close proximity to water (Rossell 2001). Knowing what song perch attributes Golden-winged Warblers select may provide guidelines for management of this imperiled species.

Methods

Song perches of ten territorial male Golden-winged Warblers were located from 26 May to 18 June 1998. Song perches were defined as any site where a male sang three consecutive type I songs (the song type used for mate attraction; Highsmith 1989). Perch sites were recorded once, although many were used repeatedly. At each song perch, relative perch height (1-5, 1 = lower 25% of tree canopy, 4 = upper 25% of tree canopy, 5 = top of tree), relative tree height (1 = canopy, 2 = subcanopy), diameter at breast height (dbh), distance to the closest forested edge, and distance to semipermanent or permanent water were recorded. Individual males were identifiable because territories were discrete and well defined. Territory boundaries were delineated by perch locations and mapped using global positioning and geographic information systems. Territories were usually separated by a forested edge and were > 34.6 m apart.

For each song perch, a corresponding random perch was identified to determine whether perch characteristics differed from those available in the surrounding habitat. Random perch trees were located using a random numbers table to generate a compass bearing and a distance of < 25 m from the perch site. Because males usually deliver type I songs above the shrub layer (Confer 1992), random perch trees were defined as a tree or shrub > 4 m in height. Once a random tree was located, perch characteristics were recorded as described above. Relative perch height was determined using a random numbers table.

Means for each bird were calculated for dbh, distance to forested edge, and distance to water for actual and randomly selected perch trees. Paired t-tests were used to compare actual vs. random attributes. Interaction effects among birds were also examined for these attributes, using repeated measures ANOVAs. For each comparison, a Bonferroni-type adjustment of the alpha level was used (Tabachnik and Fidell 1989). The experimentwise error rate was set at 0.1, and the comparisonwise error rate (alpha level) was set at 0.033. Summary statistics were calculated using the means for each bird to avoid pseudoreplication.

Results and Discussion

Table 16 summarizes the characteristics of 87 song perches. The majority of sites (78%, *n* = 68) were located in the upper 25% of the tree canopy. One perch was located at the top of a tree, and none were located in the lower 25%. The remaining 21% (*n* = 18) were evenly distributed among the second and third quartiles of the canopy.

Table 16. Attributes of actual and randomly selected song perches (n = 87) of Golden-winged Warblers during the summer of 1998.

	Actual		Random				
Variable	Mean	SE	Mean	SE	*t*	df	*P*
Dbh of perch tree (cm)	40.0	2.8	22.0	2.0	4.56	9	< 0.001
Distance to forested edge (m)	0.6	0.2	2.3	0.6	2.79	9	< 0.024
Distance to water (m)	29.3	8.0	32.9	8.5	2.71	9	0.024

Ninety percent (n = 78) of song perches were in canopy trees, compared to 33% (n = 29) of the randomly selected perches. Perch trees were significantly larger, as well as significantly closer to a forested edge and water than randomly selected trees (Table 16). Fifty-one percent (n = 44) of perches were < 15 m from water, with no significant correlation between proximity to water and distance to a forested edge (r = 0.55, P = 0.10). No significant interactions were found among birds for any attribute (all P > 0.18), except proximity to water (P < 0.0001; Table 17).

Table 17. Proximity of song perches to water (m) for ten Golden-winged Warblers during the summer of 1998.

Bird	*n*	Mean	SE	Range
1	14	8.5	3.2	3-42
2	4	16.3	10.8	2-48
3	5	23.2	7.6	9-52
4	8	57.9	8.1	25-97
5	12	28.3	4.5	5-46
6	4	90.0	58.6	11-260
7	6	13.8	4.3	5-31
8	16	21.5	3.9	3-53
9	12	10.5	2.9	1-28
10	6	12.7	4.3	4-33

Golden-winged Warblers selected song perches with consistent attributes for type I singing. Eight of the 10 males presumably attracted a mate, because they were observed on more than one occasion accompanying females on their territories.

Males selected an overwhelming majority of perches in the upper quarter of large canopy trees on the edge of wooded areas. This suggests that males were choosing sites that enhanced their ability to display vocally and visually to attract a mate. Higher perches on the edge of wooded areas likely provide greater conspicuousness and better song transmission by reducing potential vegetational interference. No perches were observed low in the canopy or in the shrub layer. In contrast, Highsmith (1989) observed males occasionally singing type I songs from low perches in thick vegetation.

Interestingly, song perches were closer to water than expected, suggesting that water is an important attribute of a territory. However, not all birds in the study selected perches in close proximity to water. This disparity probably reflects the uneven distribution of water across the study site. In areas where water was prevalent, males were frequently observed singing above or adjacent to it. Water also was considered important to Golden-winged Warblers in Michigan; its presence apparently prevented them from being displaced by Blue-winged Warblers (Will 1986).

The ecological significance of water is uncertain. General observations suggest that areas near water may have a greater diversity and abundance of insects. Thus, the presence of water in a territory may be advantageous because of the greater food resources available for provisioning young. Further research, however, needs to be conducted to determine how water benefits Golden-winged Warblers at Tulula.

F. Mammals

Wetlands in the southern Appalachians are known to provide important habitat for mammals (Boynton 1994), including rare species such as the star-nosed mole (*Condylura cristata parva*) and southern bog lemming (*Synaptomys cooperi*) (Murdock 1994). However, since few comprehensive faunal surveys have been conducted in these systems (Boynton 1994, Moorhead and Rossell 1998), little is known about their mammal communities.

Small mammals are of particular interest because they are often associated with specific microhabitat features (Price 1984). The ecological behavior of a species can vary across its geographic range (Brown 1984) as well as within different community types (e.g., Seagle 1985, Rossell and Rossell 1999). Therefore, obtaining quantitative information on how small mammals use southern mountain wetlands may be important for conservation and restoration purposes.

1. Faunal Surveys

Methods

Small mammals were surveyed from August to October 1994 using Sherman live traps (7.6 x 7.6 x 25.4 cm) and drift fences with pitfall traps. Live traps were placed in a variety of habitats across Tulula at a density of 1 trap/100 m^2. Additional traps were wired to tree trunks to survey for arboreal species. Traps were baited with rolled oats and peanut butter and left open for 24 hrs/day to capture diurnal and nocturnal animals. Traps were checked daily in the early morning. Voucher specimens are kept in the UNCA Biology Department Zoological Collection (Rossell et al. 1999). Medium and large mammals were surveyed using visual observations and other signs of activity, including tracks and scats throughout the study period (summer 1994 - fall 2000).

Results and Discussion

A list of mammals that utilized Tulula during the study period is provided in Appendix D. Thirty-two species, representing 16 families were recorded. Most of the species are relatively common in the mountains. However, the little brown bat (*Myotis lucifugus*), meadow jumping mouse (*Zapus hudsonius*), and black bear (*Ursus americanus*) are listed on the "North Carolina Animal Watchlist" (LeGrand and Hall 1999). The little brown bat and meadow jumping mouse are considered rare to uncommon in North Carolina, but populations of these species probably are not in jeopardy (LeGrand and Hall 1999). The black bear is common in North Carolina, but has been placed on the Watchlist because of increasing threats to its habitat (LeGrand and Hall 1999).

Most of the small mammals captured at Tulula probably breed on site. The meadow jumping mouse occurred only in the fen and surrounding wet, grassy areas. In contrast, the meadow vole was found only in the drier, grassy fairways. The white-footed and golden mouse both occurred most often in wooded areas, with the white-footed mouse generally occurring in thicker woodlands.

Probably all of the species documented at Tulula used the site for foraging. Many species were closely associated with water, and were observed or captured around the creek and ponds. These included the muskrat, beaver, raccoon, and all five species of bats. Black bears as well as many other species foraged on the abundant and diverse fruit supply found at Tulula. Black bears were observed every year of the study when the *Rubus* spp. berries became ripe.

The high diversity of mammals found at Tulula is a result of the wide range of successional habitat types. Management efforts should focus on maintaining successional diversity as well as increasing the size of some of the more mature interior woodlands.

2. Fen Study

Methods

A permanent grid of 93, 10 x 10 m plots was established throughout the fen. A Sherman live trap (7.6 x 7.6 x 25.4 cm) was placed near the center of each of 50 randomly selected plots (25 in the open canopy area and 25 in the closed). Traps were baited with rolled oats to minimize lure effects and ensure that only animals using the plot were sampled (Dueser and Shugart 1978). Sampling occurred during 3, 3-day trap sessions held at 1-2 week intervals between 26 June and 3 August 1995. To avoid the effects of seasonal microhabitat shifts, trapping was limited to the summer months (Kitchings and Levy 1981). Traps were set daily between 1600 and 1700 hrs, and checked between 0700 and 1000 hrs the following day. Due to the high water table across the site, pitfall traps were not an option as part of the survey efforts. Captured animals were identified to species, sexed, marked on their abdomen with a permanent marker, and released at the capture site.

Microhabitat characteristics in the 50 plots were measured between 20 June and 25 July 1995. Microtopography (hummock, hollow, or flat), herbaceous cover, presence of moss, understory thickness, and canopy closure were determined at 9 points along two diagonal transects within each plot. Overstory and understory tree density and the total length of down logs were measured in each plot. Sampling procedures used for each variable are provided in Table 18.

Because of sample size constraints, microhabitat associations were examined for only the two most abundant species, the white-footed mouse (*Peromyscus leucopus*) and golden mouse (*Ochrotomys nuttalli*). Each of the 50 plots was assigned to one of three types: those in which white-footed mice were captured, those in which golden mice were captured, or those in which neither species was captured. Eight plots were included in two groups because they were capture sites of both species. Consequently, the analysis is conservative for distinguishing differences in microhabitat variables between plot types (Dueser and Shugart 1978). Plot type was used as the independent variable in all analyses.

Table 18. Sampling procedures for measuring microhabitat variables in each of 50, 10 x 10 m plots in Tulula fen.

Variable	Method
Herbaceous cover	Mean cover (%) of foliage < 0.5 m estimated at nine points using 0.25-m^2 quadrat.
Shrub thickness	Mean cover (%) of vegetation 0.5 to 2 m sampled at nine points using shrub-profile board (Hays 1981).
Canopy closure	Mean canopy closure (%) sampled at nine points using concave spherical densiometer (Hays 1981).
Woody debris	Total length (m) of logs > 10 cm diameter.
Microtopography	Percent of nine sample points designated as flat, hummock, or hollow.
Moss	Percent of nine sample points covered by moss.
Shrub density	Total stem count (stems/100 m^2) of woody species 2.5 to 10 cm dbh, measured in a 4x4m plot.
Tree density	Total stem count (stems/100m^2) of trees > 10 cm dbh in a 10x10m plot.

An ANOVA was used to compare the three plot types for each of the ten microhabitat variables. If a significant difference occurred, then Tukey's multiple comparison procedure was used to determine which plot types differed. A Bonferroni-type adjustment of the alpha level was used because multiple comparisons were made (Tabachnik and Fidell 1989). The experimentwise error rate was set at 0.1, with a comparisonwise error rate (alpha level) of 0.003.

A discriminant function analysis was performed to determine which microhabitat variables best distinguished the three groups. This technique identifies linear combinations of variables (canonical variates) that differentiate among groups (Williams 1983).

Results and Discussion

A total of 92 captures of four species occurred during 432 trap nights in the fen. These included 3 captures of 3 meadow jumping mice, 5 captures of 4 short-tailed shrews (*Blarina brevicauda*), 39 captures of 10 white-footed mice, and 45 captures of 13 golden mice.

The results of the ANOVA comparing the ten microhabitat variables among the three plot types are presented in Table 19. None of the variables differed significantly between the two types of mouse plots (Table 20). Both types of mouse plots were characterized by significantly less herbaceous cover and significantly more canopy closure than no-capture plots. Overstory tree density was significantly greater in white-footed mouse plots than in no-capture plots.

Table 19. ANOVA results comparing microhabitat variables in Tulula fen for three types of plots: those where white-footed mice were captured, those where golden mice were captured, and those where neither species was captured (alpha = 0.003).

Variable	F	$P \geq F$
Herbaceous cover	12.1	0.0001
Shrub thickness	0.3	0.7103
Overstory cover	15.5	0.0001
Woody debris	3.5	0.0366
Flat	0.0	0.9777
Hollow	1.1	0.3464
Hummock	0.2	0.8094
Moss	3.9	0.0257
Shrub density	0.4	0.6601
Tree density	8.3	0.0007

Table 20. Means (± SD) of microhabitat variables in Tulula fen for three types of plots: those where white-footed mice were captured (P), those where golden mice were captured (O), and those where neither species was captured (N).

		Plot type	
Variable	P	O	N
Sample size (N)	15	23	20
Herbaceous cover (%)	65.7±9.3b	70.1±12.4b	82.5±9.6a
Shrub thickness (%)	33.3±12.4	35.5±11.8	37.4±18.0
Overstory cover (%)	92.7±3.5a	73.0±28.5a	48.1±26.4b
Woody debris (m)	10.8±12.6	7.7±12.1	2.0±3.4
Flat (%)	22.0±14.2	22.6±17.1	21.5±19.0
Hollow (%)	8.7± 8.3	7.8±8.0	12.0±12.0
Hummock (%)	69.3±12.8	65.2±21.7	66.5±19.8
Moss (%)	41.3±21.3	41.7±22.7	58.0±19.4
Shrub density (no./100m^2)	30.0±30.5	27.5±29.4	38.8±57.6
Tree density (no./100m^2)	4.8±3.1a	3.2±3.9ab	0.7±1.6b

Note: Values followed by the same or no letter are not significantly different across rows at $P > 0.003$.

Two canonical variables resulted from the discriminant function analysis. The first variable had a canonical correlation of 0.6783 and accounted for 91.0% of the variability. The second canonical variable had a correlation of 0.2784 and accounted for 9.0% of the variability.

The first canonical variable (Can1) had a high positive loading for herbaceous cover and high negative loadings for canopy closure and tree density (Table 21). The second canonical variable (Can2) had no well-defined interpretation but had the highest positive loadings for canopy closure, moss, hummock, and hollow. In a plot of the discriminant analysis, Can1 separated the three groups along the x-axis, but Can2 provided little separation along the y-axis (Fig. 13).

Table 21. Canonical coefficients for microhabitat variables in Tulula fen.

Variable	Can1	Can2
Herbaceous cover	0.7072	0.1607
Shrub thickness	0.1421	-0.1625
Canopy closure	-0.8076	0.3437
Woody debris	-0.3601	-0.0312
Flat	0.0077	-0.1477
Hollow	0.1824	0.3090
Hummock	-0.0635	0.3183
Moss	0.3380	0.4558
Shrub density	0.1195	0.1776
Tree density	-0.5941	0.1246

It is difficult to comment on the species richness in the fen, because small mammals have not been surveyed in other mountain fens. In general, however, the species richness was similar to that reported in eastern Tennessee upland forests (Dueser and Shugart 1978, Kitchings and Levy 1981), and greater than that reported in a Tennessee cedar glade (Seagle 1985).

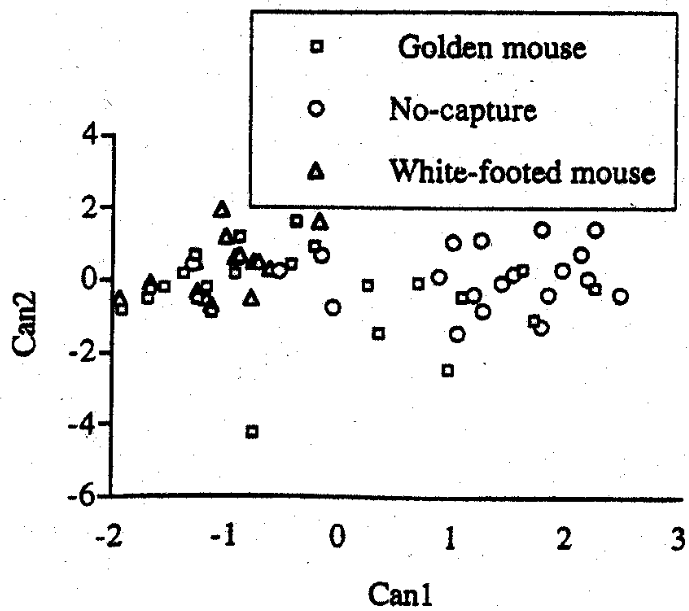

Fig. 13. Discriminant analysis of the 10 microhabitat variables for sample plots where: white-footed mice were captured, golden mice were captured, or neither species was captured. Can1, from left to right, is a gradient from high canopy closure and tree density, to high herbaceous cover. Can2, from bottom to top, represents a combination of variables, including shrub thickness and microtopography, to herbaceous cover and canopy closure.

White-footed and golden mice accounted for 91% of all captures in the fen. These species also were reported as the most abundant small mammals in the Great Dismal Swamp in Virginia and North Carolina (Rose et al. 1990) and in a cedar glade in eastern Tennessee (Seagle 1985). White-footed and golden mice both occurred in plots with moderate herbaceous cover (x = 66% and 70%, respectively) and relatively high canopy closure (x = 93% and 73%, respectively) (Table 3). No white-footed mice were captured in open areas of the fen. Other studies also have reported that white-footed mice selected wooded rather than open areas (Kitchings and Levy 1981, Kaufman et al. 1983), possibly to avoid predators (Kaufman et al. 1983).

In deciduous forests, white-footed mice are considered habitat generalists (King 1968), while golden mice are considered greater specialists (Linzey and Packard 1977). These patterns of habitat use are supported by other studies in deciduous forests (Dueser and Shugart 1978, Kitchings and Levy 1981, and Seagle 1985). However, in a structurally complex cedar glade, Seagle (1985) found that white-footed mice were habitat specialists, selecting areas with greater tree densities, while golden mice were greater generalists. A similar pattern occurred in this study, where white-footed mice were more selective than golden mice, tending to occur in areas with greater canopy closure and higher tree densities. These findings suggest that habitat complexity is associated with resource partitioning between these two species.

III. RESTORATION EFFORTS

A. Vernal Ponds

Amphibians are currently undergoing a marked global decline in both temperate and tropical ecosystems (e.g., Laurence et al. 1996, Lips 1998, Houlahan et al. 2000, Alford et al. 2001). In particular, many North American species have declined due to environmental degradation from timber harvesting and deforestation, agriculture, urbanization, stream pollution and siltation, the introduction of exotic predators, acid deposition, increased UV-B radiation associated with stratospheric thinning of the ozone, emerging diseases, and the widespread loss of wetlands (e.g., Dunson et al. 1992, deMaynadier and Hunter 1995, Stebbins and Cohen 1995, Drost and Fellers 1996, Blaustein and Kiesecker 1997, Green 1997, Daszak et al. 1999).

Frogs and salamanders are important faunal elements of many wetland systems in the eastern United States and function as both primary consumers (tadpoles) and upper-level predators (larval salamanders; adult frogs and salamanders). Fish-free habitats such as vernal ponds, mountain fens, small oxbows, seepages, and headwater streams are primary breeding sites for many amphibians, but have received little or no legal protection because of their small size (surface area generally < 1 ha).

Amphibians are increasingly being used as indicator species in restoration projects for small freshwater wetlands (e.g., Pechmann et al. 2001) because they are often community dominants, are sensitive to site hydrology, and can be easily monitored to assess ecosystem function. Amphibians play key ecological roles in wetlands such as those found in the southern Appalachian Mountains, and are the dominant vertebrate group in standing water habitats at Tulula. Because a major goal of wetlands restoration is to restore ecosystem integrity (e.g., to create functional ecosystems where all major community elements are sustained at viable levels), the response of amphibians to site restoration is a useful indicator of ecosystem function. This study is the first that we are aware of in North Carolina to examine how pond-breeding amphibians respond to wetland restoration efforts.

Because of their strong reliance on small, seasonally ephemeral habitats for breeding, the reproductive success of many amphibian species is strongly influenced by hydroperiod (seasonal duration of ponds and headwater streams). The hydroperiod affects the likelihood of amphibian larvae reaching a minimum developmental stage to complete metamorphosis. It also influences the distribution and abundance of predators such as fish and aquatic insects that feed on amphibian eggs and larvae. Short hydroperiods during periods of drought can result in catastrophic mortality of larvae due to premature pond drying, but also reduce or eliminate aquatic predators. Long hydroperiods during wet years provide ample time for amphibian larvae to complete metamorphosis, but may result in heavy mortality from predators, such as dragonfly larvae and red-spotted newts, that prefer semi-permanent ponds.

At the initiation of the study in 1994, the site contained aquatic habitats that varied from highly ephemeral to permanent ponds. Most natural breeding sites were filled and destroyed during golf course construction. During a detailed survey of the site during 1994-1995, we located 155 standing-water habitats that included 11 permanent ponds that were constructed as golf course obstacles. These contained predatory fish (bluegills, largemouth bass) and were not used as breeding sites by most resident amphibians.

The remaining 144 sites were fish-free, temporary (seasonally ephemeral) habitats that were mostly small, shallow depressions. These included tire ruts, test wells for pond sites, sluggish ditches, and stream cut-offs associated with the channelization of Tulula Creek. The median depth, surface area, and volume of temporary habitats when at full capacity were 13.7 cm, 12.1 m^2, and 1.7 m^3 of water, respectively. The largest site was a natural vernal pond with a surface area of 2,607 m^2. Collectively, seasonally-ephemeral breeding sites at Tulula in 1993-1994 comprised an estimated 7,050 m^2 (0.7 ha) of surface area and 1,018 m^3 of water when at full capacity.

Monitoring of temporary habitats during 1994-1995 indicated that most were of very low quality because of altered site hydrology associated with stream channelization, ditching, and the filling of low-lying areas. All species of vernal pond-breeders suffered high larval mortality during 1994 and 1995 because most breeding sites dried prematurely before tadpoles or salamander larvae could complete their larval stages. Despite heavy rains in late winter and early spring, about 75% of the breeding sites dried prematurely in 1994 and 60-70% in 1995. In contrast, all but 1 of 20 vernal ponds sites that we monitored at other locations in the southern Appalachians held water throughout the spring and summer of both years (J. W. Petranka, unpublished data). These observations indicated a need to construct larger and deeper ponds to replace natural breeding sites that were destroyed during golf course construction.

Ten vernal ponds were constructed between October 1995 and January 1996 to replace natural breeding habitats that were destroyed during golf course construction. Depth and contour were manipulated to create seven temporary and three permanent fish-free ponds that provide suitable habitat for all pond-breeding amphibians at Tulula. Ponds were placed spatially to provide metapopulation structure (Fig. 14). This design allowed both a degree of demographic independence and interconnectivity via dispersal. We selected 10 of the largest existing breeding sites as reference ponds to compare hydrological, physiochemical, and biotic characteristics.

Thirteen new breeding sites were also created in the fall of 1999 when golf course ponds were either filled or partially filled to create shallow ponds. Most of these were stream-fed, and now exist as shallow, permanent sites that contain small fish. In others, fish were eliminated and the sites were converted into temporary ponds. Sections of the restored stream channel also were temporarily blocked with check dams to allow channel revegetation prior to restoring stream flow. Small pools formed in the deepest sections of these channel segments and were used as breeding sites by resident amphibians. The site currently contains 23 constructed ponds and about 10 smaller breeding sites.

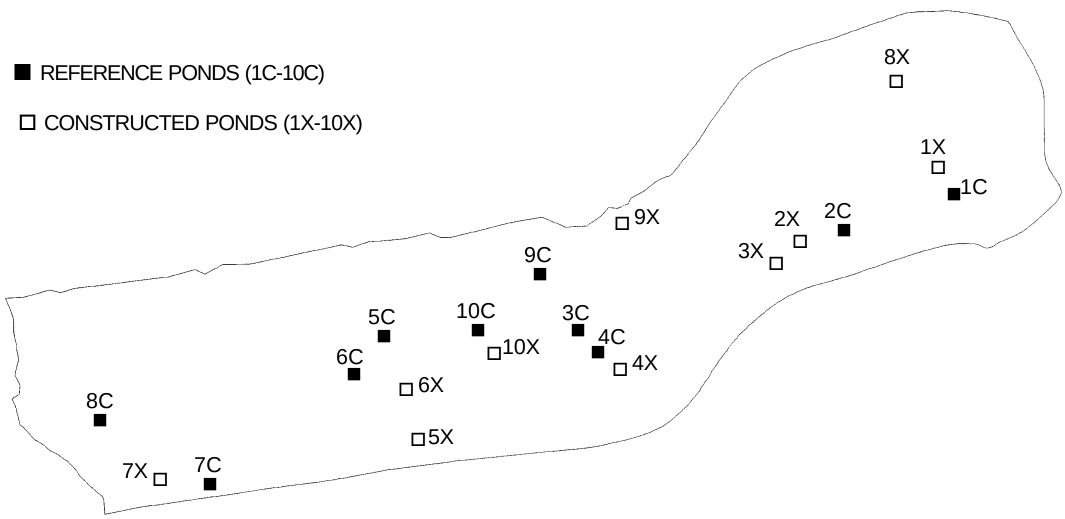

Fig. 14. Location of constructed vernal ponds and reference ponds within the study site.

1. Physiochemical characteristics of ponds.

Methods

Physiochemical characteristics of the 10 constructed and 10 reference ponds were compared by sampling at 1 to 4 week intervals to obtained data on pond pH, temperature, conductivity, and oxygen saturation. Samples were taken during the day (900-1700 hrs) and all constructed and reference ponds were sampled haphazardly during the same day. Water temperature was measured and three subsamples of water were taken from each pond at approximately equidistant points along the center of the long axis and approximately 10 cm below the water's surface. Subsamples were pooled and readings were taken from the pooled sample. Samples were placed in a cooler with ice during warm weather and dissolved oxygen was measured in the field < 3 hours after samples were collected using Corning Check-mate© meters. Conductivity and pH were measured using Corning Check-mate© and Corning 430© bench meters, respectively. We used the yearly mean for all seasonal samples in statistical comparisons of reference and constructed ponds.

Results and Discussion

Reference ponds were smaller and shallower than constructed ponds, which could influence physiochemical characteristics. At full capacity, surface areas of reference ponds averaged 82.5 m^2 (range = 13.5-220 m^2) versus 480 m^2 (range = 225-923 m^2) for constructed ponds. Respective values for maximum depths were 34 cm (range = 13-60 cm) and 62 cm (range = 38-87 cm). Comparisons of physiochemical characteristics of constructed and reference ponds from 1996-2001 are in Fig. 15.

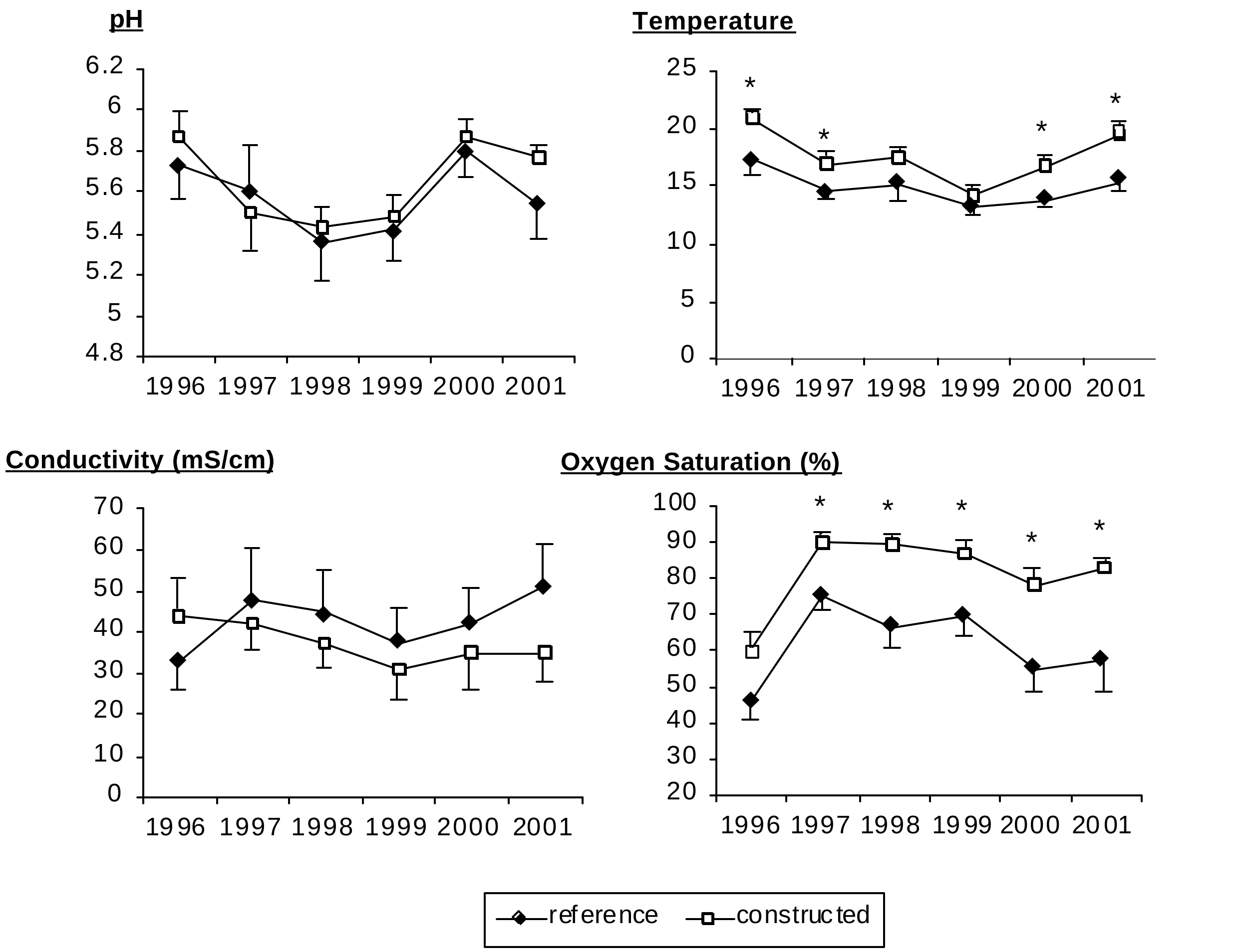

Fig. 15. Physiochemical characteristics of reference and constructed ponds. Symbols are annual means based on 3-19 seasonal samples per year. Vertical bars are 1 SE. Asterisks indicate means that differed significantly within years.

Respective grand means (+ 1 SE) based on annual averages for reference versus constructed ponds were 5.57 (0.07) versus 5.65 (0.05) for pH, 14.9 ^{o} C (0.39) versus 17.6 ^{o} C (0.35) for temperature, 42.5 (3.83) versus 37.3 (2.83) µS/cm for conductivity, and 61.9 (2.66) versus 81.4 (1.89) for percent O_2 saturation. T-tests (alpha = 0.05) indicate that means for pH and conductivity did not differ significantly for any year (pH: $P > 0.16$; conductivity: $P > 0.19$). However, constructed ponds were significantly warmer in four of six years and had significantly higher oxygen saturation levels in all but one year.

2. Use of constructed and reference ponds by amphibians.

We conducted several ecological studies to determine how seasonal hydrology, predator distributions, and predator-prey interactions influence community composition (e.g., Petranka et al. 1994, Hopey and Petranka 1994, Petranka et al. 1998, Petranka and Kennedy 1999). This information was used to design the 10 fish-free ponds (referred to as "constructed ponds") that were dug between October 1995 and January 1996 to replace natural breeding habitats that were destroyed during golf course construction. All constructed ponds filled with water before amphibians began breeding in February 1996. The use of constructed and reference ponds (see Fig. 14) by amphibians as been monitored since January 1996.

Methods

We monitored all constructed and references ponds annually to determine patterns of use by resident species. We visited ponds every 1 to 3 weeks between January-August and searched for amplexed adults, eggs, or larvae. Larvae were collected when conducting open-bottom sampling to estimate survival (see below) and when ponds were dip-netted periodically during the spring and summer to sample resident amphibians.

Results and Discussion

Resident amphibians rapidly colonized constructed ponds that first filled in 1996 (Fig. 16). Eight species of amphibians bred in the constructed ponds within 1 year of construction and 10 species have used the ponds through 2001. These are the wood frog, green frog, bullfrog, gray treefrog, spring peeper, American toad, spotted salamander, red salamander, three-lined salamander, and the red-spotted newt (Appendix B). Reference ponds were also used by 10 species of amphibians and only one, the two-lined salamander, was unique to reference ponds (breeding in 1 of 10 reference ponds). The only species unique to constructed ponds was the bullfrog, which prefers permanent or semipermanent habitats.

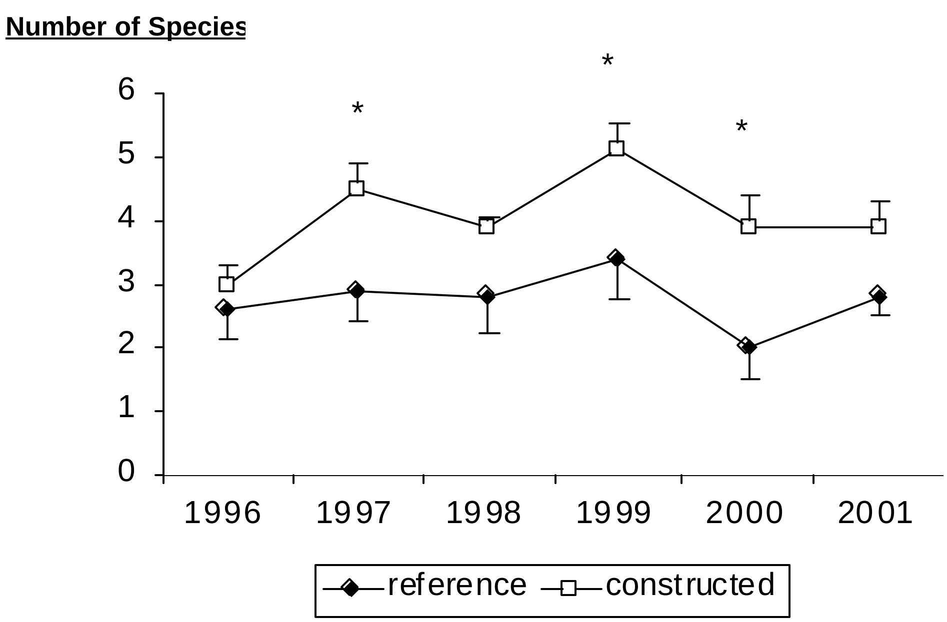

Fig. 16. Mean number of species that bred in reference and constructed ponds. Symbols are means and bars are + 1 SE. Years with asterisks are significantly different.

Overall, constructed ponds contained a significantly greater number of breeding species (mean + 1 SE = 4.05 + 0.17 species) than reference ponds (2.75 + 0.21 species) during the 6-year period (paired t-test; $P < 0.0001$). For individual years, the mean number of species per pond was significantly higher in constructed ponds for three of six years and approached significant ($P < 0.10$) for two other years (Fig. 16). Regression analysis indicates that the mean number of species using ponds annually did not increase between 1996-2001 (*P* values for reference and constructed ponds = 0.80 and 0.57, respectively). The latter suggests that constructed ponds quickly reached saturation levels within one year of construction.

3. Response of focal species to constructed ponds.

We selected the spotted salamander (*Ambystoma maculatum*) and wood frog (*Rana sylvatica*) as focal species for monitoring ecosystem function and restoration success. Both species are widely distributed across the site and are largely restricted to temporary ponds that predominated prior to golf course construction. These species lay large egg masses that can be accurately counted. Egg mass censuses serve as an index of the size of the female breeding population. Since each female wood frog deposits a single mass, the number of egg masses in a pond is an accurate estimate of the total breeding population of females. Spotted salamanders typically deposit 1 to 4 egg masses and egg mass counts provide a relative index of population size.

Methods

To obtain estimates of the overall response of the focal species to restoration efforts, we conducted a complete count of egg masses on the eastern half of the site beginning in 1995. This census included constructed ponds (1996-2001), reference ponds, and all additional breeding sites. As part of the restoration efforts, golf course ponds were either filled or partially filled to create shallow breeding sites during 1999. Sections of the restored stream channel also were temporarily blocked with check dams and held standing water. Both focal species colonized many of these new, fish-free habitats in 2000 and egg mass counts from these habitats were included in the overall count for the eastern sector.

To estimate relative changes in embryonic and larval survival across years, we estimated the total population size of hatchlings and larvae nearing metamorphosis in each pond using open-bottomed samplers. Populations were sampled using 30 gallon galvanized trashcans with bottoms that were removed with a blow torch (approximate area of can bottom = 0.11 m^2). When sampling, the can was pushed into the pond substrate to trap larvae. Repeated sweeps of the can were made with either 15 x 20 cm or 17 x 25 cm aquarium nets until no larvae were captured for five consecutive sweeps.

Ponds were sampled by walking a zig-zag transect across the entire area of the pond and taking samples at approximately equidistant points along the transect. The number of samples per pond increased with pond size and varied from 15-80. Pond surface area was estimated at the time of sampling based on 3-5 measurements of length and width using a meter tape. The total population size of hatchlings or larvae nearing metamorphosis was estimated using data on the mean number of larvae per sample, the surface area of the sampler, and the surface area of the pond.

We obtained an initial sample of hatchlings within 1-3 weeks after > 95% of the egg masses were estimated to have hatched in a pond. We intensively dip-netted ponds as larvae approached metamorphosis, and obtained a final sample immediately after the first metamorphosing larva was observed in each pond. Criteria used to recognize metamorphosing larvae were the emergence of both front legs for wood frog tadpoles and the partial or complete reabsorption of gills and dorsal fins for spotted salamander larvae. We used this estimate as a relative measure of the number of juveniles that were recruited into the terrestrial population each year.

Changes in adult population size are the most meaningful measure of the response of amphibians to site restoration efforts. However, a significant time lag in population responses occurs because of the prolonged juvenile stage. That is, juveniles that metamorphose and leave ponds may not return for 2-4 years as breeding adults. We used total egg mass censuses of the eastern half of the site to measure the effects of pond construction and site restoration on breeding populations.

Results and Discussion

The responses of breeding populations of wood frogs and spotted salamanders to pond construction are shown in Fig. 17. These data exclude two constructed ponds (7X; 10X) that occurred on the western end of the site. Some ponds were constructed where small depressions already existed and where 35% of wood frogs and 37% of spotted salamanders in the eastern half of the site oviposited in 1995. During 1996 (first year after pond construction and filling), 71% of the resident wood frogs and 59% of spotted salamanders bred in the constructed ponds. A corresponding decline in breeding effort occurred in the remaining small depressions, suggesting that many adults abandoned historical breeding sites in favor of newly constructed ponds.

The percentage of adults that bred in constructed ponds between 1996-1999 remained relatively constant. However, significant declines of both species occurred in 2000 when animals shifted to new breeding sites that were formed during site restoration from either the partial filling of golf course ponds, or the construction of check dams in the newly constructed stream channel. Approximately 42% of wood frogs and 26% of spotted salamanders bred in these newly created habitats during 2000. This trend parallels the rapid shift into constructed ponds that occurred in 1996.

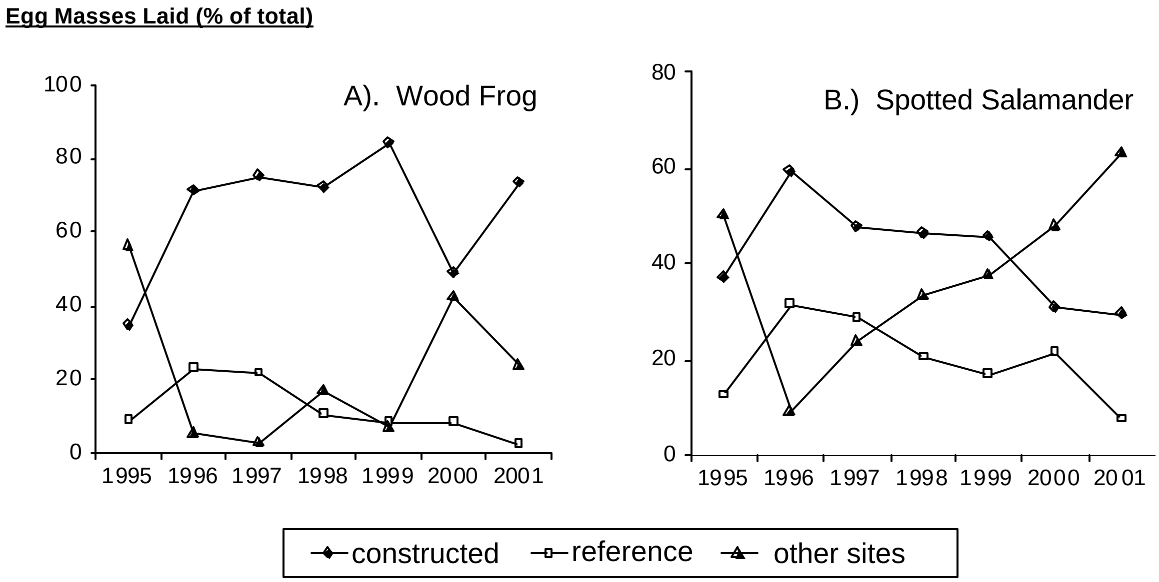

Fig. 17. Response of female wood frog and spotted salamanders to pond construction. Symbols are the number of egg masses laid on the eastern half of the site in constructed ponds, reference ponds, and all remaining breeding sites. Numbers are expressed as a percentage of the total masses laid in the eastern half of the site. 'Other" includes all sites other than reference and constructed ponds, including sites that were created during stream channel restoration.

Fig. 18 shows annual changes in the percentage of ponds that successfully produced juveniles (upper panels) and estimates for the total production of juveniles based on the number of larvae that survived to the initiation of metamorphosis (lower panels). The estimated output of terrestrial juveniles from constructed ponds (N = 217,374 wood frogs; 30,831 spotted salamanders) was exceptionally high during 1996, but progressively declined through 2001. A similar trend has occurred in reference ponds. These trends parallel a general decline in the percentage of ponds that have successfully produced juveniles each year.

Comparisons of the number of hatchlings and number of larvae surviving to the initiation of metamorphosis (Figs. 19 and 20) indicate that the decline in juvenile output was primarily due to increased larval mortality rather than increased embryonic mortality between 1996-2001. Embryonic survival varied among years, but there was no evidence of catastrophic mortality for any year. In contrast, overall juvenile production per egg mass declined markedly between 1996-2001 for both species and both sets of ponds (Fig. 20). The reduction in juvenile production is attributable to at least three factors: (1) premature pond drying and/or the failure of ponds to fill seasonally, (2) outbreaks of pathogens that caused larval die-offs, and (3) the accumulation of predators in constructed ponds after 1996.

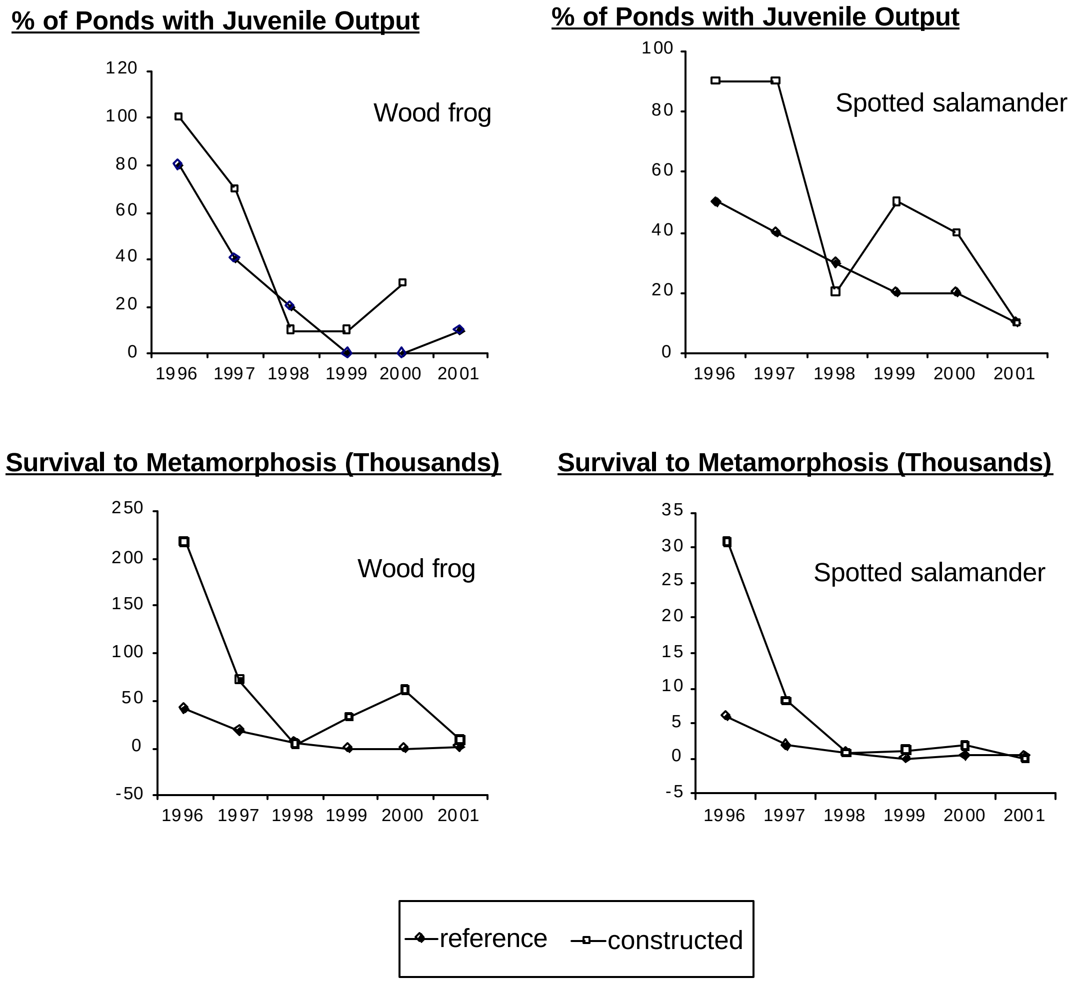

Fig. 18. Estimated total output of juveniles from 10 constructed and 10 reference ponds between 1996-2001 and the percentage of ponds that produced juveniles. Symbols for upper panels are the percentage of ponds that produced juveniles annually, while those in the lower panels are the estimated number of larvae surviving to the initiation of metamorphosis.

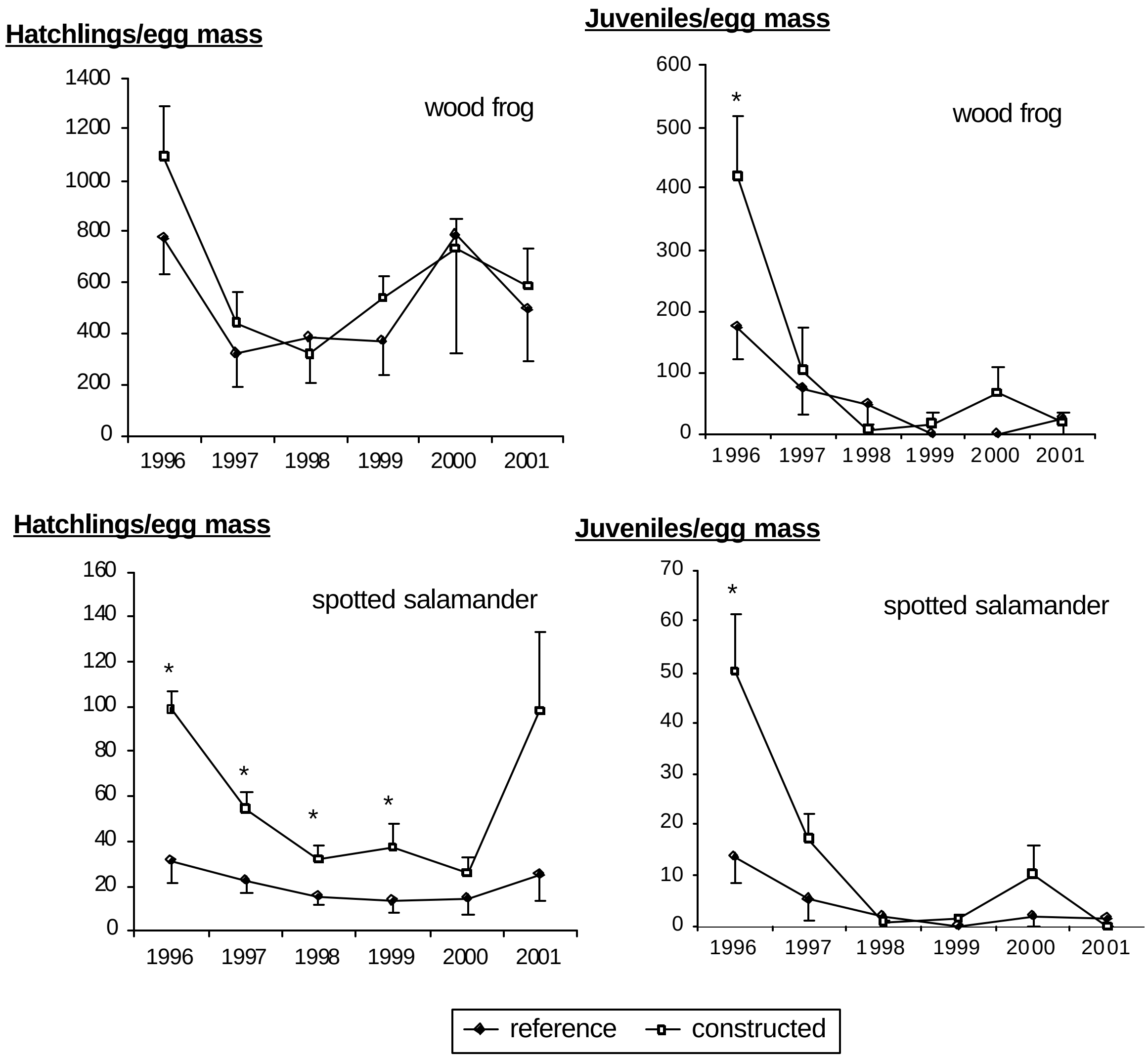

Fig. 19. Estimates for number of hatchlings and juveniles produced per egg mass for the wood frog and spotted salamander based on yields from open-bottom samplers. Symbols and bars are means and 1 SE, and asterisks indicate means that differed significantly within years.

Larval Survival (%)

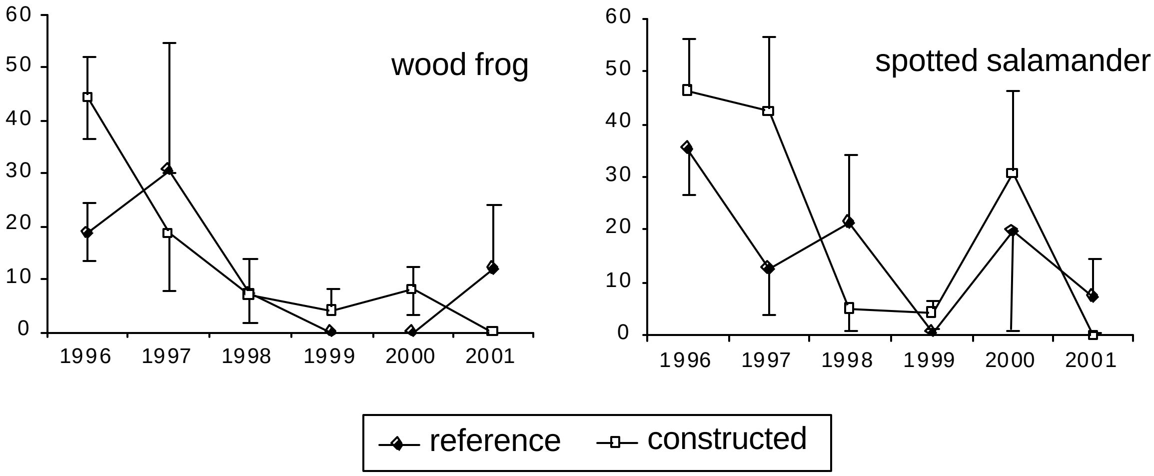

Fig. 20. Larval survival for reference and constructed ponds based on population estimates from open-bottom samplers taken shortly after hatching and at the initiation of metamorphosis. Symbols and bars are means and 1 SE.

Fig. 21 shows the percentage of ponds that either did not fill or that filled and dried prematurely between 1996-2001. Constructed ponds filled annually and usually held water sufficiently long to allow metamorphosis of both species. An exception is 2001 when 20% of ponds dried prematurely, causing catastrophic mortality.

Percentage of Ponds Dry

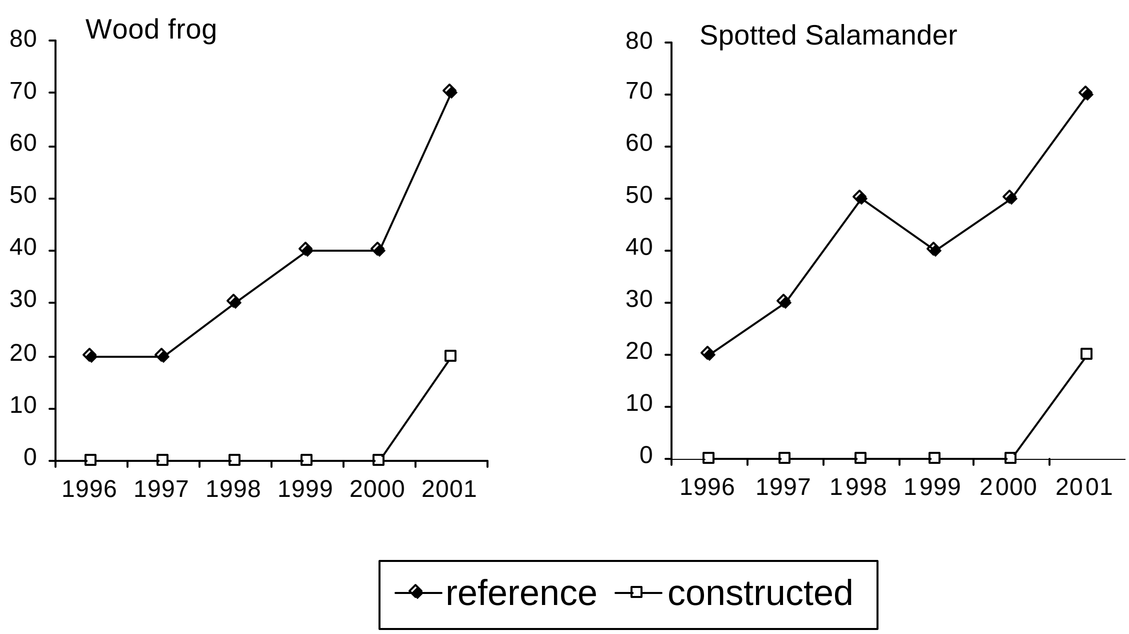

Fig. 21. Changes in the percentages of reference and constructed ponds that either did not fill seasonally or that dried prematurely.

In contrast, the more shallow reference ponds progressively deteriorated with respect to hydroperiod between 1996-2001. During 2001, 70% of the reference ponds either did not fill or dried prematurely. This pattern may in part reflect a regional drought that occurred during 1999-2001.

Disease is a second factor that contributed strongly to the decrease in juvenile output between 1996-2001. Outbreaks of a disease that caused catastrophic larval mortality were first observed in 1997. The symptoms were consistent with those of “red-leg disease” due to gram-negative bacteria, particularly the bacterium *Aeromonas hydrophila*. However, specimens were sent to National Wildlife Health Center in Madison, Wisconsin and detailed histological and molecular studies revealed that the pathogen was an iridovirus (*Ranavirus*).

Larvae of both the wood frog and spotted salamander are susceptible to *Ranavirus* infections. Infected larvae tend to become lethargic, often float at or near the water surface, and develop characteristic bloody, hemorrhagic patches on the body and fins. Infected larvae are first noticed seasonally during the latter half of the larval stage (often as larvae near metamorphosis). Catastrophic mortality typically occurs within 1-2 weeks after the first infected individuals are detected. Typically, outbreaks result in 100% mortality within a pond.

The extent to which the disease has impacted local populations in reference and constructed ponds at Tulula is shown in Fig. 22. Diseased animals and die-offs were not observed prior to 1997, at which time two die-offs occurred in two ponds. The disease rapidly spread to other ponds on site and has been a major source of larval mortality since 1998. The smaller percentage of reference ponds with die-offs between 1998-2001 reflects the fact that many reference ponds dried prematurely (e.g., prior to the time when the disease normally develops).

A final source of premetamorphic mortality that contributed to declining production of juveniles between 1996-2001 was egg and larval predation. In particular, egg predation by green frog tadpoles on wood frogs (Petranka and Kennedy 1999), and wood frog tadpoles on spotted salamanders (Petranka et al. 1998) were significant sources of mortality in certain ponds. Odonates and other predatory aquatic insects accumulated in constructed ponds after 1996 and presumably contributed to higher larval mortality.

Changes in breeding population sizes of the wood frog and spotted salamander based on counts of egg masses in the eastern half of the site are shown in Fig. 23. The size of the wood frog population was relatively stable from 1995-1998, but increased dramatically (366%) in 1999 and has remained relatively high since. Female wood frogs require 3-4 years to reach sexual maturity after metamorphosing (Bervin 1982). Thus, the marked increase in population size in 1999 corresponds to when the large output of juveniles in 1996 first returned to breed as adults. Inspection of Fig. 23 suggests that the overall increase in wood frogs at Tulula is associated with the greater use of constructed ponds at the site.

Percentage with die-offs

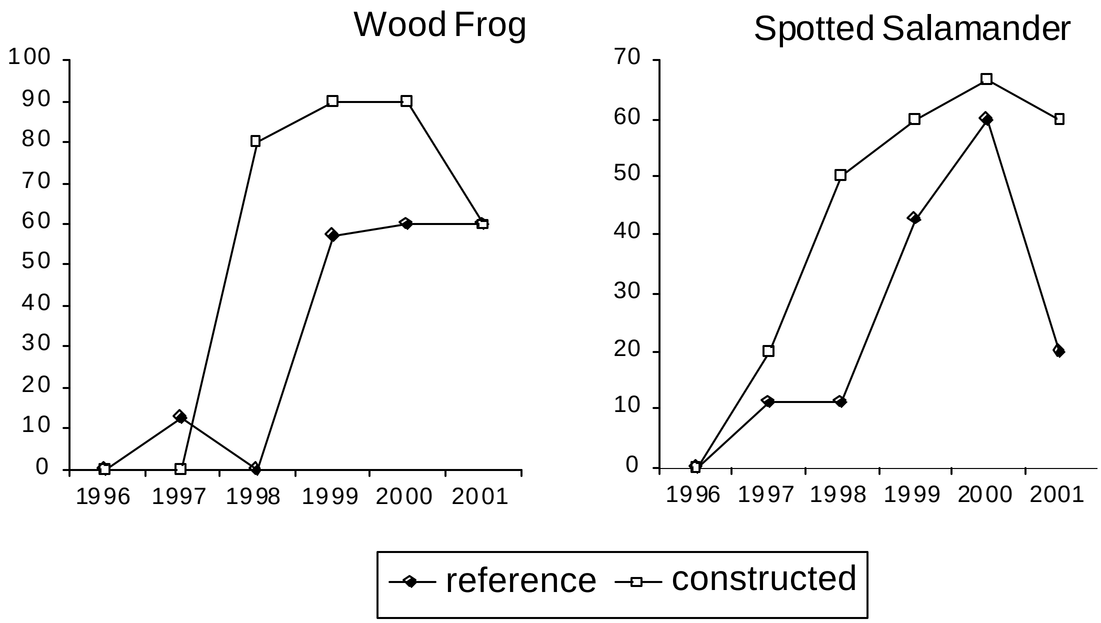

Fig. 22. Changes in the percentage of reference and constructed ponds in which catastrophic die-offs of larvae occurred from *Ranavirus* infections.

Number of Egg Masses

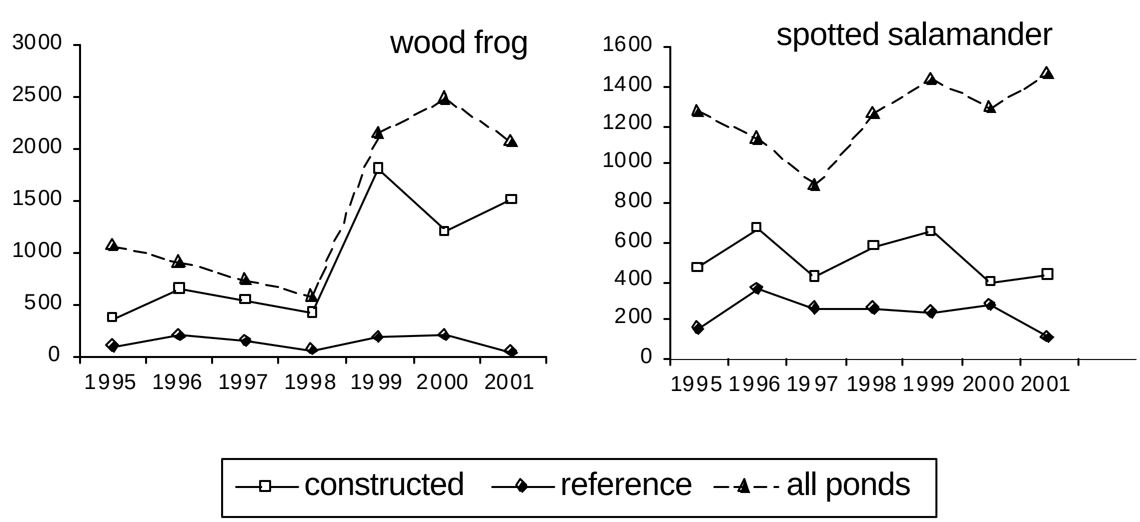

Fig. 23. Changes in adult breeding population size based on annual egg mass counts.

The population of spotted salamanders did not increase as markedly. However, the size of the breeding population has slowly increased and reached its highest level in 2001. Females of this species may require 3-5 years to reach sexual maturity (Petranka 1998), so the gradual increase in breeding population size may reflect recruitment from the relatively large output of juveniles in 1996 and 1997.

Summary

Data collected from 1996-2001 indicate that constructed ponds are of higher quality than reference ponds based on physiochemical characteristics, seasonal hydroperiod, and use by resident amphibians. The constructed ponds tended to be warmer and have higher oxygen levels. Since larval growth is directly proportional to temperature, and high oxygen levels reduce physiological stress, physiochemical conditions are judged to be superior to those of reference ponds. The reference ponds have undergone progressive deterioration between 1996-2001 with respect to seasonal hydroperiod. In 2001 the majority either did not fill or dried prematurely, resulting in catastrophic mortality of larvae. In contrast, the hydroperiod of most constructed ponds appears to be ideal for most vernal pond breeders. Seven of 10 ponds currently undergo seasonal drying, typically in late summer or fall when larvae have metamorphosed. Three ponds are permanent but fish-free and are used by many amphibians. Amphibians rapidly colonized the constructed ponds, and the number of species that utilize these as breeding sites averaged about 50% higher than that of reference ponds.

Outbreaks of *Ranavirus* have dramatically reduced the output of juveniles from both constructed and reference ponds. Similar outbreaks of this disease have been reported in several areas of the United States (Daszak et al. 1999) and have resulted in catastrophic die-offs of larvae. Amphibians often exhibit boom-and-bust recruitment patterns in which juvenile recruitment may be near zero in some years and high in others (e.g., Gill 1978, Semlitsch et al. 1996). Local populations are buffered from these effects since the adults may live many years and metapopulation dynamics allow for some recruitment annually. Thus, years with complete reproductive failure in local ponds may not necessarily translate to long-term declines of local populations.

Scientists currently know very little about the epidemiology of amphibian *Ranavirus*. For example, we do not know how the virus is spread between ponds, whether a subset of larvae are resistant to the virus, or whether the infections subside after several years of outbreaks. One scenario for the Tulula populations is that the severity of die-offs will decline with time as local populations evolve immunity or as the virus undergoes normal erratic patterns of outbreak. A second is that the virus will consistently produce annual die-offs in most or all ponds. The latter could ultimately result in amphibian species undergoing population bottlenecks or even local extinctions.

The invasion of beaver (*Castor canadensis*) and completion of stream restoration will influence future site hydrology and the dynamics of amphibian populations at Tulula. Beaver invaded the site shortly before stream channel construction began and were eliminated through trapping. Although none currently occur on site, they will likely reinvade after work is completed in 2001. Monitoring of focal species in future years will document how amphibians respond to altered hydrology from stream restoration and beaver activity. It will also help resolve the extent to which *Ranavirus* infections ultimately impact breeding populations of amphibians.

B. Vegetation plantings

One of the restoration goals at Tulula is to restore the original plant communities in disturbed areas. These are primarily flat portions of the floodplain that were drained, cleared, and graded for golf fairways. Aerial photography and anecdotal evidence indicate that prior to the construction of golf fairways, the floodplain was forested. At present, the dominant canopy tree in the floodplain is red maple. Although disturbed wetlands may revegetate naturally once hydrological conditions are restored (Reinartz and Warne 1993), wetland managers are often advised to implement a planting regime to ensure that desired species develop on the site (Jarman et al. 1991). Our objective was to plant a portion of one disturbed airway with nursery-propagated red maple saplings, in order to evaluate survivorship. We also wanted to evaluate the survivorship of selected species of shrubs that might be planted in open areas of the floodplain.

Methods

In March 1995, we planted 231 red maple saplings and 132 shrub saplings in two disturbed fairways adjacent to the fen. Shrub species included silky dogwood, black chokeberry, red chokeberry, and elderberry, all of which are abundant throughout the fen, and were available locally at moderate cost. All plants were bare-root stock, purchased from a wholesale plant nursery in Tennessee. Seventy-seven red maple saplings were planted on 3-m centers in three 20x30m plots. Three additional plots were left unplanted, to facilitate future comparisons of ecosystem dynamics. Shrubs were planted on 2.5-m centers in a stratified random design in one 20x30m plot, as this plot was wetter at one end than at the other. Between 31 and 38 saplings of each shrub species were planted. Plots were inventoried regularly to monitor survival.

Results and Discussion

The survival of planted stems is presented in Tables 22 and Table 23. Although survival rates appear to vary from year to year, this is likely an artifact of the difficulty in distinguishing some naturally-regenerating individuals from planted individuals. In these cases, the tops of the bare-root saplings died, but the roots survived, sending up new shoots away from the original stem. Also, new seedlings sometimes germinated and became established right next to the nursery planted stems, eventually leading to uncertainty as to which was the planted stem.

Overall, red maple survival was generally at least 70% (Table 22). More saplings survived in plots 3 and 4 than in plot 2. In addition, we observed many more naturally-regenerated red maple seedlings and saplings in plots 3 and 4. Clearly, conditions in these two plots were more conducive to the growth of young red maples. Most of the surrounding vegetation in these plots was shorter, and there was less competition from natural succession by asters, brambles, and shrubs. Although the saplings that we planted survived reasonably well, even after 6 years of growth they were not as tall or as vigorous as many of the naturally-regenerated maples. We are convinced that large-scale planting of canopy trees is unnecessary at Tulula, unless the specific restoration goal is to increase the diversity of canopy trees.

Table 22. Percent survival of red maple saplings planted in winter 1995.

Plot	Spring 1995	Fall 1995	Spring 1996	Spring 1997	Spring 2000	Spring 2001
2	62	70	53	55	55	64
3	77	84	77	83	88	92
4	82	77	71	75	86	86
Mean of all plots	74	77	67	71	76	81

Of the shrubs, elderberry fared the worst, with only 25% surviving after 6 years (Table 23). Silky dogwood survived extremely well, with 30 out of 32 stems (94%) alive after 6 years. Black chokeberry also survived well, with 73% survival after 2 years. About that time, natural regeneration of black chokeberry was so good that it became difficult to tell which stems were planted and which had germinated on their own. Red chokeberry fared less well. After 6 years, only about half of the planted saplings were alive.

Table 23. Percent survival of shrub saplings planted in winter 1995.

Species	Spring 1995	Fall 1995	Spring 1996	Spring 1997	Spring 1998	Spring 2001
Elderberry	94	55	33	22	28	25
Silky dogwood	94	97	94	94	94	94
Red chokeberry	50	68	47	47	18	55
Black chokeberry	90	84	71	73	100	100

In 1998, shrubs that had produced fruit were noted during inventory. Only black chokeberry and silky dogwood produced fruit, with 42% of black chokeberries and 30% of silky dogwoods fruiting. Clearly, black chokeberry and silky dogwood not only survived well at Tulula, but contributed to the supply of fruit available to birds and mammals at the site.

C. Vegetation response to spoil removal

Restoration efforts at Tulula involved removing spoil from portions of the floodplain that had been filled to create golf fairways. Once the spoil was removed, the original hydric soils were exposed. This provided an excellent opportunity to monitor the emergence of vegetation, and to compare the species emerging from these soils to those emerging from the fen soil samples in our earlier seed bank study (section II.C. 3.).

Methods

Three 10x10m plots were established in each of two adjacent but hydrologically distinct zones in a fairway where spoil was removed (total of six plots). One zone was very wet, with pools of standing water, while the other was topographically higher. In each plot, 10, 0.25-m^2 quadrats were placed at permanently marked random points. All plants occurring in each quadrat were identified, and percent cover was visually estimated. For woody seedlings, the number of stems were counted, as well. The mean percent cover of each taxon in each of the two zones was calculated. A specimen of each taxon was collected from the vicinity of the quadrats, and deposited into the Tulula reference collection. Two water table gauges were installed in each of the six plots in May 2000 (a total of 12 gauges), using the installation methods described in Section II.A.1.

Results and Discussion

In the wet zone, 27 taxa emerged (nomenclature follows Radford et al. 1968), nearly half of which were forbs. In addition, one-third of the plant cover consisted of forbs (Table 24). The dominant species was arrowhead (*Sagittaria latifolia*), an obligate wetland plant that was uncommon at Tulula prior to spoil removal and the uncovering of the original hydric soils. Another one-third of the plant cover in the wet zone consisted of sedges and rushes (primarily *Juncus* spp. and an obligate wetland sedge, *Eleocharis obtusa*). The remaining one-third of the plant cover consisted of redtop grass (*Agrostis stolonifera*), which was seeded by NCDOT. Less than one percent of the plant cover consisted of woody plants.

Table 24. Mean percent coverage of plant taxa emerging from wet and dry zones where spoil was removed.

	Zone	
Taxon	Wet	Dry
Forbs		
Ambrosia artemisiifolia	0.10	0.20
Amphicarpa bracteata	0.03	0
Apios americana	0	3.60
Bidens tripartita	0.27	0.03
Boehmeria cylindrica	0	0.03
Cassia nictitans	0	0.10
Erigeron canadensis	0	0.30
Eupatorium fistulosum	0	0.37
Hypericum mutilum	0.20	0.40
Lespedeza striata	0	0.43
Lindernia dubia	1.73	0
Ludwigia alternifolia	0.13	0
Ludwigia palustris	3.30	0
Oxalis florida	0	0.03

Plantago rugelii	0	0.03
Polygonum cespitosum	0	0.10
Polygonum punctatum	0.20	0.83
Polygonum sagittatum	0.77	0.33
Polygonum scandens	0	0.20
Sagittaria latifolia	27.40	0
Solidago sp.	0	0.20
Solidago rugosa	0	0.33
Sparganium americanum	2.00	0
*******Trifolium repens*	1.93	11.57
Unknown forbs	0.47	1.33
Total cover of forbs (%)	38.53	20.41
Taxonomic richness	13	19
<u>Grasses</u>		
Agrostis perennans	0	0.40
*****Agrostis stolonifera*	32.03	80.60
Calamagrostis sp.	0	0.17
*****Secale cereale*	0.10	3.40
Total cover of grasses (%)	32.13	84.57
Taxonomic richness	2	4
<u>Sedges</u>		
Carex sp.	1.17	0.67
Cyperus strigosus	0.03	0
Dulichium arundinaceum	0.47	0
Eleocharis obtusa	6.13	0.03
Scirpus polyphyllus	2.53	0
Scirpus purshianus	0.30	0
Total cover of sedges (%)	10.63	0.70
Taxonomic richness	6	2
<u>Rushes</u>		
Juncus spp.	7.73	0.83
Juncus subcaudatus	5.87	0.17
Juncus tenuis	0.30	0.03
Total cover of rushes (%)	13.90	1.03
Taxonomic richness	3	3
<u>Woody plants</u>		
Acer rubrum	0.03	0.03
Rubus sp.	0.03	0.60
Salix sp.	0.13	0
Sambucus canadensis	0	0.17
Total cover of woody plants (%)	0.19	0.80
Taxonomic richness	3	3
Grand total of plant cover (%)	95.38	107.51
Grand total of cover excluding planted species*(%)	61.32	11.94
Grand total of taxonomic richness	27	31

* Species planted by NCDOT in seeding mixture after spoil was removed

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In the dry zone, 31 taxa emerged, almost two-thirds of which were forbs. However, 85% of the plant cover consisted of redtop grass that was seeded by NCDOT. Another 12% was white clover (*Trifolium repens*), which also was seeded by NCDOT. Only 8% of the naturally-occurring plant cover consisted of forbs, and 1% or less of the cover consisted of sedges, rushes, or woody plants.

The water table in the plots where spoil was removed is shown in Fig. 24. The water table in the dry plots was 30 to 50 cm below that of the wet plots. The wet zone is hydrologically more similar to the open canopy region of the fen, while the dry zone is most similar to the disturbed fairway adjacent to the fen. Our 1994 seed bank study (section II.C.3) showed that soils from the open canopy region of the fen produced mostly rush and sedge seedlings. However, our study here showed primarily forbs (with some sedges and rushes) emerging in the wet zone. The 1994 seed bank study showed that soils from the drier fairway produced mostly sedges, with some forbs and grasses. In the current study, if we overlook the tremendous emergence of redtop grass that was seeded by NCDOT, primarily forbs emerged in the dry zone. Over the next few years, we plan to continue to monitor the plant communities that become established in these plots.

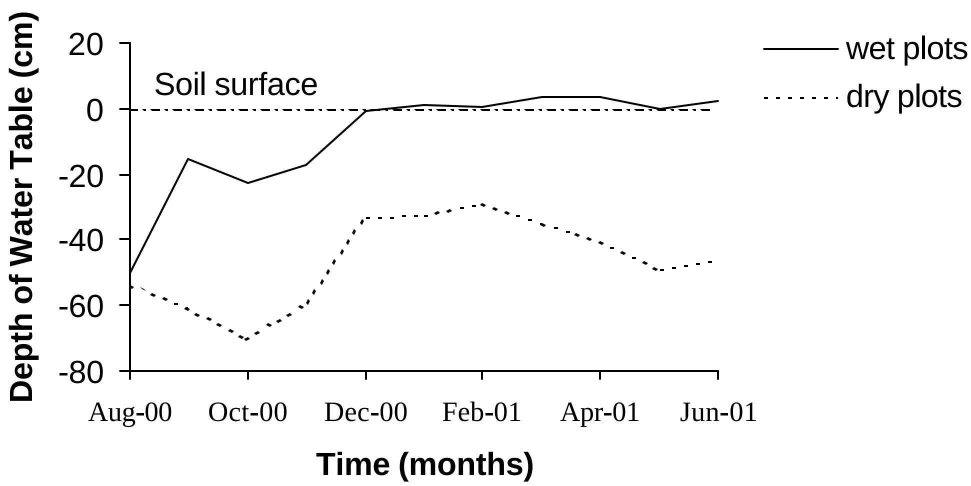

Fig. 24. The depth of the water table for the wet and dry plots established in areas where spoil had been removed.

D. Channel Realignment

The primary focus of restoration at Tulula is to restore the historic hydrology of the site. Tulula Creek originally had a meandering, slightly entrenched channel with a low width-to-depth ratio and would have been classified as an E5 stream type (Rosgen 1996). Since dredging, the channel is classified as a G6c stream, a gully-type channel that is highly entrenched with a sinuosity less than 1.1 (North Carolina Department of Transportation 1997). The NCDOT hired a contractor to construct a meandering channel (1.9 km in length) across the floodplain to re-create an E5 stream type.

The design of the new channel was partially based on the physical characteristics of a relic channel found mainly at the lower end of the site. Relic-channel measurements indicated a bankfull cross-sectional area averaging 1.42 m^2 (North Carolina Department of Transportation 1997). The contractor used the relic channel, wherever practical, as part of the new meandering channel. Spoil removed during construction of the new channel will be used to partially backfill the old channel when possible. The footprint of the new channel has been completed, and the contractor will join the separate segments of the new channel together by crossing the existing Tulula Creek in 2001 (Fig. 25).

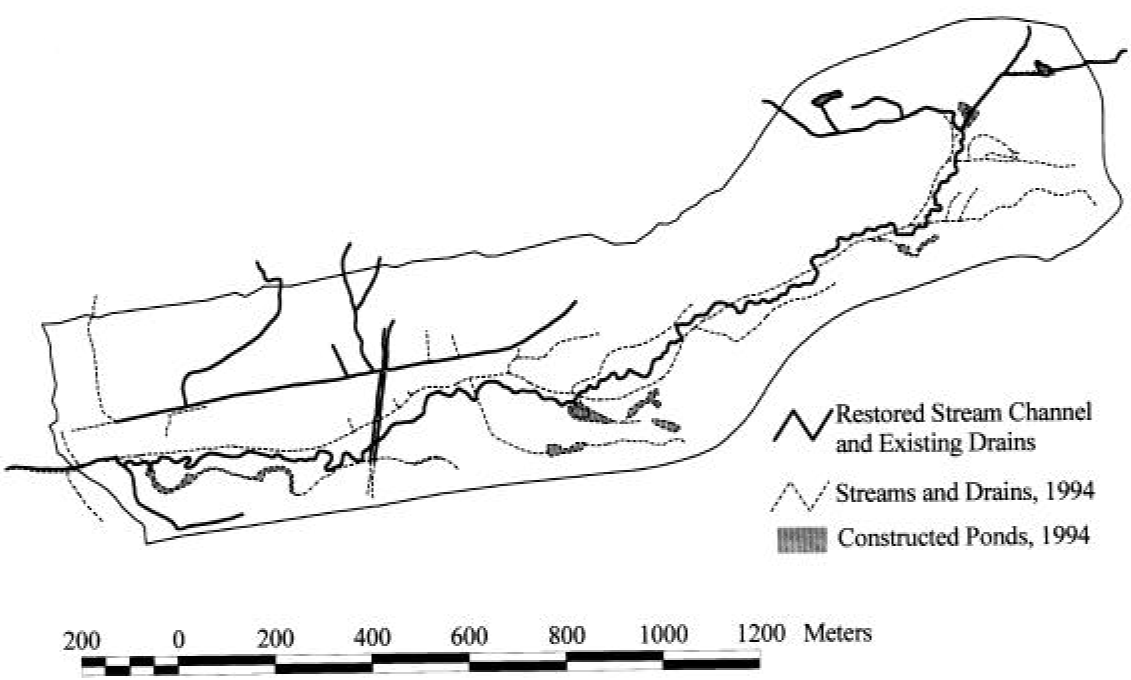

Fig. 25. The restored Tulula stream channel and associated drainage systems. Water introduction to the new channel will commence in the fall of 2001.

The banks of the new channel are being protected from streambank erosion with a natural fiber matting that covers the sides of the channel banks and one to two feet of the adjacent floodplain. To increase the protection of stream banks, a contractor installed coir fiber rolls along the bottom of the outside banks of constructed meanders and planted live stakes of willow (*Salix* spp.) or silky dogwood (*Cornus amomum*) on the sides of banks and on the adjacent floodplain. The contractor installed random root wads in the channel banks to improve fish habitat. The exposed soils in the disturbed corridor of the new channel were seeded with a mixture of annual grasses, including winter rye and switchgrass. The seeded grasses covered drier (higher) portions of the floodplain, but wetter (lower) areas of exposed soils were quickly colonized by wetland species. The corridor of the new channel will be planted with canopy tree species after the channel segments are connected.

Concurrent with construction of the new channel, the contractor blocked the outlets of drainage ditches and partially refilled the ditches with adjacent spoil. We intentionally left segments of these drainage ditches to collect water to serve as amphibian habitat. Recreating the meandering channel should decrease water velocity, which, coupled with the backfilling of drainage ditches, should raise the level of the water table across the floodplain and allow for more frequent overbank flooding. The contractor also partially backfilled 10 of the 11 golf ponds with spoil removed during their construction to create vernal pond conditions.

UNCA has collected information on the geomorphology of the new channel and will use this information to determine overall channel stability over time. We established 47 cross section points along the channel to calculate cross-sectional areas, maximum channel depth, and bankfull width. Six meandering segments (three in constructed areas and three in the relic channel) were selected to determine the arc angle of the meanders and channel characteristics at the points of inflection and midpoint of the meander. We also conducted pebble counts and determined the particle size distribution of channel sediments in a meander and riffle at these six locations.

IV. GIS SUPPORT

Our efforts to document the ecological conditions at Tulula and the impacts of site restoration on the ecology of Tulula were enhanced by using GIS to evaluate landscape-level patterns of vegetation, hydrology, and fauna response to site conditions. We have used GIS to generate maps that show the existing landscape patterns and to model different ecological responses to existing or changing site conditions.

Aerial photography, flown in 1994, 1998, and 2000, was scanned to help differentiate the various vegetation communities on site. The scanned photography was used to develop digital files on vegetation communities that were verified by field observation. We have described 13 vegetation communities at Tulula, including four disturbed and nine natural communities (Fig 26) (see Appendix E for detailed descriptions of community types).

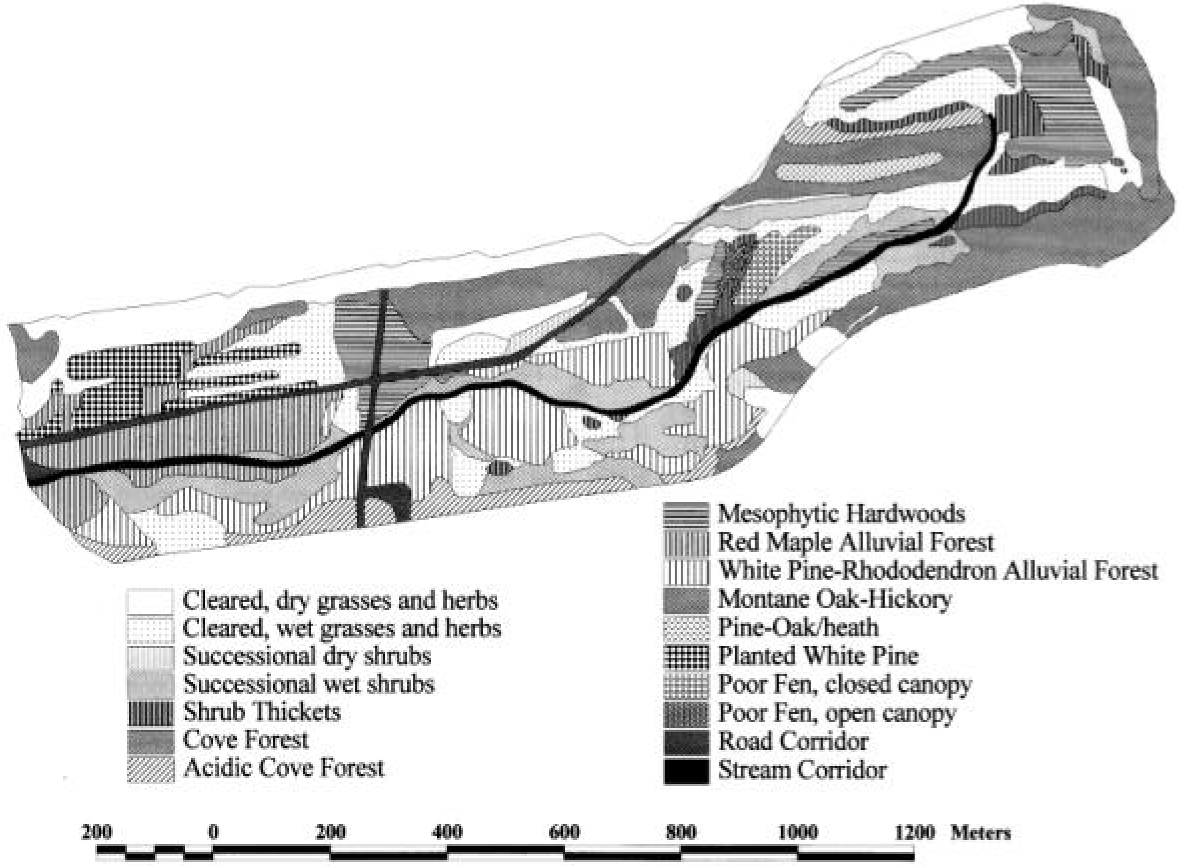

Fig. 26. Vegetation communities of Tulula based on photointerpretation of 1998 aerial photography and field verification.

The natural communities include upland forest, the red maple/white pine alluvial forest, fens, and a transitional mixed mesophytic hardwood forest and serve as reference areas for research and restoration activities. The disturbed communities are mostly in fairways and are now in various stages of succession. Because of the heterogeneous nature of the site, and because of the fine-scaled research projects carried out at Tulula, the community nomenclature used here is unique to the site.

The vegetation community datafiles also were used for analysis of habitat for bird surveys (see Section II.E). The vegetation communities were collapsed into four general habitat classes: grass, shrub, forest, and water. Cleared grasses and herbs were grouped into grass, successional shrubs and shrub thickets were grouped into shrub, and all forest and fen communities were grouped into forest.

V. DISCUSSION

A. Assessment and Long-Term Management

In assessing the success of wetland restoration at Tulula, we have the advantage of extensive data collected during the six years before large-scale restoration began. This data will be used to determine how the new meandering stream and backfilled ditches alter site hydrology, whether the new channel is stable over time, how plant community succession proceeds, and how animals respond to changes in plant communities.

Wetland mitigation credit is typically based on the restoration of wetland functions. After Tulula is restored, the site is expected to support 40 ha of wetlands, 38 ha of upland buffers, and 11 ha of surrounding upland protection areas (North Carolina Department of Transportation 1997). The proposed mitigation credit for Tulula is based on restored surface water and groundwater flow gradients in wetland areas, coupled with spoil removal from the floodplain. The likely mitigation ratio for the wetlands restoration will be two units of mitigation area for one unit of impacted area. The NCDOT is requesting stream restoration credit for more than 3,350 linear m. If granted, mitigation credit for upland buffer restoration or protection will likely be at a 20:1 ratio. The site has already been used to compensate for wetland losses associated with recent highway projects, even though wetland restoration has not been completed (a Aback-ordering≅ that underscores the difficulty of finding appropriate sites for wetland mitigation in western North Carolina).

The NCDOT is responsible for the success of this restoration and is committed to a five-year post-restoration assessment of ecological conditions at the site. Once the site has been deemed a success by the Mitigation Bank Review Team, which includes members from various federal and state agencies, and from UNCA, land ownership may transfer to UNCA. So far, this living laboratory has provided research and monitoring activities for more than 50 undergraduates at the university, including numerous senior research projects. University ownership of Tulula will provide the opportunity for long-term ecological field studies.

The final costs associated with restoring Tulula will not be known until the contracted work and site assessments are completed. The NCDOT paid $465,000 for the land. Construction of the vernal ponds cost about $40,000. Costs for the meandering channel, blocking and filling the drainage ditches, and partially backfilling the golf ponds are estimated at $573,000. Other costs include hiring a contractor to model the ground water dynamics and site flooding potential before and after hydrology is restored. In addition, UNCA received federal and state funding to conduct an ecological assessment of the site, including a post-restoration assessment.

B. Prospects

The likelihood for long-term success of the wetland restoration activities at Tulula is enhanced by three important factors. First, the site is nearly surrounded by the Nantahala National Forest, so that external pressures on the site are limited to some sediment loading from a housing development on a slope adjacent to the eastern end. Fortunately, the sediment enters a constructed golf pond that was retained for that purpose. The second factor providing Tulula with some guarantee of success is the condition of the soils on site. For the most part, disturbance to soil profiles during the golf course construction was limited to the surface layer. Pedogenic processes leading to the development of mature soil profiles require much longer time scales than the biological processes leading to mature plant community development (Bradshaw 1997). Associated with the intact soil profile is a remnant seed bank that should enhance development of the plant community. Planting efforts can focus on accelerating the canopy component of the community. The herbaceous community has developed quickly from the seed bank in areas disturbed during restoration, and naturally regenerating woody plants can be found throughout the mitigation bank. Floodplain soil exposure during restoration was limited to the corridor where the meandering channel was constructed (a linear strip ranging in width from 20 to 50 m in the interior of the site) and to areas where spoil was backfilled into golf ponds.

In summary, Tulula is the first wetlands mitigation bank in the Blue Ridge Province of North Carolina. Most of the mitigation banks of North Carolina are located in the Coastal Plain, and differ considerably from Tulula in terms of their hydrology and ecology. Our database on hydrology, soils, flora, and fauna will provide the framework for documenting the long-term success of wetland restoration activities at Tulula. Cooperation among members of the Mitigation Bank Review Team has been enhanced by a thorough understanding of the unique ecological conditions at this site. The data have been useful for designing restoration activities, and have influenced planning for long-term management.

Without restoration, Tulula would probably have developed into a red maple-dominated alluvial forest with considerably less wetland area. The banks of the existing channel were so undercut, and so much of the original area had been drained that only a narrow active floodplain could have developed. Most of the historic floodplain, including the fens, would have remained much drier -- in essence, a terrace. The original wetland complex described by Gaddy (1981), that of a high-quality wetland with relatively high floristic diversity, would have been largely lost had the hydrology not been restored. In addition, creating vernal ponds throughout the site has improved the breeding habitat for amphibians, and enhancing the biodiversity of the floodplain forest should ultimately increase the value of the site for wildlife.

VI. RECOMMENDATIONS

1. Any assessment of site hydrology for NCDOT mitigation banks should include an evaluation of precipitation to determine the relationship between water table levels and precipitation patterns. Above and below average precipitation may influence water table levels as much as the restoration of site hydrology will.

2. Assessments of baseline ecological conditions for NCDOT mitigation banks should include an evaluation of soil profiles, seed banks, and adjacent land uses to help determine the potential long-term

success of wetlands restoration.

3. NCDOT should minimize the use of nonwetland species to control soil erosion in wetland areas. Erosion of exposed wetland soils can be readily prevented if there is a viable seed bank.

4. When the final grading is done during restoration work, an effort should be made to include some heterogeneity in microtopography. Microtopographical relief is important in maximizing the niches available to wetland flora, which will maximize species diversity.

5. Natural regeneration of woody species should be evaluated for its potential to restore forested wetlands. Native plants outperformed and outcompeted planted stock on the Tulula floodplain.

6. Monitoring for noxious species should be included in post restoration assessment. For example, cattails have recently colonized areas of the disturbed Tulula floodplain, and should be controlled if they begin to outcompete other vegetation.

7. Annual variations in populations of faunal groups suggest that multi-year assessment efforts are necessary to document population dynamics of key species.

8. Some early successional habitats will result directly from restoration work, such as removing spoil. These areas may eventually enhance overall site biodiversity. Consequently, NCDOT should avoid "manicuring" landscapes during restoration. For example, areas on the Tulula floodplain that were manipulated during the back filling of golf ponds have a wide diversity of plant communities due to the wide diversity of habitats created by the movement of heavy equipment.

9. Portions of the site should be actively managed so that they remain in early successional stages. These areas are critical to many unique and uncommon species of plants and animals. A prescribed burn regimen or bushhogging should be considered for Tulula to maintain early successional plant communities.

10. NCDOT should open a dialogue with the U.S. Forest Service about establishing a no-harvest buffer around the perimeter of the site. A minimum of 300 m would provide habitat for adult stages of amphibians (such as the spotted salamander), as well as forested habitat for box turtles and other fauna that regularly use the Tulula floodplain.

11. Flexibility is needed in the regulatory components of restoration. The standard approach of trying to "cookbook" restoration may conflict directly with individual site conditions. For example, Tulula does not need a mass planting of woody stems using the cookbook approach of planting 350-400 stems per acre. Federal and state agencies that work cooperatively on wetland restoration activities should use site-specific baseline ecological conditions to develop restoration strategies that are appropriate for each site.

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Appendix A. Flora of Tulula
(Nomenclature follows Radford et al. 1968)
***** = possible new record for Graham County

LYCOPODIACEAE	
*****_Lycopodium appressum_ (Chapman) Lloyd & Underwood	Southern Bog Clubmoss
*****_Lycopodium obscurum_ L.	Groundpine
OPHIOGLOSSACEAE	
Botrychium virginianum (L.) Swartz	Rattlesnake Fern
OSMUNDACEAE	
*****_Osmunda cinnamomea_ L.	Cinnamon Fern
Osmunda regalis var. _spectabilis_ (Willd.) Gray	Royal Fern
PTERIDACEAE	
Adiantum pedatum L.	Maidenhair Fern
Dennstaedtia punctilobula (Michx.) Moore	Hay-scented Fern
Pteridium aquilinum (L.) Kuhn	Bracken Fern
ASPIDIACEAE	
Athyrium asplenioides (Michx.) A.A. Eaton	Southern Lady Fern
Dryopteris intermedia (Willd.) Gray	Fancy Fern
Onoclea sensibilis L.	Sensitive Fern
Polystichum acrostichoides (Michx.) Schott	Christmas Fern
Thelypteris noveboracensis L.	New York Fern
BLECHNACEAE	
*****_Woodwardia areolata_ (L.) Moore	Netted Chain-fern
ASPLENIACEAE	
Asplenium platyneuron (L.) Oakes	Ebony Spleenwort
PINACEAE	
Pinus rigida Miller	Pitch Pine
Pinus strobus L.	White Pine
Pinus virginiana Miller	Scrub Pine
Tsuga canadensis (L.) Carr.	Eastern Hemlock
CUPRESSACEAE	
*****_Juniperus virginiana_ L.	Red Cedar
TYPHACEAE	
Typha latifolia L.	Common Cattail
SPARGANIACEAE	
Sparganium americanum Nutt.	Bur-reed
ALISMATACEAE	
Sagittaria latifolia var. _pubescens_ (Muhl.) J.G. Smith	Wapato, Duck Potato, Arrowhead
POACEAE	
Agrostis perennans(Walter)Tuckerman	
*****_Agrostis stolonifera_ L.	Redtop
Andropogon glomeratus (Walter) BSP	Bushy Broomsedge
Andropogon scoparius Michx.	Little Bluestem
Andropogon virginicus L.	Broomsedge
Anthoxanthum odoratum L.	Sweet Vernal Grass
Bromus commutatus Schrader	Hairy Chess
Bromus japonicus Thunberg	Japanese Chess
Bromus tectorum L.	Downy Chess
*****_Calamagrostis cinnoides_ (Muhl.) Barton	Reed Grass
Dactylis glomerata L.	Orchard Grass
*****_Danthonia compressa_ Austin	Mountain Oat Grass

***Danthonia spicata* (L.) Beauvois ex. R&S	
***Elymus canadensis* L.	Wild Rye Grass
Festuca elatior L.	Tall Meadow Fescue
***Festuca myuros* L.	Rattail Fescue
Festuca obtusa Biehler	Nodding Fescue
Holcus lanatus L.	Velvet Grass
***Hystrix patula* Moench	Bottlebrush Grass
Leersia oryzoides (L.) Swartz.	Rice Cutgrass
***Muhlenbergia schreberi* J.F. Gmelin	
Panicum boscii Poiret	Panic Grass
***Panicum clandestinum* L.	Deer Tongue Witchgrass
Panicum dichotomum L.	Cypress Witchgrass
Panicum ensifolium Baldwin ex. Ell.	
Panicum lanuginosum Ell.	Panic Grass
Panicum laxiflorum Lam.	Panic Grass
***Panicum virgatum* L.	Switch Grass
Paspalum laeve Michx. var. *longipilum*	Field Paspalum
Phleum pratense L.	Timothy
***Poa trivialis* L.	Rough Blue Grass
Secale cereale L.	Rye
Setaria geniculata (Lam.) Beauvois	Bristle Grass
***Setaria glauca* (L.) Beauvois	Yellow Bristle Grass
Sorghastrum nutans (L.) Nash	Indian Grass
Tridens flavus (L.) Hitchcock	Purple Top
***Uniola laxa* (L.) BSP	Oat Grass
CYPERACEAE	
***Carex atlantica* Bailey	
***Carex bullata* Schkuhr	
***Carex communis* Bailey	
Carex crinita Lam. var. *gynandra* (Schweinitz) Schweinitz & Torrey	Fringed Sedge
Carex debilis Michx.	White-edge Sedge
Carex festucacea Schkuhr	
Carex incomperta Bickn.	Prickly Bog Sedge
***Carex intumescens* Rudge	Bladder Sedge
Carex lurida Wahl.	Shallow Sedge
Carex rosea Schkuhr	
***Carex stricta* Lam.	Tussock Sedge
Carex vulpinoidea Michx.	Fox Sedge
Cyperus spp.	
Cyperus strigosus L.	
Dulichium arundinaceum (L.) Britt.	Three-way Sedge
Eleocharis obtusa (Willd.) Schultes	
Eleocharis tenuis (Willd.) Schultes	Slender Spike Rush
***Rhynchospora glomerata* (L.) Vahl.	Clustered Beak Rush
***Scirpus expansus* Fernald	
Scirpus sp.	Bulrush
Scirpus polyphyllus Vahl.	
Scirpus purshianus Fern.	
ARACEAE	
Arisaema triphyllum (L.) Schott	Jack-in-the-pulpit
**Peltandra virginica* (L.) Kunth	Arrow Arum
XYRIDACEAE	

Xyris torta Smith	Yellow-eyed Grass
ERIOCAULACEAE	
***Eriocaulon decangulare* L.	Ten-angled Pipewort
COMMELINACEAE	
Commmelina communis L.	Asiatic Dayflower
JUNCACEAE	
Juncus acuminatus Michx.	
Juncus effusus L.	Soft Rush
Juncus marginatus Rostk.	
***Juncus subcaudatus* (Engelm.) Coville & Blake	
Juncus tenuis Willd.	Path Rush
LILIACEAE	
Aletris farinosa L.	Colicroot
Allium vineale L.	Field Garlic
Clintonia umbellulata (Michx.) Morong	Speckled Wood Lily
***Erythronium americanum* Ker	Trout Lily
Hemerocallis fulva L.	Day Lily
***Lilium canadense* L. var. *editorum* Fern.	Red Canada Lily
Medeola virginiana L.	Indian Cucumber Root
Polygonatum biflorum (Walter) Ell.	Smooth Solomon's Seal
Smilacina racemosa (L.) Desf.	False Solomon's Seal
Smilax glauca Walter	Sawbrier
Smilax rotundifolia L.	Common Greenbrier
Trillium erectum var. *vaseyi* (Harbison)Ahler	Wake Robin
Trillium undulatum Willd.	Painted Trillium
Uvularia perfoliata L.	Bellwort
DIOSCOREACEAE	
Dioscorea villosa L.	Wild Yam
AMARYLLIDACEAE	
Hypoxis hirsuta (L.) Cov.	Yellow Stargrass
IRIDACEAE	
Sisyrinchium angustifolium Miller	Blue-eyed Grass
***Sisyrinchium mucronatum* Michx.	Slender Blue-eyed Grass
ORCHIDACEAE	
Aplectrum hyemale (Muhl. ex Willd.)Torrey	Puttyroot
Goodyera pubescens (Willd.) R. Brown	Downy Rattlesnake Plantain
Habenaria ciliaris (L.) R. Brown	Yellow Fringed Orchid
Habenaria clavellata (Michx.) Sprengel	Small Green Wood Orchid
***Spiranthes cernua* (L.) Richard	Nodding Ladies Tresses
SALICACEAE	
Salix humilis Marshall	Tall Prairie Willow
Salix sericea Marshall	Silky Willow
JUGLANDACEAE	
Carya cordiformis (Wang.)K. Koch	Bitternut Hickory
BETULACEAE	
Alnus serrulata (Ait.) Willd.	Tag Alder
Betula lenta L.	Sweet Birch
***Corylus americana* Walter	American Hazel-nut
FAGACEAE	
Castanea dentata (Marsh.) Borkh.	American Chestnut
Fagus grandifolia Ehr.	American Beech
Quercus alba L.	White Oak

***Quercus coccinea* Muench.	Scarlet Oak
Quercus rubra L.	Northern Red Oak
Quercus velutina Lam.	Black Oak
URTICACEAE	
Boehmeria cylindrica (L.) Swartz	False Nettle
SANTALACEAE	
Pyrularia pubera Michx.	Buffalo Nut
ARISTOLOCHIACEAE	
Hexastylis arifolia (Michx.)Small	Wild Ginger
POLYGONACEAE	
***Polygonum cespitosum* var. *longisetum* (DeBruyn) Stewart	
***Polygonum hydropiper* L.	
Polygonum punctatum Ell.	Dotted Smartweed
Polygonum sagittatum L.	Tearthumb
***Polygonum scandens* L.	
Rumex acetosella L.	Field Sorrel, Sheep Sorrel
Rumex obtusifolius	Bitter Dock
PHYTOLACCACEAE	
Phytolacca americana L.	Poke, Pokeweed
CARYOPHYLLACEAE	
Cerastium holosteoides var. *vulgare* (Hartman) Hylander	Mouse-ear Chickweed
***Dianthus armeria* L.	Deptford Pink
***Holosteum umbellatum* L.	Jagged Chickweed
Silene virginica L.	Fire Pink
Stellaria media (L.) Cyrilla	Chickweed
Stellaria pubera Michx.	Giant Chickweed
RANUNCULACEAE	
Actaea pachypoda Ell.	Baneberry, Doll's Eye
***Anemone quinquefolia* L.	Wood Anemone, Windflower
Anemone virginiana L.	Thimbleweed
Aquilegia canadensis L.	Columbine
Clematis virginiana L.	Virgin's Bower
Ranunculus hispidus Michx.	Bristly Buttercup
Ranunculus recurvatus Poiret	Hooked Crowfoot
Thalictrum clavatum DC.	
Thalictrum polygamum Muhl.	Tall Meadow Rue
Thalictrum thalictroides (L.) Boivin	Rue Anemone
Xanthorhiza simplicissima Marsh.	Yellow-root
BERBERIDACEAE	
Podophyllum peltatum L.	Mayapple
MAGNOLIACEAE	
Liriodendron tulipifera L.	Yellow-poplar
Magnolia sp.	Magnolia
CALYCANTHACEAE	
Calycanthus floridus var. *laevigatus* (Willd.) T&G	Sweetshrub
LAURACEAE	
Lindera benzoin (L.) Blume	Spicebush
Sassafras albidum (Nutt.) Nees	Sassafras
PAPAVERACEAE	
Papaver sp.	Poppy
BRASSICACEAE	
***Arabis canadensis* L.	Sicklepod

Barbarea vulgaris R. Brown	Yellow Rocket
***Brassica napus* L.	Turnip Rape
Cardamine hirsuta L.	Hairy Bittercress
Lepidium virginicum L.	Wild Peppergrass
***Nasturtium officinale* R. Brown	Watercress
SARRACENIACEAE	
Sarracenia purpurea L.	Northern Pitcher Plant, Purple Pitcher Plant
SAXIFRAGACEAE	
Hydrangea arborescens L. ssp. *arborescens*	Wild Hydrangea
Heuchera americana L.	Alumroot
Tiarella cordifolia L.	Foamflower
HAMAMELIDACEAE	
PLATANACEAE	
Platanus occidentalis L.	Sycamore
ROSACEAE	
Agrimonia parviflora Aiton	Agrimony
Amelanchier arborea (Michx. f.) Fern. var. *laevis* (Wiegand) Ahles	Serviceberry
Aruncus dioicus (Walter) Fern.	Goatsbeard
Crataegus punctata Jacquin	Hawthorn
Fragaria virginiana Duchesne	Wild Strawberry
Geum canadense Jacq.	White Avens
***Geum virginianum* L.	Yellow Avens
Gillenia trifoliata (L.) Moench	Bowman's Root, Indian Physic
***Malus angustifolia* (Aiton) Michaux	Crabapple
***Potentilla canadensis* L.	Dwarf Cinquefoil
Potentilla norvegica L.	Rough Cinquefoil
Potentilla recta L.	Rough-fruited, Sulfur Cinquefoil
Potentilla simplex Michx.	Common Cinquefoil
***Prunus americana* Marshall	Wild Plum
***Prunus serotina* Ehrhart	Black Cherry
***Rosa multiflora* Thunberg	Multiflora Rose
Rosa palustris Marshall	Swamp Rose
***Rubus allegheniensis* Porter	Common Blackberry
Rubus argutus Link	Serrate-leaf Blackberry
***Rubus hispidus* L.	Swamp Dewberry
Rubus occidentalis L.	Black Raspberry
Rubus odoratus L.	Flowering Raspberry
Sorbus arbutifolia (L.) Heynold var. *arbutifolia*	Red Chokeberry
Sorbus melanocarpa (Michx.) Schneider	Black Chokeberry
FABACEAE	
Amorpha fruticosa L.	False Indigo
Apios americana Medicus	Ground Nut
Baptisia tinctoria (L.) R. Brown	Wild Indigo
Cassia fasiculata Michx.	Partridge Pea
Cassia nictitans L.	Wild Sensitive Plant
Clitoria mariana L.	Butterfly Pea
***Desmodium canescens* (L.) DC	Hoary Tick Trefoil
***Desmodium ciliare* (Muhl. ex Willd.) DC	Hairy Small-leaved Tick Trefoil
***Desmodium cuspidatum* (Muhl. ex Willd.) Loudon	Large-bracted Tick Trefoil
Desmodium nudiflorum (L.)DC	Naked Tick Trefoil
Desmodium paniculatum (L.) DC	Panicled Tick Trefoil
***Lespedeza cuneata* (Dumont) G. Don	Sericea

Lespedeza intermedia (Watson) Britt.	Wandlike Bush Clover
Lespedeza stipulacea Maxim.	Korean Clover
Lespedeza striata (Thunberg) H & A	Japanese Clover
Melilotus alba Desr.	White Sweet Clover
Melilotus officinalis L.	Yellow Sweet Clover
*****Pueraria lobata* (Willd.) Ohwi	Kudzu
*****Robinia pseudo-acacia* L.	Black Locust
*****Stylosanthes biflora* (L.) BSP	Pencil Flower
Tephrosia virginiana (L.) Pers.	Goat's Rue
*****Thermopsis villosa* (Walter) Fern. & Schub.	Thermopsis
*****Trifolium campestre* Schreber	Low Hop Clover
Trifolium hybridum L.	Alsike Clover
*****Trifolium incarnatum* L.	Crimson Clover
Trifolium pratense L.	Red Clover
Trifolium repens L.	White Clover, Ladino Clover
Vicia caroliniana Walter	Wood Vetch
LINACEAE	
*****Linum virginianum* L. var. *virginianum*	Flax
OXALIDACEAE	
*****Oxalis florida* var. *filipes* (Small)Ahles	Creeping Wood Sorrel
Oxalis stricta L.	Yellow Wood Sorrel
GERANIACEAE	
Geranium carolinianum L.	Carolina Cranesbill
Geranium maculatum L.	Wild Geranium
POLYGALACEAE	
Polygala curtissii Gray	Curtiss' Milkwort
*****Polygala cruciata* L.	Marsh Milkwort, Cross-leaved Milkwort
*****Polygala incarnata* L.	Milkwort
*****Polygala verticillata* L. var. *ambigua* Wood	Whorled Milkwort
EUPHORBIACEAE	
Acalypha sp.	Three-seeded Mercury
Euphorbia corollata L.	Flowering Spurge
ANACARDIACEAE	
Rhus copallina L.	Winged Sumac
Rhus glabra L.	Smooth Sumac
Rhus radicans L.	Poison Ivy
AQUIFOLIACEAE	
Ilex opaca Aiton	American Holly
Ilex verticillata (L.) Gray	Winterberry
CELASTRACEAE	
Euonymous americanus L.	Strawberry Bush, Bursting Heart
ACERACEAE	
Acer pensylvanicum L.	Striped Maple
Acer rubrum L.	Red Maple
BALSAMINACEAE	
Impatiens capensis Meerb.	Spotted Touch-me-not, Jewelweed
Impatiens pallida Nutt.	Pale Touch-me-not, Jewelweed
RHAMNACEAE	
Ceanothus americanus L.	New Jersey Tea
VITACEAE	
Parthenocissus quinquefolia (L.) Planchon	Virginia Creeper
Vitis aestivalis Michx.	Summer Grape

Vitis labrusca L.	Fox Grape
Vitis rotundifolia Michx.	Grape
MALVACEAE	
***Abutilon theophrastii* Medicus	Velvetleaf
HYPERICACEAE	
***Hypericum canadense* L.	St. Johnswort
Hypericum gentianoides (L.) BSP	Pineweed
Hypericum mutilum L.	Dwarf St. Johnswort
Hypericum punctatum Lam.	Spotted St. Johnswort
Hypericum stragalum P. Adams and Robson	St. Andrew's Cross
VIOLACEAE	
Viola blanda Willd.	Large-leaf White Violet
Viola cucullata Aiton	
Viola hastata Michx.	Halberd-leaved Violet
***Viola macloskeyi* var. *pallens* (Banks ex DC)C.L. Hitchcock	
***Viola papilionacea* Pursh.	Common Blue Violet
***Viola pedata* L.	Bird-foot Violet
***Viola primulifolia* L.	Primrose-leaved Violet
Viola rostrata Pursh.	Long-spurred Violet
Viola sagittata Ait.	Arrow-leaved Violet
ELAEAGNACEAE	
***Elaeagnus pungens* Thunberg	Silverberry
MELASTOMATACEAE	
Rhexia mariana L.	Maryland Meadow Beauty
Rhexia virginica L.	Meadow Beauty
ONAGRACEAE	
Circaea sp.	Enchanter's Nightshade
Ludwigia alternifolia L.	Seedbox
Ludwigia palustris (L.) Ell.	
Oenothera biennis L.	Evening Primrose
Oenothera tetragona Roth.	Evening Primrose
ARALIACEAE	
Aralia spinosa L.	Hercules Club
APIACEAE	
Angelica venenosa (Greenway) Fern.	Angelica
Cryptotaenia canadensis (L.) DC	Honewort
Daucus carota L.	Wild Carrot, Queen Anne's Lace
Oxypolis rigidior L.	Cowbane
Thaspium trifoliatum (L.) Gray var. *trifoliatum*	Meadow Parsnip
Zizia aurea (L.) W.D.J. Koch	Golden Alexander
NYSSACEAE	
Nyssa sylvatica Marshall var. *sylvatica*	Black Gum
CORNACEAE	
Cornus alternifolia L. f.	Alternate-leaved Dogwood
Cornus amomum Mill.	Silky Dogwood
Cornus florida L.	Flowering Dogwood
CLETHRACEAE	
Clethra acuminata Michx.	Sweet Pepperbush

ERICACEAE

Chimaphila maculata (L.) Pursh	Spotted Wintergreen, Pipsissewa
Kalmia latifolia L.	Mountain Laurel
Leucothoe axillaris (Lam.) D. Don var. *editorum* (Fern. & Schubert) Ahles	Drooping Leucothoe, Doghobble
Lyonia ligustrina (L.) DC	Maleberry
Monotropa uniflora L.	Indian Pipe
Oxydendrum arboreum (L.) DC	Sourwood
Rhododendron calendulaceum (Michx.) Torr.	Flame Azalea
Rhododendron maximum L.	Rosebay, Great Laurel
Vaccinium constablaei Gray	Blueberry
******Vaccinium corymbosum* L.	Highbush Blueberry
Vaccinium stamineum L.	Deerberry
Vaccinium vacillans Torrey	Blueberry
DIAPENSIACEAE	
Galax aphylla L.	Galax
PRIMULACEAE	
Lysimachia lanceolata Walter var. *lanceolata*	Fringed Loosestrife
Lysimachia quadrifolia L.	Whorled Loosestrife
GENTIANACEAE	
******Gentiana quinquefolia* L.	Stiff Gentian
Sabatia angularis L.	Rose Pink
******Sabatia campanulata* (L.) Torr.	Slender Marsh Pink
ASCLEPIADACEAE	
Asclepias incarnata L.	Swamp Milkweed
Asclepias quadrifolia Jacquin	Four-leaved Milkweed
Asclepias tuberosa L.	Butterfly Weed
CONVOLVULACEAE	
Cuscuta campestris Yuncker	Field Dodder
POLEMONIACEAE	
******Phlox glaberrima* L.	Smooth Phlox
******Phlox maculata* L. ssp. *pyramidalis* (Smith) Wherry	Wild Sweet William
PHRYMACEAE	
Phryma leptostachya L.	Lopseed
LAMIACEAE	
Collinsonia canadensis L.	Horse Balm
******Lycopus uniflorus* Michx.	Northern Bugleweed
Lycopus virginicus L.	Virginia Bugleweed
Mentha piperita L.	Peppermint
Monarda clinopodia L.	Basil Balm
Monarda didyma L.	Oswego Tea
Monarda fistulosa L.	Wild Bergamot
Prunella vulgaris L.	Selfheal
Pycnanthemum incanum (L.) Michx.	Hoary Mountain Mint
Pycnanthemum muticum (Michx.) Persoon	Short-toothed Mountain Mint
Pycnanthemum verticillatum (Michx.) Pers.	Mountain Mint
Salvia lyrata L.	Lyre-leaved Sage
Scutellaria elliptica Muhl.	Hairy Skullcap
******Scutellaria serrata* Andrz.	Showy Skullcap
SOLANACEAE	
Solanum carolinense L.	Horse Nettle
SCROPHULARIACEAE	

Agalinis purpurea (L.) Pennell	False Foxglove
*****Chelone obliqua* L.	Red Turtlehead
*****Lindernia dubia* (L.)Pennell	
Melampyrum lineare Desr.	Cowwheat
Mimulus ringens L.	Monkey Flower
Pedicularis canadensis L.	Wood Betony
Verbascum blattaria L.	Moth Mullein
Verbascum thapsus L.	Woolly Mullein
Veronica officinalis L.	Common Speedwell
LENTIBULARIACEAE	
*****Utricularia subulata* L.	Zigzag Bladderwort
PLANTAGINACEAE	
Plantago lanceolata L.	English Plantain
*****Plantago major* L.	Common Plantain
Plantago rugelii Dcne	Red-stemmed Plantain
Plantago virginica L.	Pale-seed Plantain
RUBIACEAE	
Diodia teres Walter	Buttonweed
Galium aparine L.	Cleavers
*****Galium asprellum* Michx.	Rough Bedstraw
Galium circaezans Michx.	Wild Licorice
Galium tinctorium L.	Stiff Marsh Bedstraw
Galium triflorum Michx.	Sweet-scented Bedstraw
Houstonia caerulea L.	Bluets, Quaker Ladies
Houstonia purpurea L.	Large Houstonia
*****Houstonia serpyllifolia* Michx.	Creeping Bluet
CAPRIFOLIACEAE	
Lonicera japonica Thunberg	Japanese Honeysuckle
Sambucus canadensis L.	Elderberry
Triosetum aurantiacum Bicknell	Orange-fruited Horse Gentian
Viburnum cassinoides L.	Witherod
VALERIANACEAE	
Valerianella radiata (L.) Dufr.	Beaked Corn Salad
*****Valerianella umbilicata* (Sullivant) Wood	Corn Salad
CAMPANULACEAE	
Campanula americana L.	Tall Bellflower
*****Campanula aparinoides Pursh.	Marsh Bellflower
Campanula divaricata Michx.	Southern Harebell
Lobelia inflata L.	Indian Tobacco
Lobelia puberula Michx.	Downy Lobelia
Lobelia siphilitica L.	Great Lobelia
*****Lobelia spicata* Lam.	Spiked Lobelia
Specularia perfoliata (L.) A. DC	Venus' Looking-glass
ASTERACEAE	
Achillea millefolium L.	Milfoil, Yarrow
Ambrosia artemisiifolia L.	Annual Ragweed
Ambrosia trifida L.	Giant Ragweed
*****Aster concolor* L.	Eastern Silvery Aster
Aster divaricatus L.	Heart-leaved Aster
Aster infirmus Michx.	Cornel-leaved Aster
Aster novae-angliae L.	New England Aster
Aster paternus Cronq.	White-topped Aster

*****_Aster pilosus_ Willd. var. _pilosus_	Frost Aster
*****_Aster prenanthoides_ Muhl.	Crooked Stem Aster
*****_Aster puniceus_ L.	
*****_Aster undulatus_ L.	Wavy-leaved Aster
*****_Bidens frondosa_ L.	Beggar's Ticks
*****_Bidens tripartita_ L.	Beggar's Ticks
Cacalia atriplicifolia L.	Pale Indian Plantain
*****_Carduus altissimus_ L.	Tall Thistle
*****_Carduus lanceolatus_ L.	Bull Thistle
Chrysanthemum leucanthemum L.	Ox-eye Daisy
Coreopsis major Walter var. _stellata_ (Nuttall) Robinson	Greater Coreopsis
Coreopsis tripteris L.	Tall Coreopsis
Erechtites hieracifolia (L.) Raf.	Fireweed
Erigeron annuus (L.) Persoon	Daisy Fleabane
Erigeron canadensis var. _canadensis_ L.	Horseweed
Erigeron philadelphicus L.	Philadelphia Fleabane
Erigeron pulchellus Michx.	Robin's Plantain
Eupatorium fistulosum Barratt	Hollow Joe-pye-weed
Eupatorium perfoliatum L.	Boneset
*****_Eupatorium pilosum_ Walter	Rough Boneset
*****_Eupatorium rotundifolium_ L.	Round-leaf Thoroughwort
Eupatorium rugosum Houttuyn	White Snakeroot
Galinsoga ciliata (Raf.) Blake	Peruvian Daisy
Gnaphalim purpureum L.	Cudweed
*****_Helenium autumnale_ L.	Sneezeweed
Helianthus atrorubens L.	Hairy Wood Sunflower
Helianthus microcephalis T.& G.	Small Wood Sunflower
Heterotheca sp.	Golden Aster
Hieracium gronovii L.	Hawkweed
Hieracium venosum L.	Rattlesnake Weed
Hypochoeris radicata L.	Cat's Ear
Lactuca canadensis L.	Wild Lettuce
*****_Liatris spicata_ (L.) Willd.	Blazing Star
*****_Rudbeckia triloba_ L.	Thin-leaved Coneflower
Senecio smallii Britton	Ragwort
*****_Solidago altissima_ L.	Tall Goldenrod
*****_Solidago caesia_ L.	Blue-stemmed Goldenrod
*****_Solidago erecta_ Pursh.	Erect Goldenrod
Solidago gigantea Ait.	Late Goldenrod
*****_Solidago juncea_ Ait.	Early Goldenrod
Solidago nemoralis Ait.	Gray Goldenrod
*****_Solidago rugosa_ Miller var. _rugosa_	Rough-stemmed Goldenrod
Solidago sp.	Goldenrod
*****_Solidago uliginosa_ Nuttall	Bog Goldenrod
Taraxacum officinale Wiggers	Common Dandelion
Verbesina alternifolia (L.) Britton ex Kearney	
Vernonia noveboracensis (L.) Michx.	Ironweed
SPHAGNACEAE	
Sphagnum spp.	Peat Moss
POLYTRICHACEAE	
Polytrichum sp.	Haircap Moss

LICHEN FLORA (IN FEN)

CLADONIACEAE
Cladonia cristatella Tuck.
Cladonia cryptochlorophae Asah.
Cladonia verticillata (Hoffm.) Schaer.
COLLEMATACEAE
Leptogium cyanescens (Ach.) Korb.
HYPOGYMNIACEAE
Hypogymnia physoides (L.) Nyl.
Pseudevernia consocians (Vain.) Hale & Culb.
PARMELIACEAE
Cetraria ciliaris Ach.
Cetraria oakesiana Tuck.
Cetraria viridus Schwein
Hypotrachyna livida (Tayl.) Hale
Parmelia rudecta Ach.
Parmelia subrudecta Nyl.
Pseudoparmelia caperata (L.) Hale
Plasmatti tuckermanii (Oakes) Culb. & Culb.
PELTIGERACEAE
Peltigera canina (L.) Willd.
PHYSICIACEAE
Heterodermia leucomelaena (L.) Poelt
RAMALINACEAE
Ramalina americana Hale
STICTACEAE
Lobaria pulmonaria L. Hoffm.
Lobaria quercizans Michx.
Pseudocyphellaria aurata (Ach.) Vain
Sticta weigelil (Ach.) Vain
USNEACEAE
Usnea rubicunda Stirt.
Usnea strigosa (Ach.) Eaton

APPENDIX B. Amphibian and Reptile species at Tulula

Common Name	Scientific name
Family Ambystomatidae	
spotted salamander	*Ambystoma maculatum*
Family Plethodontidae	
four-toed salamander	*Hemidactylium scutatum*
Ocoee salamander	*Desmognathus ocoee*
black-bellied salamander	*D. quadramaculatus*
Blue Ridge two-lined salamander	*Eurycea bislineata wilderae (= E. wilderae)*
three-lined salamander	*E. guttolineata*
black-chinned red salamander	*Pseudotriton ruber schencki*
Blue Ridge spring salamander	*Gyrinophilus porphyriticus danielsi*
southern Appalachian salamander	*Plethodon oconaluftee*
southern red-backed salamander	*Plethodon serratus*
Family Salamandridae	
red-spotted newt	*Notophthalmus v. viridescens*
Family Bufonidae	
American toad	*Bufo a. americanus*
Family Ranidae	
bullfrog	*Rana catesbeiana*
green frog	*Rana clamitans melanota*
wood frog	*Rana sylvatica*
Family Hylidae	
northern spring peeper	*Pseudacris c. crucifer*
gray treefrog	*Hyla chrysoscelis*

Family Chelydridae	
common snapping turtle	*Chelydra s. serpentina*
Family Emydidae	
bog turtle	*Clemmys muhlenbergii*
eastern box turtle	*Terrepene c. carolina*
Family Iguanidae (Phyrynosomatidae)	
eastern fence lizard	*Sceloporus u. undulatus*
Family Scincidae	
five-lined skink	*Eumeces fasciatus*
Family Colubridae	
northern water snake	*Nerodia s. sipedon*
eastern garter snake	*Thamnophis s. sirtalis*
eastern ribbon snake	*Thamnophis s. sauritis*
northern ringneck snake	*Diadophis punctatus edwardsii*
black rat snake	*Elaphe o. obsoleta*
northern black racer	*Coluber c. constrictor*
Family Viperidae	
timber rattlesnake	*Crotalus horridus*
northern copperhead	*Agkistrodon contortrix mokasen*

APPENDIX C. Bird Species at Tulula Wetland (1994-2001).

(1) Probably breeding.
(2) Nest found.
(3) Migrant.
(4) Foraging, but not breeding.
(5) Winter resident.

Common Name	Scientific Name
Family Ardeidae (herons and bitterns)	
Great Blue Heron (4)	*Ardea herodias*
Green Heron (4)	*Butorides striatus*
Family Anatidae (waterfowl)	
Wood Duck (4)	*Aix sponsa*
Family Cathartidae (American vultures)	
Black Vulture (4)	*Coragyps atratus*
Turkey Vulture (4)	*Cathartes aura*
Family Accipitridae (hawks)	
Red-tailed Hawk (4)	*Buteo jamaicensis*
Red-shouldered Hawk (4)	*Buteo lineatus*
Broad-winged Hawk (2)	*Buteo platypterus*
Cooper's Hawk (4)	*Accipiter cooperii*
Family Pandionidae (ospreys)	
Osprey (3)	*Pandion haliaetus*
Family Strigidae (typical owls)	
Eastern Screech Owl (4)	*Otus asio*
Barred Owl (4)	*Strix varia*
Great Horned Owl (2)	*Bubo virginianus*
Family Tetraonidae (grouse)	
Ruffed Grouse (4)	*Bonasa umbellus*
Family Phasianidae (quail, pheasants, etc.)	
Northern Bobwhite (1)	*Colinus virginianus*
Family Meleagrididae (turkeys)	
Wild Turkey (2)	*Meleagris gallopavo*
Family Scolopacidae (sandpipers)	
American Woodcock (1)	*Scolopax minor*
Common Snipe (4)	*Capella gallinago*
Solitary Sandpiper (3)	*Tringa solitaria*
Spotted Sandpiper (3)	*Actitis macularia*
Family Columbidae (pigeons and doves)	
Mourning Dove (1)	*Zenaida macroura*
Family Cululidae (cuckoos)	
Yellow-billed Cuckoo (4)	*Coccyzus americanus*
Black-billed Cuckoo (3)	*Coccyzus erythropthalmus*
Family Caprimulgidae (goatsuckers)	
Whip-poor-will (1)	*Caprimulgus vociferus*
Family Apodidae (swifts)	
Chimney Swift (4)	*Chaetura pelagica*
Family Trochilidae (hummingbirds)	
Ruby-throated Hummingbird (2)	*Archilochus colubris*
Family Alcedinidae (kingfishers)	
Belted Kingfisher (4)	*Ceryle alcyon*
Family Picidae (woodpeckers)	

Northern Flicker (2)	*Colaptes auratus*
Pileated Woodpecker (4)	*Dryocopus pileatus*
Hairy Woodpecker (4)	*Picoides villosus*
Downy Woodpecker (1)	*Picoides pubescens*
Family Tyrannidae (flycatchers)	
Acadian Flycatcher (1)	*Empidonax virescens*
Alder Flycatcher (3)	*Empidonax alnorum*
Eastern Pewee (1)	*Contopus virens*
Family Hirundinidae (swallows)	
Northern Rough-winged Swallow (4)	*Stelgidopteryx serripennis*
Tree Swallow (4)	*Tachycineta bicolor*
Barn Swallow (4)	*Hirundo rustica*
Family Corvidae (jays and crows)	
Blue Jay (1)	*Cyanocitta cristata*
Common Raven (4)	*Corvus corax*
American Crow (4)	*Corvus brachyrhynchos*
Family Paridae (titmice)	
Carolina Chickadee (1)	*Parus carolinensis*
Tufted Titmouse (1)	*Parus bicolor*
Family Sittidae (nuthatches)	
White-breasted Nuthatch (1)	*Sitta carolinensis*
Red-breasted Nuthatch (3)	*Sitta canadensis*
Family Certhiidae (creepers)	
Brown Creeper (4)	*Certhia americana*
Family Troglodytidae (wrens)	
Carolina Wren (1)	*Thryothorus ludovicianus*
Winter Wren (3)	*Troglodytes troglodytes*
Family Mimidae (mockingbirds, catbirds, thrashers)	
Gray Catbird (1)	*Dumetella carolinensis*
Brown Thrasher (1)	*Toxostoma rufum*
Family Turdidae (thrushes)	
American Robin (1)	*Turdus migratorius*
Hermit Thrush (3)	*Catharus guttatus*
Wood Thrush (1)	*Hylocichla mustelina*
Family Sylviidae (kinglets, etc.)	
Blue-gray Gnatcatcher (2)	*Polioptila caerulea*
Golden-crowned Kinglet (3)	*Regulus satrapa*
Ruby-crowned Kinglet (3)	*Regulus calendula*
Family Bombycillidae (waxwings)	
Cedar Waxwing (1)	*Bombycilla cedrorum*
Family Virionidae (vireos)	
White-eyed Vireo (1)	*Vireo griseus*
Yellow-throated Vireo (1)	*Vireo flavifrons*
Solitary Vireo (1)	*Vireo solitarius*
Red-eyed Vireo (1)	*Vireo olivaceus*
Family Parulidae (wood warblers)	
Black-and-white Warbler (1)	*Mniotilta varia*
Swainson's Warbler (1)	*Limnothlypis swainsonii*
Worm-eating Warbler (3)	*Helmitheros vermivorus*
Golden-winged Warbler (1)	*Vermivora chrysoptera*
Blue-winged Warbler (3)	*Vermivora pinus*
Northern Parula (2)	*Parula americana*

Pine Warbler (1)	*Dendroica pinus*
Black-throated Blue Warbler (3)	*Dendroica caerulescens*
Black-throated Green Warbler (3)	*Dendorica virens*
Yellow-throated Warbler (1)	*Dendroica dominica*
Chestnut-sided Warbler (1)	*Dendroica pensylvania*
Yellow Warbler (3)	*Dendroica petechia*
Ovenbird (2)	*Seiurus aurocapillus*
Kentucky Warbler (2)	*Oporornis formosus*
Common Yellowthroat (1)	*Geothlypis trichas*
Yellow-breasted Chat (1)	*Icteria virens*
Canada Warbler (3)	*Wilsonia canadensis*
Hooded Warbler (2)	*Wilsonia citrina*
American Redstart (3)	*Setophaga ruticilla*
Family Icteridae (blackbirds)	
Common Grackle (1)	*Quiscalus quiscula*
Red-winged Blackbird (4)	*Agelaius phoenicus*
Brown-headed Cowbird (1)	*Molothrus ater*
Family Traupidae (tanagers)	
Scarlet Tanager (1)	*Piranga olivacea*
Family Fringillidae (finches, etc.)	
Northern Cardinal (1)	*Cardinalis cardinalis*
Indigo Bunting (2)	*Passerina cyanea*
Blue Grosbeak (3)	*Guiraca caerulea*
American Goldfinch (1)	*Carduelis tristis*
Rufous-sided Towhee (2)	*Pipilo erythrophthalmus*
Northern Junco (5)	*Junco hyemalis*
White-throated Sparrow (5)	*Zonotrichia albicollis*
Field Sparrow (3)	*Spizella pusilla*
Fox Sparrow (3)	*Passerella iliaca*
Swamp Sparrow (5)	*Melospiza georgiana*
Song Sparrow (1)	*Melospiza melodia*

APPENDIX D. Mammal species at Tulula Wetland (1994-2001).

(1) Captured by pitfall trap or mist net. (3) Visual Observation.
(2) Captured by Sherman live-trap. (4) Tracks. (5) Other signs of activirty.

Common Name	Scientific Name
Family Diadelphidae (opossums)	
Opossum (4)	*Didelphis marsupialis*
Family Soricidae (shrews)	
Masked Shrew (1)	*Sorex cinerus*
Smoky Shrew (1)	*Sorex fumeus*
Short-tailed Shrew (1)	*Blarina brevicauda*
Family Talpidae (moles)	
Hairytail Mole (1)	*Parascalops breweri*
Family Vespertilionidae (bats)	
Little Brown Myotis (1)	*Myotis lucifugus*
Keen's Bat (1)	*Myotis keenii*
Eastern Pipistrelle (1)	*Pipestrellus subflavus*
Big Brown Bat (1)	*Eptesicus fuscus*
Red Bat (1)	*Lasiurus borealis*
Family Leporidae (rabbits and hares)	
Eastern Cottontail (3)	*Sylvilagus floridanus*
Family Sciuridae (squirrels and chipmunks)	
Eastern Gray Squirrel (3)	*Sciurus carolinensis*
Eastern Chipmunk (3)	*Tamias striatus*
Woodchuck (3)	*Marmota monax*
Southern Flying Squirrel (1,2)	*Glaucomys volans*
Red Squirrel (3)	*Tamiasciurus hudsonicus*
Family Castoridae	
Beaver (3)	*Castor canadensis*
Family Cricetidae (new world rats and mice)	
White-footed Mouse (1,2)	*Peromyscus leucopus*
Golden Mouse (1,2)	*Ochrotomys nuttalli*
Meadow Vole (1)	*Microtus pennsylvanicus*
Pine Vole (1)	*Pitymys pinetorum*
Muskrat (3,5)	*Ondatra zibethicus*
Family Zapodidae (jumping mice)	
Meadow Jumping Mouse (1)	*Zapus hudsonius*
Woodland Jumping Mouse (2)	*Napaeozapus insignis*
Family Ursidae (bears)	
Black Bear (3,4)	*Ursus americanus*
Family Mustelidae (weasels, skunks, badgers, etc.)	
Mink (3)	*Mustela vison*
Family Procyonidae (raccoons, ringtail, coati)	
Raccoon (4,5)	*Procyon lotor*
Family Cervidae (deer, elk, etc.)	
White-tailed Deer (3)	*Odocoileus virginianus*
Family Suidae (old world swine)	
Wild Boar (5)	*Sus scrofa*
Family Felidae (cats)	
Bobcat (3)	*Lynx rufus*
Family Canidae (dogs, wolves, foxes)	
Coyote (5)	*Canis latrans*
Red Fox (5)	*Vulpes fulva*

APPENDIX E. Vegetation communities of Tulula.

The boundaries and extent of vegetation community types were established through GIS analysis of aerial photography and field verification. As much as possible, we have identified synonymy with Schafale and Weakley (SW90; 1990) and Weakley et al. (WPLP98; 1998). The following categories and areas were determined using the 1998 aerial photography:

Pine - Oak/Heath (1.2 hectares, 1.4% of the site) - This community type is found at the highest, driest portion of the site, located on the Forest Service Knoll. It is dominated by pines (*Pinus rigida, P. strobus, and P. virginiana*) in the canopy, sourwood (*Oxydendrum arboreum*) and dogwood (*Cornus florida*) in the subcanopy, and various ericaceous species (*Vaccinium* sp., *Kalmia latifolia*) in the shrub layer.

SW90: Pine - Oak/Heath (Virginia pine forest; Pitch pine heath; Table mountain pine heath)

WPLP98: I.A.8.N.b.190. *Pinus virginiana* Forest Alliance - Virginia Pine Forest Alliance

Montane Oak - Hickory Forest (7.3 hectares, 8.8% of the site) - Oak/hickory forests dominate the higher, south-facing slope positions, and the portion of the Forest Service Knoll just below the pine-oak/heath-dominated sites. Representative species include several oak species (*Quercus alba, Q. coccinea, Q. rubra, and Q. velutina*), mockernut hickory (*Carya alba* or *tomentosa*), red maple (*Acer rubrum*), tulip poplar (*Liriodendron tulipifera*), black locust (*Robinia pseudo-acacia*), black gum (*Nyssa sylvatica*), sourwood and dogwood, with sparse ericaceous shrubs in the understory. The sparse shrub/herb layer is dominated by buffalo nut (*Pyrularia pubera*), wild yam (*Dioscorea villosa*), Christmas fern (*Polystichum acrostichoides*), and poison ivy (*Toxicodendron radicans*).

SW90: Montane Oak - Hickory Forest (Mixed oak, yellow poplar, hickory forest; White oak forest; Mixed oak slope)

WPLP98: I.B.2.N.a.260. *Quercus alba - Quercus* (*coccinea, rubra, velutina*) Forest Alliance - White Oak - (Scarlet Oak, Red Oak, Black Oak) Forest Alliance

Rich Cove Forest (depauperate) (7.2 hectares, 8.7% of the site) - This community type is found primarily on the north-facing slope at the southeast corner of the site, and as a remnant patch near the center of the site. Much compromised by fragmentation and nearby disturbances, this community type still exhibits many features of the rich cove hardwood forests that once dominated these sites. The canopy layer includes tulip poplar, red maple, white oak, sweet birch (*Betula lenta*), and hickories; the subcanopy is dominated by sourwood, dogwood and spicebush (*Lindera benzoin*). The herb layer is dense and relatively rich compared to the rest of the site, but is not as diverse as more typical cove hardwood forests.

SW90: Rich Cove Forest (Mixed Mesophytic Forest)

WPLP98: I.B.2.N.a.235. *Liriodendron tulipifera - Tilia americana* var. heterophylla -*Aesculus flava - Acer saccharum* Forest Alliance - Tuliptree - Appalachian Basswood - Yellow Buckeye - Sugar Maple Forest Alliance

Acidic Cove Forest (3.2 hectares, 3.9% of the site) - This community type is found in isolated areas at the wet base of north-facing slopes, and is entirely dominated by dense rosebay rhododendron (*Rhododendron maximum*) thickets. The canopy consists mostly of white oak with some tulip poplar; there is little subcanopy and almost no herb layer development.

SW90: Acidic Cove Forest (Mixed Mesophytic Forest)

WPLP98: I.C.3.N.a.260. *Tsuga canadensis - Liriodendron tulipifera* Forest Alliance -Eastern Hemlock - Tuliptree Forest Alliance

Mixed Mesophytic Hardwoods (5.1 hectares, 6.1% of the site) - Remnant patches of mesophytic hardwood forests are found throughout the site on low slopes and flat areas in the upper floodplain of Tulula Creek. Similar to Cove Hardwood and Montane Oak-Hickory forests, the canopy is dominated by red maple, white oak, and tulip poplar, with some white pine, sourwood, and sweet birch. The well-developed subcanopy layer includes tag alder (*Alnus serrulata*), American holly (*Ilex opaca*), sourwood, spicebush, rosebay Rhododendron, dogwood, and pignut hickory (*Carya glabra*). It is distinguished from the other two by being substantially wetter, supporting a diverse herb layer dominated by New York fern (*Thelypteris noveboracensis*), Cinnamon fern (*Osmunda cinnamomea*), Christmas fern, yellowroot (*Xanthorhiza simplicissima*), clubmoss (*Lycopodium obscurum*), and Virgin's bower (*Clematis virginiana*).

SW90: Rich Cove Forest (Mixed Mesophytic Forest)

WPLP98: I.B.2.N.a.235. *Liriodendron tulipifera - Tilia americana* var. *heterophylla -Aesculus flava - Acer saccharum* Forest Alliance - Tuliptree - Appalachian Basswood - Yellow Buckeye - Sugar Maple Forest Alliance

Red Maple-dominated Alluvial Forest (5.0 hectares, 6.0% of the site) - Located at the west end of the site adjacent to Tulula Creek, this community type is similar to the Mesophytic Hardwood Forest but is distinguished from it by having a red maple-dominant canopy, fairly open subcanopy and understory layers, and groundcover dominated largely by ferns, jewelweed (*Impatiens capensis*), swamp dewberry (*Rubus hispidus*), and doghobble (*Leucothoe fontanesiana*).

SW90: Swamp Forest-Bog Complex (Mixed Mesophytic Forest)

WPLP98: I.C.3.N.d.020. *Tsuga canadensis - Acer rubrum* Saturated Forest Alliance - Eastern Hemlock - Red Maple Saturated Forest Alliance

Rosebay Rhododendron-dominated Alluvial Forest (8.9 hectares, 10.7% of the site) - Representing another facet of the swamp forest-bog/fen complex vegetation found throughout the site, Rhododendron-dominated alluvial forests are located close to Highway 129, along the southwestern third of the site. This community type differs from both the Red Maple-dominated Alluvial Forest and the Mesophytic Hardwood Forest by having an understory dominated by Rosebay Rhododendron and an extremely sparse herb layer. It differs from the Acidic Cove Forest in two respects: its canopy is dominated by red maple, tulip poplar, white pine, and some sweet birch, with almost no white oak is present, and soils here are much wetter, with numerous small depressions.

SW90: Acidic Cove Forest (Mixed Mesophytic Forest)

WPLP98: I.C.3.N.a.260. *Tsuga canadensis - Liriodendron tulipifera* Forest Alliance -Eastern Hemlock - Tuliptree Forest Alliance

Poor Fen, Forested (0.6 hectares, 0.7% of the site) - Located just west of the main fen and in an isolated pocket at the far west end of the site, this community type represents an overlap between the various alluvial forest types and the open-canopy, herbaceously-dominated true fen. The canopy is dominated by red maple and black gum, and the patchy shrub layer includes tag alder, chokeberry (*Aronia arbutifolia*), and deciduous holly (*Ilex verticillata*). The herb layer is dominated by sphagnum moss, cinnamon fern, and herbaceous wetland species.

SW90: Swamp Forest-Bog Complex (Mixed Mesophytic Forest)

WPLP98: I.C.3.N.d.020. *Tsuga canadensis - Acer rubrum* Saturated Forest Alliance -Eastern Hemlock - Red Maple Saturated Forest Alliance

Poor Fen, Early Successional (2.3 hectares, 2.8% of the site) - Poor fens, or Southern Appalachian mountain bogs, as they have been known in the past, are found in four widely spaced areas of the site, generally close to Tulula Creek. These areas have no canopy, scattered shrubs, and a lush, diverse herbaceous flora that includes sedges (*Carex folliculata*, C. sp.), bulrush (*Scirpus cyperinus*), beakrush (*Rhynchospora sp*.), stiff gentian (*Gentiana clausa*), red turtlehead (*Chelone obliqua*), cinnamon fern, royal fern (*Osmunda regalis*), and sphagnum moss.

SW90: Southern Appalachian Bog (Southern Subtype) (Poor Fen)

WPLP98: V.A.5.N.m.020. *Carex* (*atlantica, echinata*) - *Eriophorum virginicum* - *Rhynchospora capitellata* - *Solidago patula* Saturated Herbaceous Alliance - (Prickly Bog Sedge, Star Sedge) - Tawny Cottongrass - Northern Beaksedge - Roughleaf Goldenrod Saturated Herbaceous Alliance

Cleared Areas: Dry, Herbaceous (13.4 hectares, 16.1% of the site) - These areas are found on exposed, south-facing slopes and in any location raised above the natural water table by grading. Before golf course construction, these areas likely supported Montane Oak-Hickory Forests. At this time, however, they are dominated by early successional forbs and grasses.

No synonymy

Cleared Areas: Wet, Herbaceous (14.6 hectares, 17.6% of the site) - These areas are found throughout the site, located within the Tulula Creek floodplain. They likely supported a combination of all the wetter community types still represented at the site. At this time they are dominated by herbaceous wetland species (rushes, sedges), blackberries, and are succeeding to red maple and tag alder.

No synonymy

Cleared Areas: Shrubs (11.8 hectares, 14.2% of the site) - These areas exist alongside and comingled with the wet, herb-dominated, cleared sites, and represent a more advanced state of succession. In these areas, tag alder, chokeberry, blackberries, and other shrub species dominate in a mixed grass and grass-like plant matrix. While these areas may be succeeding to one of the alluvial forest types or poor fen, their shrub dominance represents a clear distinction in community type.

SW90: No synonymy

Planted White Pine Forest (2.5 hectares, 3.0% of the site) - A remnant of a planted white pine plantation exists in the northwestern portion of the site. In this gently sloping, south-facing area, white pine-dominated strips, with sparse understory and fern-dominated herb layer, are separated by cleared areas. The planted white pine forest was removed in 1999 as part of site restoration.

SW90: No synonymy

WPLP98: I.A.8.N.b.140. *Pinus strobus* Forest Alliance - Eastern White Pine Forest Alliance

APPENDIX F. Dissemination of information.

a. Presentations

Rossell, I.M. and K. K. Moorhead. Wetlands restoration project in Graham County. UNCA Faculty Forum. March 1995.

Wells, C.L. A comparison of the seed banks of adjacent disturbed and undisturbed North Carolina wetlands. National Conference on Undergraduate Research, Schenectady, NY. April 1995.

Moorhead, K.K. Hydrology and soils of a southern Appalachian swamp-bog complex. Annual meeting of the Association of Southeastern Biologists. Knoxville, TN. April 1995.

Moorhead, K.K. Restoration of Southern Appalachian swamp-bog complexes. Mountain/Piedmont Wetlands Management Workshop. Elkin, NC. May 1995.

Rossell, C.R., Jr., I.M. Rossell, J.W. Petranka, and K.K. Moorhead. Characteristics of a partially disturbed southern Appalachian forest-gap bog complex. Appalachian Biogeography Symposium. Blacksburg, VA. June 1995.

Rossell, C.R., Jr., and I.M. Rossell. Ecology of a mountain bog. Invited presentation. Elisha Mitchell Audubon Society. January 1996.

Rossell, C.R., Jr. Characteristics of a partially disturbed southern Appalachian forest-gap bog. Natural Science Seminar. Warren Wilson College. February 1996.

Moorhead, K.K., and I.M. Rossell. Southern mountain bogs and fens. Conference on Southern Forested Wetlands. Clemson, SC. March 1996.

Rossell, I.M., and C.R. Rossell, Jr. Ecology of a southern Appalachian wetland. Invited presentation. Asheville Men's Garden Club. April 1996.

Rossell, I.M., and C.R. Rossell, Jr. A holistic approach for monitoring restoration of a proposed wetland mitigation bank in western North Carolina. Connections: Transportation, Wetlands, and the Natural Environment Conference. Tacoma, WA. September 1996.

Rossell, C.R., Jr., and I.M. Rossell. Using the structure and composition of vegetation to guide restoration of wildlife habitat in forested wetlands. Connections: Transportation, Wetlands, and the Natural Environment Conference. Tacoma, WA. September 1996

Rossell, C.R., Jr. Habitat selection by small mammals in a southern Appalachian forest-gap bog. Natural Science Seminar. Warren Wilson College. September 1996.

Moorhead, K.K. Soil characteristics of three southern Appalachian bogs in western North Carolina. Annual meeting of the American Society of Agronomy. Indianapolis, IN. November 1996.

Rossell, C.R., Jr., and I.M. Rossell. Microhabitat selection by small mammals in a southern Appalachian forest-gap bog. Seventh Colloquium on the Conservation of Mammals in the South and Central United States. Black Mountain, NC. February 1997.

Wilds, S.P., C.R. Rossell, Jr., and I.M. Rossell. Avian species composition, landscape diversity, and vegetative structure in a partially disturbed southern Appalachian forest-gap bog complex. Association of Southern Biologists annual meeting. Greenville, SC. April 1997.

Moorhead, K. K. Tulula Bog/wetland restoration. National Consortium of Specialized Secondary Schools of Science, Mathematics, and Technology. Science field trip. June 1997.

Moorhead, K. K. Mountain bog restoration. TRB Mid-Year Workshop. Asheville, NC. August 1997.

Petranka, J.W. Direct and indirect effects of predators in structuring amphibian communities in an Appalachian wetlands complex. Invited seminar speaker. Department of Biology, East Tennessee State University. September, 1997.

Rossell, C. R. Jr., I.M. Rossell, K.K. Moorhead, and J.W. Petranka. Monitoring restoration of mountain wetlands using an ecosystem approach. Eighth Annual Southern Appalachian Man and the Biosphere Conference. Gatlinburg, TN. November 1997.

Wells, C.L. and I.M. Rossell. A comparison of the seed banks in a southern Appalachian fen and an adjacent disturbed floodplain. Eighth Annual Southern Appalachian Man and the Biosphere Conference. Gatlinburg, TN. November 1997.

Moorhead, K. K. Tulula wetlands restoration project. Invited speaker. Annual meeting of the Water Resources Research Institute. Raleigh, NC. April 1998

Colburn, K. C., and I. M. Rossell. The use of a bottomland ecosystem by the eastern box turtle, *Terrapene carolina carolina*. National Conference for Undergraduate Research. Salisbury, MD. April 1998.

Vitale, A. C., K. K. Moorhead, and G. Kormanik. A model of contiguity of disturbed and natural habitats of Tulula Bog, NC. National Conference for Undergraduate Research. Salisbury, MD. April 1998.

Hayes, L. J., and J. W. Petranka. Chemically mediated avoidance of a predatory odonate (*Anax junius*) by American toad (*Bufo americanus*) and wood frog (*Rana sylvatica*) tadpoles. National Conference for Undergraduate Research. Salisbury, MD. April 1998.

Moorhead, K. K. Soil characteristics of southern Appalachian fens. Annual meeting of the Society of Wetland Scientists. Anchorage, Alaska. June 1998.

Moorhead, K. K., I. M. Rossell, C. R. Rossell Jr., and J. W. Petranka. Ecological restoration at a a wetlands mitigation bank in western North Carolina. Connections 98: Transportation, Wetlands, and the Natural Environment. New Bern, NC. September 1998.

McCann, M., C. R. Rossell Jr., and I. M. Rossell. Assessing restoration of a floodplain forest on a population of eastern box turtle (*Terrapere carolina*). Poster presentation. Connections 98: Transportation, Wetlands, and the Natural Environment. New Bern, NC. September 1998.

Rossell, C. R. Jr. Song perch characteristics of golden-winged warblers in a disturbed floodplain in western North Carolina. Southeast Migratory Bird Workshop and Conference. Biloxi, MI. January 1999.

Moorhead, K. K., I. M. Rossell, J.W. Petranka, and C. R. Rossell. Tulula Wetlands Mitigation Bank, North Carolina. Abstracts, p.A-93. Annual meeting of the Society of Wetland Scientists. Norfolk, VA June 1999.

Rossell, I. M. Mountain wetland ecology. North Carolina Statewide Wetland and Stream Management Committee Meeting. NC Arboretum, Asheville, NC. 1999.

Petranka, J. W. Direct and indirect effects of predators in structuring amphibian communities in a southern Appalachian wetlands complex. Invited Seminar. Appalachian State University. 2000.

Moorhead, K. K. Effects of drought on the water table of a mountain floodplain/fen complex. Abstracts, p.47. Annual meeting of the Society of Wetland Scientists. Chicago, IL. June 2001

b. Publications

Published or in press

Rossell, I.R. 1997. Noteworthy collections from North Carolina: *Lilium canadense* ssp. editorum. Castanea 61:196-197.

Moorhead, K.K. and I.M. Rossell. 1997. Southern mountain fens. Pages 379-403 in: Southern forested wetlands: ecology and management. Lewis Publishers, NY. 616 pp.

Petranka, J.W., A.W. Rushlow and M.E. Hopey. 1998. Predation by tadpoles of *Rana sylvatica* on embryos of *Ambystoma maculatum*: Implications of ecological role reversals by *Rana* (predator) and *Ambystoma* (prey). Herpetologica 54:1-13.

Petranka, J. W. and L. J. Hayes. 1998. Chemically mediated avoidance of a predatory odonate (*Anax junius*) by American toad (*Bufo americanus*) and wood frog (*Rana sylvatica*) tadpoles. Behavioural Ecology and Sociobiology 42:2262-2271.

Rossell, C.R., Jr., I.M. Rossell, J.W. Petranka, and K.K. Moorhead. 1999. Characteristics of a partially disturbed southern Appalachian forest-gap bog complex. The Virginia Museum of Natural History, Special Publication No. 3.

Rossell, C. R., Jr. and I. M. Rossell. 1999. Microhabitat selection by small mammals in a southern Appalachian fen in the USA. Wetlands Ecology and Management 7:219-224.

Rossell, I. M. And C. L. Wells. 1999. The seed banks of a southern Appalachian fen and an adjacent degraded wetland. Wetlands 19:365-371.

Petranka, J. W. And C. A. Kennedy. 1999. Pond tadpoles with generalized morphology: is it time to reconsider their functional roles in aquatic communities? Oecologia 120:621-631.

Starnes, S. M., C. A. Kennedy, and J. W. Petranka. 2000. Sensitivity of embryos of southern Appalachian amphibians to ambient solar UV-B radiation. Conservation Biology 14:277-282.

Moorhead, K. K., R. E. Moynihan, and S. L. Simpson. 2000. Soil characteristics of four southern Appalachian fens in North Carolina. Wetlands 20:560-564.

Moorhead, K. K. 2001. Water table dynamics of a southern Appalachian floodplain and associated fen. Journal of the American Water Resources Association 37:105-114.

Moorhead, K. K., I. M. Rossell, J. W. Petranka, and C. R. Rossell, Jr. 2001. Tulula Wetlands Mitigation Bank. Ecological Restoration 19:75-81.

Rossell, C. R., Jr. 2001. Song perch characteristics of Golden-winged Warblers in a mountain wetland. Wilson Bulletin. In Press.

Undergraduate Research Publications

Wells, C. L., I. M. Rossell, and J. Perry. 1995. A comparison of the seed banks of adjacent disturbed and undisturbed North Carolina wetlands. Proceedings of the National Conference on Undergraduate Research IX:872-876.

Riddle, W. K. and I. M. Rossell. 1996. A microhabitat analysis of *Sarracencia purpurea* in western North Carolina bogs. Proceedings of the National Conference on Undergraduate Research X:1731-1735.

Cacka, J. E. and J. W. Petranka. 1997. Effects of wood frog (*Rana sylvatica*) predation on spotted salamaner (*Ambystoma maculatum*): Oviposition site selection. Proceedings of the National Conference on Undergraduate Research XI:1392-1396.

Rushlow, A. and J. W. Pretranka. 1997. Consequences of opportunistic predation by a primary consumer (Rana) on a predator (Ambystoma). Proceedings of the National Conference on Undergraduate Research XI:1397-1401.

Rash, W. J., D. I. Cahan, K. K. Moorhead, and K. E. Krumpe. 1997. The effect of carbon content on the redox potential and fermentation products of wetland soils. Proceedings of the National Conference of Undergraduate Research XI:1835-1839.

Vitale, A., K. K. Moorhead, and G. A. Kormanik. 1998. A model of contiguity of disturbed and natural habitats at Tulula Bog, NC. Proceedings of the National Conference of Undergraduate Research XII:1316-1320.

Colburn, K., and I. M. Rossell. 1998. The use of a bottomland riparian ecosystem by *Terrapene carolina carolina*. Proceedings of the National Conference of Undergraduate Research XII:1795-1799.

Brooks, G., and I. M. Rossell. 1999. Proximity to and use of water bodies by the eastern box turtle. Proceedings of the National Conference of Undergraduate Research XIII.

Grant proposals funded

Riddle, W.K. The introduction of carnivorous plants to Tulula Bog. Funded for $2000 by the UNCA Undergraduate Research Program. Summer 1995.

McCann, M. Eastern box turtles at Tulula Bog: a seasonal study of microhabitat. Funded for $1000 by the UNCA Undergraduate Research Program. Summer 1998.

c. Undergraduate senior research projects

Hoyle, D.L. A study of seed germination in the rare red Canada lily. (UNCA Biology Department, 1994-1995).

Wells, C.L. A comparison of the seed banks of adjacent disturbed and undisturbed North Carolina wetlands. (UNCA Biology Department, 1994-1995).

Roberts, K. Ecological interactions between wood frogs and spotted salamanders in a western North Carolina bog complex. (UNCA Biology Department, 1995)

Riddle, W.K. Carnivorous plants at Tulula Bog. (UNCA Environmental Studies Program, 1995-1996).

Humphries, W. An insect survey of Tulula Bog. (UNCA Environmental Studies Program, 1996).

Kilpatrick, A. Natural regeneration of red maple (*Acer rubrum*) in a disturbed forest-gap bog complex. (UNCA Environmental Studies Program, 1996-1997).

Rash, W. The effects of soil organic matter content and redox potential on fermentation products from flooded hydric soils. (UNCA Environmental Studies Program, 1996-1997).

Colburn, K. The use of a bottomland ecosystem by the eastern box turtle, Terrapene carolina carolina. (UNCA Environmental Studies Program, 1997-1998).

Hayes. L. A study of chemically mediated avoidance of odonates by American toad and wood frog tadpoles. (UNCA Biology Department, 1997-1998).

Koenings, C. Ecological implications of predation of green frog tadpoles on wood frog eggs. (UNCA Biology Department, 1997-1998).

Vitale, A. A model of contiguity of disturbed and natural habitats of Tulula Bog. (UNCA Biology Department, 1998).

Brooks, G. Microhabitat preferences of the eastern box turtle: proximity to and use of water bodies. (UNCA Environmental Studies Program, 1998).

McCann, M. Eastern box turtles at Tulula Bog: a seasonal study of microhabitat. (UNCA Environmental Studies Program, 1998-1999).

deBettencourt, D. Species diversity of soil dwelling insects in Tulula Fen. (Departments of Biology and Environmental Studies, 1999)

Smith. M. Habitat use by golden-winged warblers in a disturbed western North Carolina floodplain. (UNCA Environmental Studies Department, 1999-2000).

Montgomery, T. A home range analysis of the eastern box turtle. (UNCA Environmental Studies Department, 1999-2000).

Guerry, C. And L. Lawson. Prevalence and distribution of *Aeromonas* and other gram-negative bacteria at the Tulula Wetlands. (UNCA Biology Department, 2000).

Anderson, A. Effects of predator chemicals on hatching time and morphology of amphibian larvae. (UNCA Biology Department, 2000).

Alvarado, H. Correlations between hydrology, soils, and vegetation in a disturbed southeastern Appalachian floodplain. (UNCA Environmental Studies Department, 2000).

Kesgen, J. Habitat partitioning by red and black chokeberry in a mountain fen. (UNCA Environmental Studies Department, 2000)

d. Undergraduate students who have participated in research at Tulula.

Joe-Ann Lawrence
Carolyn Wells
Diane Ducharme
Rachel Reese
Christy Roberts
Jay Ham
Ford Mauney
Andy Kilpatrick
Daphne Thomas
Richard Burgner
Marie McCann
Amy Burnett
Caroline Koenings
Abigail Vitale
Susan Starnes
Josiah Sheehan
Huma Alvarado
Todd Montgomery
Rayson Smith
William Kris Riddle
Paul Myers
Mark Hopey
Rachel Moynihan
Kevin Caldwell
Kevin Hining
Wesley Humphries
Katie Underwood
Andrea Rushlow
Suzanne Konopka
Gretchen Brooks
Kevin Colburn
Laura Hayes
Kelly Booth
Cindy Byron
Mamie Smith
Robert Warren
Daniel deBettencourt
Andrea Oswald

Shane Hill
Susan Murray
Athena Anderson
Elizabeth Harp
Jenna Kesgen
Troy Shriver
Scot Waring
Katie Harmuth
David Losure
Kat Duhnam
Stacey Hatcher

e. Graduate Student Research Projects

Quinn, D. Geomorphology and Stability of the Realigned Channel at Tulula Wetlands Mitigation Bank. M.S. degree. Department of Forestry. North Carolina State University

Warren, R. The Impact of Woody Canopy Disturbance on Vegetation Diversity in a Southern Appalachian Wetland. Department of Biology. Western Carolina University.