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Final Report

Ecological Assessment of a Wetlands Mitigation Bank (Phase II: Continued Restoration Efforts)

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16. Abstract
The overall objective for the Tulula Wetlands Mitigation Bank has been to restore the functional and structural characteristics of the wetlands. Specific restoration objectives of this Phase II study included: 1) determining the success of stream realignment by evaluating the geomorphology of the new channel before and after water release, 2) evaluating changes in ecosystem structure and function associated with plant community succession in planted and unplanted portions of the floodplain in response to restored hydrology, and 3) evaluating wildlife use of the site in response to changing hydrologic conditions (amphibians) and plant community succession (birds). A meandering channel (1.2 miles in length) was constructed across the floodplain and a portion of the constructed channel was connected to the existing Tulula Creek in fall 2001. Six random channel segments were used for measurements of stream geomorphology and after four months of water flow few differences were noted for channel morphology, partially reflecting the lack of substantial precipitation events since completion of the constructed channel. The hydrology of Tulula has been influenced by a regional drought that began in the summer of 1998 and the lack of precipitation has made hydrology assessment difficult at Tulula. Substantial natural regeneration of woody plants is occurring in the fairways at Tulula. We inventoried regenerating stems in a portion of one fairway, and found that 42% were shrubs, and 58% were sapling trees. Species diversity was much higher for shrubs than for trees, as 93% of all regenerating tree stems were red maple. When NCDOT commenced restoration activities, spoil was removed from one fairway, and the original hydric soils and accompanying seed bank were exposed. In this area, coverage by one group of wetland plants (rushes) increased significantly between 2000 and 2001. Amphibians rapidly colonized constructed vernal ponds, and the number of species that utilize these as breeding sites averaged about 50% higher than that of reference ponds. The survivorship and output of wood frog and spotted salamander juveniles have declined since pond construction, in part due to the accumulation of predators in ponds, the outbreak of a virus pathogen, and premature pond drying associated with drought. Bird species richness in 2002 was the highest of the four years that surveys have been conducted, with 39 species recorded. Relative bird abundance increased 49% (215 to 321 birds) from 2000 to 2002. Four species, American Robin, Red-winged Blackbird, Northern Cardinal, and Song Sparrow, increased in relatively large numbers, accounting for 50% (53 birds) of the total increase in relative abundance in 2002.

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EXECUTIVE SUMMARY

Assessing the success of wetland restoration projects requires an evaluation of ecosystem structure and function. Long-term success is rarely documented, and failure is common for a variety of reasons. Our goal is to document the ecological success of the wetlands at the Tulula Wetlands Mitigation Bank (Graham County) in response to restored hydrology, soils, vegetation, amphibians and birds. Our data should provide NCDOT an ecological assessment that may be useful for evaluating other wetland restoration projects located throughout the state.

The following objectives provide the framework for a comprehensive ecological assessment of the restored wetlands of Tulula: 1) determine the success of stream realignment by evaluating the geomorphology of the new channel before and after water is introduced, 2) evaluate changes in ecosystem structure and function associated with plant community succession in planted and unplanted portions of the floodplain in response to a higher water table and overbank flooding, and 3) evaluate wildlife use of the site in response to changing hydrologic conditions (amphibians) and plant community succession (birds).

A primary focus of restoration at Tulula was to improve site hydrology. A meandering channel (1.2 miles in length) was constructed across the floodplain and four sections in the upper and middle portions of the site were joined together by crossing the dredged channel of Tulula Creek in fall 2001. Six random channel segments were used for measurements of stream geomorphology, including sinuosity, cross-sectional areas of riffles and pools, bank slope, stream grade, and overall channel configuration. After four months of water flow, few differences were noted for channel morphology, partially reflecting the lack of substantial precipitation events since completion of the constructed channel.

The hydrology of Tulula has been influenced by a regional drought that began in the summer of 1998. The lack of precipitation for the past four years has made hydrology assessment difficult as the stream channel was restored and drainage ditches plugged. Restoration of hydrology at Tulula, like many wetland sites, will be evaluated primarily by changes in water-table depth. The assumption is that after the channel is restored and drainage ditches are plugged, the overall water table of the site will rise. The lack of normal precipitation has hindered this evaluation.

Water-table depth has been evaluated over the past eight years with manual wells. In 2000, 29 electronic wells were installed on site, allowing a comparison of the well types. Five of the 29 electronic wells were installed within three feet of five existing manual wells. Before correcting for the subtle differences in elevation between wells, the average monthly difference was 3.3 in (ranging from 2.1 to 5.8 in). After correcting for elevation, the average monthly difference was 2.0 in (ranging from 1.1 to 2.8 in). The decision to install electronic wells or manual wells depends on several factors but if water-table depth is expressed as a monthly average for NCDOT, then manual wells may provide adequate information about location of water table for mitigation sites.

Natural succession is well underway in the fen, and in the fairways. Over the last 7 years, woody basal area increased significantly in the closed fen, while the number of herbaceous species declined. Seven uncommon species of herbaceous plants (all relatively small heliophytes), disappeared from forested sites over the seven year period. However, the number of woody plant species doubled in the open fen and floodplain between 1994 and 2001.

Substantial natural regeneration of woody plants is occurring in the fairways at Tulula. We inventoried regenerating stems in a portion of one fairway, and found that 42% were shrubs, and 58% were sapling trees. Species diversity was much higher for shrubs than for trees, as 93% of all regenerating tree stems were one species (red maple, *Acer rubrum*). Red maple is the dominant overstory tree across much of the site, and it also continues to regenerate in some forested areas.

When NCDOT commenced restoration activities, spoil was removed from one fairway, and the original hydric soils and accompanying seed bank were exposed. In this area, coverage by one group of wetland plants (rushes) increased significantly between 2000 and 2001. This confirmed the results of an earlier seed bank study in which we found a large number of rush seeds in soils at Tulula. In addition, by 2001, large numbers of a previously uncommon OBL species (arrowhead, *Sagittaria latifolia*) emerged in the restored area.

Ten ponds were constructed in 1995-1996 to replace natural breeding sites that were destroyed during golf course construction. Data collected from 1996-2002 indicate that the constructed vernal ponds are of higher quality than reference ponds based on physiochemical characteristics, seasonal hydroperiod, and use by resident amphibians. The reference ponds have undergone progressive deterioration between 1996-2002 with respect to seasonal hydroperiod. In 2002 the majority either did not fill or dried prematurely, resulting in catastrophic mortality of pond amphibian populations. In contrast, the hydroperiod of most constructed ponds appears to be ideal for most vernal pond breeders. Seven of the 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. The survivorship and output of juveniles of two focal species (wood frog; spotted salamander) have declined since pond construction, in part due to the accumulation of predators in ponds, the outbreak of a virus pathogen, and premature pond drying associated with drought. Nonetheless, the current size of each breeding population remains at or above that found prior to pond construction.

Bird species richness in 2002 was the highest of the four years that surveys have been conducted, with 39 species recorded. The Blue-headed Vireo, Brown-headed Cowbird, Eastern Phoebe, Red-winged Blackbird, and Wood Duck were new species recorded during 2002 breeding bird surveys. Relative bird abundance increased 49% (215 to 321 birds) from 2000 to 2002. Four species, American Robin, Red-winged Blackbird, Northern Cardinal, and Song Sparrow, increased in relatively large numbers, accounting for 50% (53 birds) of the total increase in relative abundance in 2002. Golden-winged Warbler and Yellow-breasted Chat continued to decline in abundance. A species of particular concern is the Golden-winged Warbler, which is currently under status assessment for federal listing. Since 1994, this species has declined 81% (31 to 6 birds) at Tulula. Herb and shrub cover decreased significantly in bird plots in 2002, while the amount of standing water on site appeared to increase. These habitat changes likely contributed to the trends in bird richness and abundance and to the continued decline of the Golden-winged Warbler and Yellow-breasted Chat.

I. INTRODUCTION

Surface transportation projects such as highway construction often impact wetland resources and cause unavoidable losses of small wetland areas. Increasingly, wetland losses are being mitigated by the creation of "banks" of restored or natural wetlands that are protected from future disturbance. Mitigation banks allow the consolidation of efforts to mitigate for small wetland losses, facilitate advanced planning, and enhance the monitoring and evaluation of mitigation projects (Short 1988). The Tulula Wetland Mitigation Bank was created to offset impacts of highway projects in western North Carolina, particularly in the Little Tennessee River basin (1,158,883 ac) located in Macon, Swain, Graham, Jackson, Clay, and Transylvania Counties. The site is ideal for a mitigation bank in the mountains of North Carolina because of its relatively large size (235 ac) and its need for large-scale restoration.

The Tulula Wetland Mitigation Bank (ATulula≅) (35°17'N, 83°41'W) is located in Graham County, NC in the floodplain of Tulula Creek, 7.7 miles west of Topton. The site is roughly 235 ac at an elevation ranging from 2500 to 2800 ft. It is characterized by a relatively large, level floodplain along Tulula Creek, and is bordered by forested uplands and infrequent seepage communities on adjacent slopes. The floodplain includes scattered, small depressions where *Sphagnum* spp. accumulate. These Aboggy≅ 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 Abog≅ is a misnomer for the depressional areas, as 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. A complete description of vegetative communities at Tulula is found in Moorhead et al. (2001a).

Tulula was part of the Nantahala National Forest and owned by the U.S. Forest Service until the mid-1980's, when it was traded to a group of developers for commercial development of a golf course. During construction of the 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 golf ponds was spread over portions of the floodplain. A large portion of the floodplain forest was removed during the construction of 18 fairways. Development plans included lots for 60 single-family homes on the adjacent sloping land, and much of the understory was removed in areas designated for housing. About 40% of the wetlands were disturbed by drainage and timber harvest during golf course construction. 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.

Tulula was purchased in 1994 by the North Carolina Department of Transportation (NCDOT) to develop a wetlands mitigation bank. We have collected information on baseline ecological conditions (soils, hydrology, flora, and fauna) and have evaluated restoration activities at the site since 1994 (see www.unca.edu/tulula for details and species lists).

Assessing the success of wetland restoration projects requires an evaluation of ecosystem structure and function. Long-term success is rarely documented, and failure is common for a variety of reasons. Our goal was to document the ecological success of the wetlands at Tulula in response to restored hydrology, soils, and vegetation. Our data should provide NCDOT an ecological assessment that may be useful for evaluating other wetland restoration projects located throughout the state.

The following objectives provide the framework for a comprehensive ecological assessment of the restored wetlands of Tulula: 1) determine the success of stream realignment by evaluating the geomorphology of the new channel before and after water is introduced,
2) following restoration of site hydrology, evaluate changes in ecosystem structure and function associated with plant community succession in the floodplain in response to a higher water table and overbank flooding, and 3) evaluate wildlife use of the site in response to changing hydrologic conditions (amphibians) and plant community succession (birds).

II. RESEARCH METHODS AND RESULTS

Ecological conditions at Tulula have been documented for over eight years by UNCA (see www.unca.edu/tulula, North Carolina Department of Transportation 1997, Rossell et al. 1999, Moorhead et al. 2001a, Moorhead et al. 2001b). Ecological success of wetlands restoration at Tulula has been evaluated by comparing the extensive pre-restoration database to the post-restoration data.

A. Stream Restoration and Hydrology

1. Stream Restoration

A primary focus of restoration at Tulula was to improve site hydrology. A meandering channel (1.9 km in length) was constructed across the floodplain during the winter of 1999/2000. The design of the new channel was partially based on the physical characteristics of a relic channel found primarily at the lower end of the site. The relic channel was used, when practical, as part of the new meandering channel. The grade of the constructed channel was modified in 2001. Common streambank erosion techniques, such as fiber matting, coir fiber rolls, root wads, and live stakes of willow (*Salix* spp.), silky dogwood (*Cornus amomum*), and other woody plants were installed to improve the short-term stability of the new channel. Four sections of the constructed channel, in the upper and middle portions of the site, were joined together by crossing the dredged channel of Tulula Creek in fall 2001. The fifth and final section was under construction and will be completed by fall 2002.

Concurrent with construction of the new channel, drainage ditches were blocked and filled. Re-creating the meandering channel should decrease water velocity, which, coupled with backfilling drainage ditches, should raise the level of the water table across the floodplain and allow for more frequent overbank flooding.

Methods

One primary objective for restoration efforts at Tulula was to determine the success of stream realignment by evaluating the geomorphology of the new channel before and after water introduction. Six random channel segments were chosen in the four stream-channel sections that were restored in 2001. The channel geomorphology was evaluated for the six segments to help a graduate student at the North Carolina State University fulfill his project obligations. A seventh segment was established in the fifth constructed channel section in June 2002 and an eighth segment was added in a relic reach of the fifth section in July 2002. Each segment included four to six riffle-pool sequences varying in length from 120 to 180 ft. Each segment began and ended at the top of a riffle and the origin and end were permanently staked with PVC pipe and rebar. These two points served as reference to partially describe the channel geomorphology. A 300-ft measuring tape was secured between the origin pin and the end pin. Beginning at 0 ft (the origin pin), the orthogonal distance from the tape to the left bank, thalweg, and right bank was measured every 6 ft on the 300-ft tape. The data were used to develop overall channel configuration and to determine sinuosity of channel segments.

In each of the six segments, two riffles and two pools (defined as the middle of a meander) were chosen to establish permanent cross-sections. Bankfull width was determined and channel cross-sections were determined by taking depth measurements every 8 in along a tape that was stretched from the two bank pins of a riffle or pool at the top of each bank. Bank inclination was determined with a clinometer. Erosion bank pins were placed in the channel at the riffle and pool cross-sections. The erosion pins were hammered 18 in into the bank walls with 6 in exposed in the channel.

The channel segment profile was surveyed using standard surveying equipment. A 300-ft tape was placed in the channel along the thalweg, with a start point in the channel by the origin pin. The features of each segment (each pool and riffle) were surveyed at the top of the left and right banks and for the thalweg. The water depth was also noted for the thalweg. The top, middle, and bottom of each riffle were surveyed as well as the middle of a meander. The distance of these features were noted from the 300-ft tape lying in the thalweg of the channel. The permanent riffle or pool cross-section pins were also surveyed. Benchmarks for each segment were chosen by using established NCDOT surveying points or by placing a nail in a nearby tree (benchmarks were established throughout the Tulula floodplain by NCDOT during channel construction).

The channel plan, riffle and pool cross-sections, and channel profile were re-evaluated after four months of water flow. The goal will be to evaluate the geomorphology of the channel every 12 months after the date of water release.

Results and Discussion

Our goal was to have eight channel segments in the five constructed stream channel sections to evaluate stream geomorphology over time. Due to delays in construction at Tulula, only four restored channel sections were connected in 2001 (Fig. 1). Water release began in September and continued into November 2001. We placed two segments for channel evaluation in Section 1, one each in Section 2 and Section 3, and two in Section 4. The cross-sectional area and bankfull widths of riffle and pools of six channel segments are listed in Table 1.

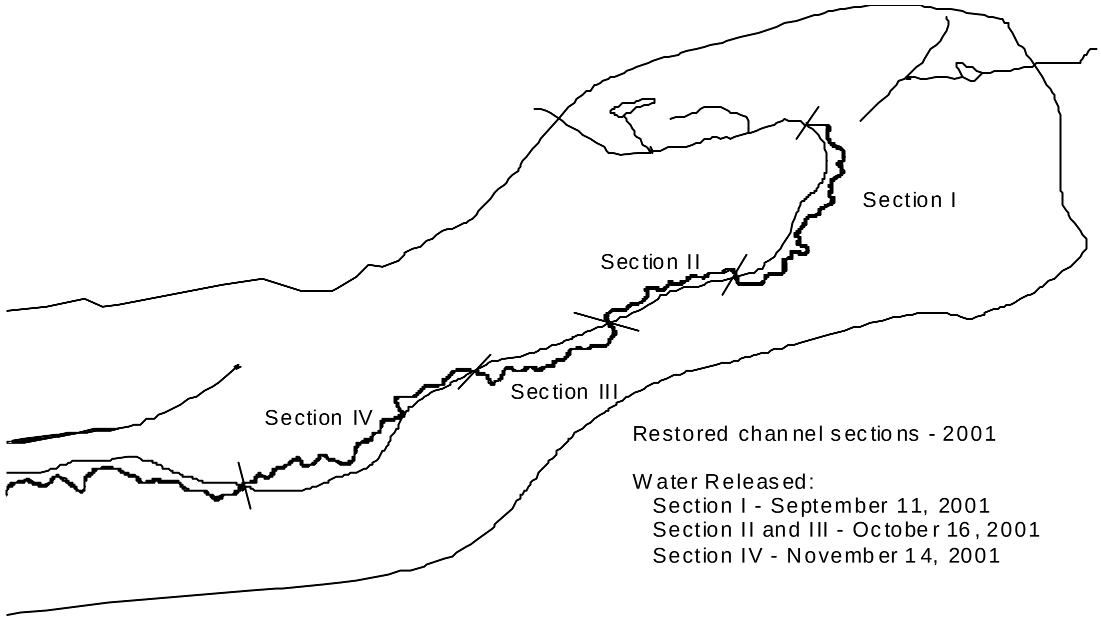

Fig. 1. Restored channels sections of Tulula Creek in 2001.

As anticipated, riffles typically had lower cross-sectional areas and shorter bankfull widths compared to pools. Bankfull widths did not change after four months of water flow but subtle changes in cross-sectional areas were noted for both riffles and pools. With one exception, the cross-sectional areas of riffles increased after four months of water flow. Pools increased and decreased in cross-sectional area with no consistent pattern. The cross sectional areas for pools will probably fluctuate as scouring occurs during high flow events and deposition occurs during base flow.

The cross-sectional areas of riffles and pools of the relic channel of Tulula Creek were typically smaller than the restored stream segments (Table 2). A more noticeable but related difference was the shorter bankfull width of the relic channel. The dredged channel of Tulula Creek had comparable bankfull widths to the relic channel but much higher cross-sectional areas. Tulula Creek was dredged for the golf course and in many places the maximum depth of the channel bottom was five to six feet below the floodplain surface. The maximum depth of the restored channel is two to three feet below the floodplain surface.

Table 1. Cross-sectional area (ft^2) and bankfull width (ft) of riffles and pools after four months of water flow.

	Before Water Release		After Water Release	
	Cross-Sectional Area	Bank Full Width	Cross-Sectional Area	Bank Full Width
Section I				
Riffle 1	20.10	13.58	20.31	13.55
Pool 1	33.27	15.42	32.65	15.39
Riffle 2	14.59	11.81	14.46	11.79
Pool 2	26.71	15.42	28.45	15.36
Section IA				
Riffle 1	13.84	10.50	14.42	10.40
Pool 1	19.07	10.27	18.96	10.30
Riffle 2	19.50	12.96	19.86	12.89
Pool 2	18.94	12.57	17.97	12.50
Section II				
Riffle 1	19.67	16.34	21.89	16.24
Pool 1	36.18	16.01	27.01	15.95
Riffle 2	13.69	12.80	15.26	12.70
Pool 2	20.29	14.31	23.56	14.21
Section III				
Riffle 1	18.55	13.29	19.52	13.32
Pool 1	31.27	18.87	34.22	18.80
Riffle 2	23.89	16.90	25.44	16.86
Pool 2	26.88	17.88	22.53	17.91
Section IV				
Riffle 1	16.14	12.53	16.91	12.53
Pool 1	21.35	14.08	22.73	13.91
Riffle 2	18.91	12.73	19.88	12.70
Pool 2	26.38	14.57	27.65	14.60
Section IVa				
Riffle 1	14.62	12.40	12.46	12.37
Pool 1	22.29	13.58	20.75	13.62
Riffle 2	19.22	15.13	20.04	15.09
Pool 1	19.71	13.52	20.49	13.45

Table 2. Cross-sectional area (ft^2) and bankfull width (ft) of the relic stream channel and existing Tulula Creek (dredged creek).

	Cross-Sectional Area	Bank Full Width
Relic I		
Riffle 1	14.63	10.27
Pool 1	18.01	11.06
Riffle 2	14.35	8.66
Pool 2	18.92	10.50
Relic II		
Riffle 1	16.52	10.53
Pool 1	15.88	11.06
Riffle 2	15.19	9.88
Pool 2	16.29	10.14
Tulula Creek (dredged)		
Ditch 1	20.10	9.84
Ditch 2	22.83	11.16

Bank inclinations of riffles and pools created for the restored channel were commonly between 20 and 30 degrees (Table 3). In comparison, bank inclinations of riffles and pools of the relic channel and of the dredged Tulula Creek were much higher. The banks of the restored channel should change over time in response to normal erosion processes associated with high water flow from significant rainfall events in the watershed of Tulula Creek.

Overall channel configuration did not change substantially during four months of water flow, possibly due to the lack of precipitation events that would contribute to water flow in the channel. The most notable changes occurred in the location of the thalweg and the water depth associated with the thalweg. Annual evaluation of channel geomorphology in subsequent years should provide a better understanding of channel dynamics as time and precipitation events contribute to the changes that will occur. We have noticed the formation of point bars on many inside banks of meanders and related erosion of outside banks. Overall the channel has been stable since water release. The below average rainfall at Tulula has probably facilitated bank stabilization in the new channel.

Table 3. Bank inclination (degrees) of the restored channel, the relic channel, and the dredged Tulula Creek.

	Restored Channel					
	Section I	Section Ia	Section II	Section III	Section IV	Section IVa
Riffle 1						
Left bank	30	38	22	23	26	21
Right bank	26	32	20	27	25	23
Pool 1						
Left bank	37	90	32	24	28	27
Right bank	33	25	31	30	26	66
Riffle 2						
Left bank	31	33	28	27	30	23
Right bank	26	28	24	54	31	24
Pool 2						
Left bank	21	59	29	25	36	37
Right bank	33	19	32	30	32	24

	Relic I	Relic II	Ditch I	Ditch II
Riffle 1				
Left bank	90	37	62	90
Right bank	23	90	75	90
Pool 1				
Left bank	90	37		
Right bank	90	28		
Riffle 1				
Left bank	43	29		
Right bank	90	90		
Pool 2				
Left bank	90	90		
Right bank	90	61		

2. Hydrology

Site hydrology has been monitored for over eight years with a series of shallow water table wells and piezometers. Most of the wells and all of the piezometers are located in a 4-ha floodplain/fen complex that serves as a reference area for several UNCA research projects. We have documented seasonal patterns of water table elevation and vertical hydraulic gradient in this area and determined the influence of hillslopes on fen hydrology (Moorhead 2001).

Methods

Established water table wells were used to determine if the floodplain water table was higher because of the new channel and blocked drainage ditches. Twenty-nine electronic (continuous reading) wells were installed in transects perpendicular to the new channel and 12 manual wells were installed in vegetation plots established in floodplain areas where spoil was moved to partially fill golf ponds. Half of the twelve manual wells were installed in low areas having a high-water table, whereas the other six were installed in areas of higher elevation (see Plant Community Succession section for results).

Five of the 29 electronic wells were installed within three feet of manual wells to compare water-table depth by using two types of wells. Electronic wells can be programmed to read the water table daily but they are very costly relative to manual wells. Long-term data for water-table wells are typically expressed as monthly averages and Tulula provided an opportunity to compare monthly averages in water-table depth using the two types of wells. The water table was recorded daily for the electronic wells and two to four times a month for the manual wells. The data were corrected for any subtle differences in elevation between adjacent wells by correcting the water-table depth to the elevation of the lower well.

Results and Discussion

The hydrology of Tulula has been influenced by a regional drought that began in the summer of 1998. Graham County was classified as having conditions of moderate to severe drought from July 1998 through most of 2001. In summer 2002 the area was classified as having abnormally dry conditions. The below normal precipitation for the past four years has made hydrology assessment difficult as the stream channel was restored and drainage ditches plugged. Restoration of hydrology at Tulula, like many wetland sites, will be evaluated primarily by changes in water-table depth. The assumption was that after the channel was restored and the drainage ditches were plugged, the overall water table of the site would rise. The lack of normal precipitation has hindered this evaluation.

The electronic wells were installed in July 2000. Water was released into the first section of the new channel in September 2001 and, therefore, the electronic wells were used as part of the evaluation of water-table depth before and after restoration. Several of the manual wells installed in 1994 provide a more thorough evaluation of pre-restoration water table conditions at Tulula. For the most part, the electronic wells were installed in transects that run perpendicular to the new channel. The daily water-table level recorded by the electronic wells is found in Appendix A. The well data are shown for transects located in restored sections of Tulula Creek (see Fig. 2) and for a few of the isolated wells. Overall, the water table in the Tulula floodplain was typically higher and had less variation in the months of December through May. The water table fluctuated more during summer and fall, decreasing between precipitation events during months of peak evapotranspiration. The short-term duration of data from the electronic wells, coupled with the regional drought, does not provide enough information to conclusively demonstrate that stream restoration has raised the water table of the Tulula floodplain.

Water-table depth will continue to be assessed for several years. Assuming that more normal rainfall conditions return, the effects of channel restoration and ditch plugging on site hydrology will be more thoroughly understood.

Data from some of the manual wells have been collected since 1994. Fig. 3 shows the location of 12 manual wells used to assess the monthly water table of Tulula Fen (six wells averaged each month) and nearby floodplain (six wells averaged each month). The locations of paired electronic and manual wells are also noted in Fig. 3. The average monthly water tables of Tulula Fen and the adjacent floodplain are shown in Fig. 4. The effects of the drought were clearly noted for the fen and floodplain as the water table was lower, regardless of season, during the drought period. The data from manual wells will provide a more complete assessment of the restored hydrology at Tulula given that higher than average annual precipitation was recorded for the period of June 1994 through 1997.

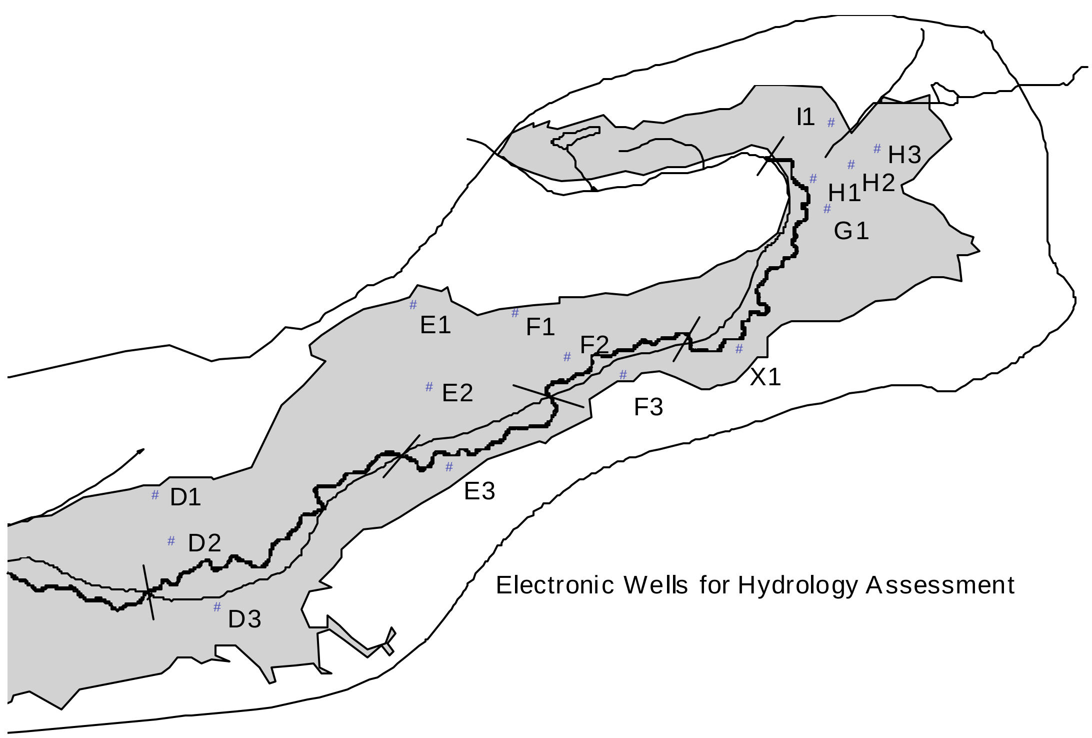

Fig 2. Transects and individual electronic wells used to assess site hydrology of the restored stream channel. See Appendix A for daily water-table levels of wells.

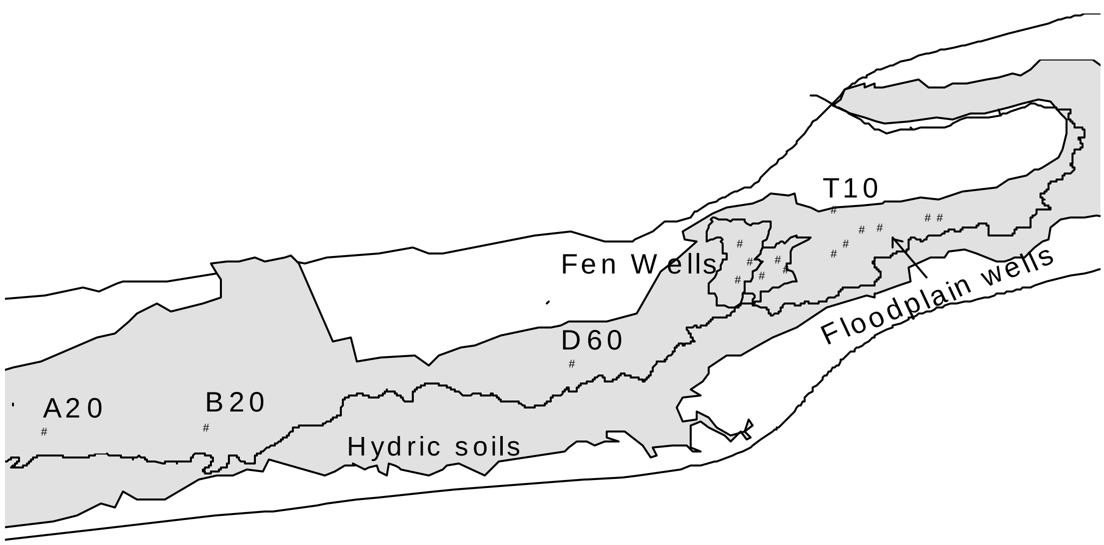

Fig. 3. Location of manual wells in Tulula Fen and adjacent floodplain. A20, B20, D60, and T10 are locations of paired manual and electronic wells. One additional pair is located in the fen.

The average monthly water-table level for the five pairs of electronic and manual wells is shown in Appendix B. Before correcting for the subtle differences in elevation between wells, the average monthly difference was 3.3 in (ranging from 2.1 to 5.8 in). After correcting for elevation, the average monthly difference was 2.0 in (ranging from 1.1 to 2.8 in). The decision to install electronic wells or manual wells depends on several factors but if water-table depth is expressed as a monthly average for NCDOT, then manual wells may provide adequate information about location of water table for mitigation sites. Other factors that may influence the choice of wells include the distance to the wetland site, the number of wells needed, the frequency of collecting data, and the overall length of the assessment period. Labor and travel costs increase for operating manual wells but 50 to 60 manual wells can be constructed and installed for the price of one electronic well.

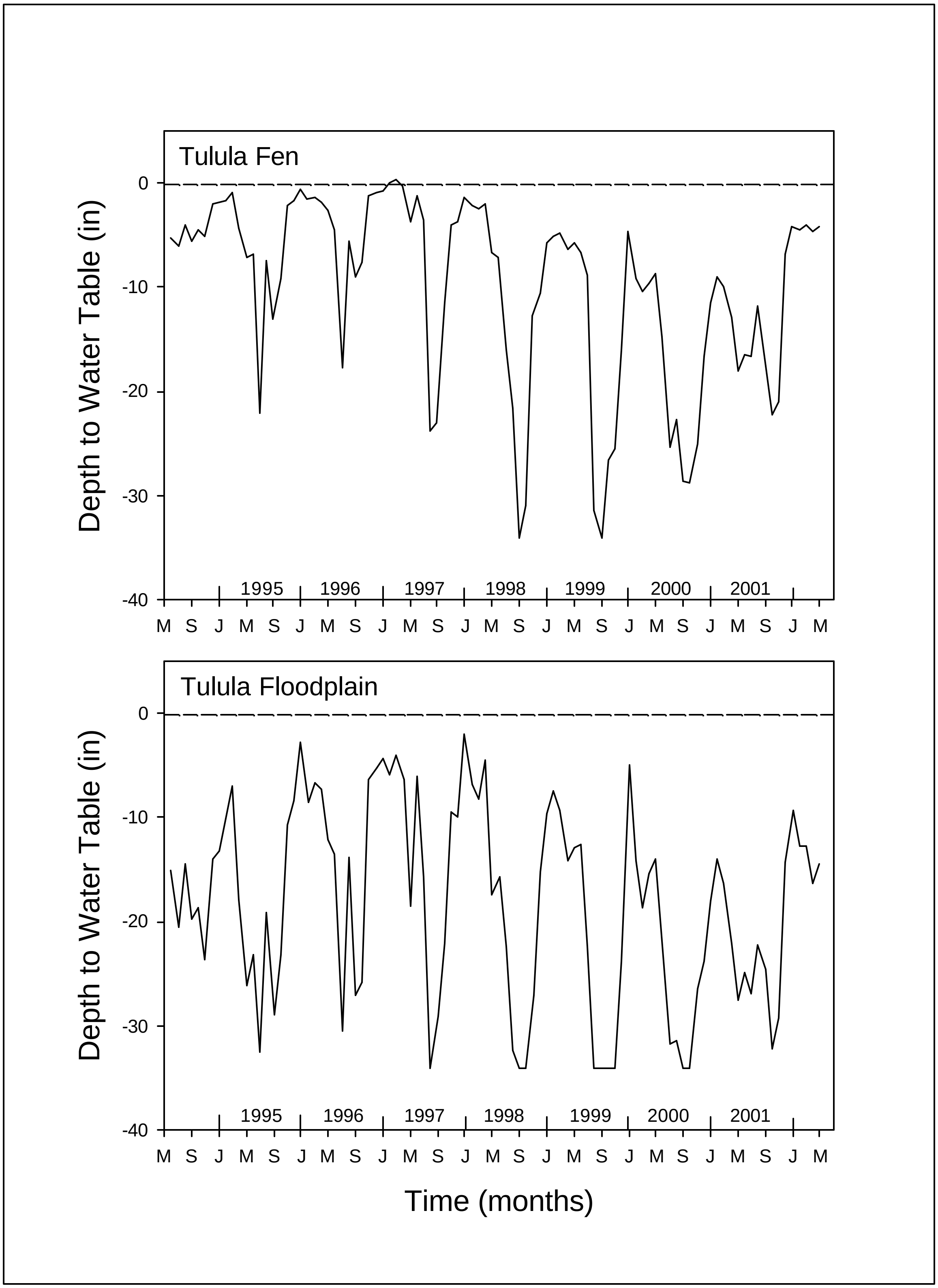

Fig. 4. The water table of Tulula Fen and adjacent floodplain. The regional drought began in July 1998 and has continued into 2002. Time is represented in four month intervals.

B. Plant Community Succession

Wetlands such as those occurring across the Tulula floodplain are small, but scarce features in the mountainous landscape of the southern Appalachians. These small “islands” in the landscape provide refuge to a wide variety of unique and uncommon wetland plants. Little ecological research has been done on these wetland systems, or on the plant communities that characterize them (Weakley and Schafale 1994). Ecological information on vegetation dynamics, or how plant communities change through time, is particularly relevant to wetland restoration projects. Knowing how communities progress naturally can help wetland managers evaluate the effects that disturbance or restoration might have on native plants.

In 1994, we initiated a study of the vegetation in two areas (open and closed canopy) of Tulula Fen, and in an adjacent disturbed floodplain. In this section, we report on changes in woody and herbaceous plants in these areas over a 7-year period. We also examined the dynamics of red maple, which is the dominant overstory tree across the floodplain, and we report here on its dominance, age and size distribution, and regeneration. Lastly, we examined the emergence and establishment of vegetation in a newly restored wetland area, over a 2-year period.

1. Vegetation dynamics in Tulula Fen and adjacent fairways

Methods

To examine changes in the overall vegetation composition of the fen and adjacent fairways, we re-inventoried a series of nested plots that were established in 1994. Three areas were sampled in June and July of 1994 and 2001: an open canopy fen (open fen), a closed canopy fen (closed fen), and the adjacent disturbed floodplain (open floodplain). A fourth site, a forested portion of the floodplain (closed floodplain), was sampled only in 2001.

In 1994, a grid of 120 yd^2 plots was established in the fen. Approximately half of the plots were located in the open canopy area, and half in the closed canopy area. Twenty plots were randomly selected in each area. The diameter at breast height (DBH) of all overstory trees (DBH > 4 in) was measured in 32.8 ft x 32.8 ft quadrats. The diameter of shrubs and saplings (DBH 0.8 – 4 in) was measured in 13.1 ft x 13.1 ft quadrats. Herbaceous plants and woody seedlings < 0.8 in DBH were inventoried in 3.3 ft x 3.3 ft quadrats. The percent cover of herbaceous plants was visually estimated, and woody seedlings were counted.

In the fairway adjoining the fen, 6, 65.6 ft x 98.4 ft plots were sampled in July of 1994 and 2001. The same protocol described above was used, except herbaceous vegetation was inventoried in four randomly located 3.3 ft x 3.3 ft quadrats in each plot. No shrub-layer or overstory vegetation occurred in these plots in 1994, but by 2001, there was sufficient woody vegetation present to warrant sampling using 23 ft x 23 ft (shrub-layer) and 59 ft x 59 ft (overstory) nested quadrats within each of the six plots (these yielded a total sampling area comparable to the fen). The closed floodplain was inventoried in July 2001 only. A grid of 40, 120 yd^2 plots was established in this area, and vegetation was sampled using the same protocol as for the fen.

All vegetation was identified using Radford et al. (1968) and Weakley (2000). Nomenclature follows Weakley (2000) except when taxonomically unclear, in which case Kartesz (1994) was used. Voucher specimens from 1994 are stored at the UNCA Herbarium and 2001 samples are stored at the Western Carolina University Herbarium.

The wetland indicator status of all plant species was determined using USFWS (1996) guidelines for Region 2 (the Southeast). In addition, USFWS (1988) and U.S. Department of Agriculture (2001) were consulted. Wetland indicator categories are: obligate (OBL; occur in wetlands with >99% frequency), facultative wetland (FACW; occur with 67-99% frequency), facultative (FAC; occur with 34-66% frequency), facultative upland (FACU; occur with 1-33% frequency) and upland (UPL; occur with <1% frequency).

Data were analyzed per the seven spatio-temporal data sets: 1994 open fen, 1994 open floodplain, 1994 closed floodplain, 2001 open fen, 2001 open floodplain, 2001 closed fen and 2001 closed floodplain. Statistical Analysis Systems (SAS Institute, Inc., 2001) were used for all analyses. One-way analyses of variance (ANOVA, $p \leq 0.05$) were used to test for significant differences between the seven data sets for the cover of ground-layer vegetation, the species richness of ground-layer vegetation, and the basal area of woody plants. Log (Y + 1) and $[\text{Log}(Y+1)]^2$ transformations were applied when necessary, and significant differences were tested using the Ryan-Einot-Gabriel-Welsch Multiple Range Test. Student t-tests ($p \leq 0.05$) were used to compare the coverage and frequency of uncommon wetland species in the open and closed data sets, 1994 and 2001 data sets, and fen and floodplain data sets. Importance values (I.V.) were calculated for woody species by adding relative density ([stem density for a species/total stem density for all species] x 100) and relative basal area ([basal area for a species/total basal area for all species] x 100) and dividing by two for a constant potential value of 100 for each stand.

Results and Discussion

A total of 102 taxa representing 50 families were documented in 1994 and 2001 (Appendices C and D). The plant types best represented were forbs (42 taxa), graminoids (21 taxa), and shrubs (18 taxa). Almost half (49) of the taxa were OBL and FACW wetland plants (Appendix C). More OBL and FACW species occurred in the wetter fen sites than in the drier floodplain sites (Appendix E).

Total woody basal area increased significantly in the closed fen between 1994 and 2001 (Table 4), but not in the open floodplain and fen. However, woody succession continues to occur in the open fen, as the woody basal area in the open fen did not differ statistically from that in the closed fen in 2001.

There was a significant negative correlation ($p < 0.002$, $r^2 = 0.94$) between woody basal area and percent ground cover across all of the data sets (Fig. 5). Clearly, the increase in woody basal area (and its associated canopy cover) created too much shade for the herbaceous plants in the ground layer.

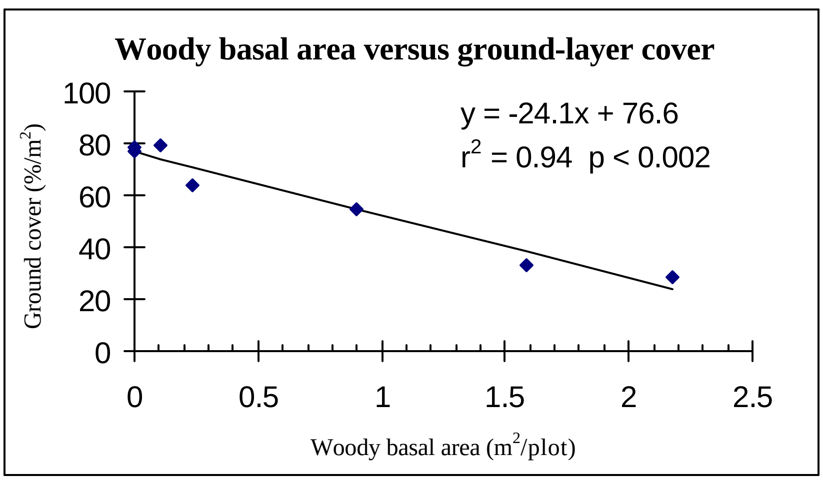

Fig. 5. Linear regression of mean woody basal area (shrub and tree layers) (m^2/plot) versus mean percent ground cover (per m^2 plot) across data sets.

Table 4. Means ± S.E. of woody basal area (shrub and tree layers) and percent cover of ground-layer vegetation. Letters in each column indicate the significance of post-hoc multiple comparisons (α = 0.05).

	Mean basal area (m^2/plot)			Cover (percent/plot)
Data set	Total	Tree	Shrub	Ground-layer
1994 open floodplain	0.0 ± 0.0a	0.0	0.0	77.0 ± 9.5a
2001 open floodplain	0.002 ± 0.001a	0.0	0.002	78.8 ± 8.1a
1994 open fen	0.1 ± 0.1a	0.0	0.1	79.5 ± 6.7a
2001 open fen	0.3 ± 0.2ab	0.1	0.2	64.1 ± 7.0ab
1994 closed fen	1.0 ± 0.4b	0.9	0.1	54.7 ± 9.8b
2001 closed fen	1.6 ± 0.6c	1.5	0.1	32.8 ± 4.7c
2001 closed floodplain	2.2 ± 0.5c	2.2	0.01	28.8 ± 5.0c

The percent cover of ground-layer vegetation decreased significantly in the closed fen between 1994 and 2001 (Table 4, Fig. 6). At the same time, the percent cover of woody species in the ground-layer more than doubled between 1994 and 2001 at all sites (Fig. 5).

The species richness of herbaceous plants remained relatively unchanged in the open fen and floodplain between 1994 and 2001, whereas the richness of woody species doubled at each site (Table 5). In the closed fen, woody species richness essentially remained the same between 1994 and 2001 but herbaceous species richness declined. It is clear that additional woody species are colonizing the open sites, while woody plant growth is increasing in the forested sites.

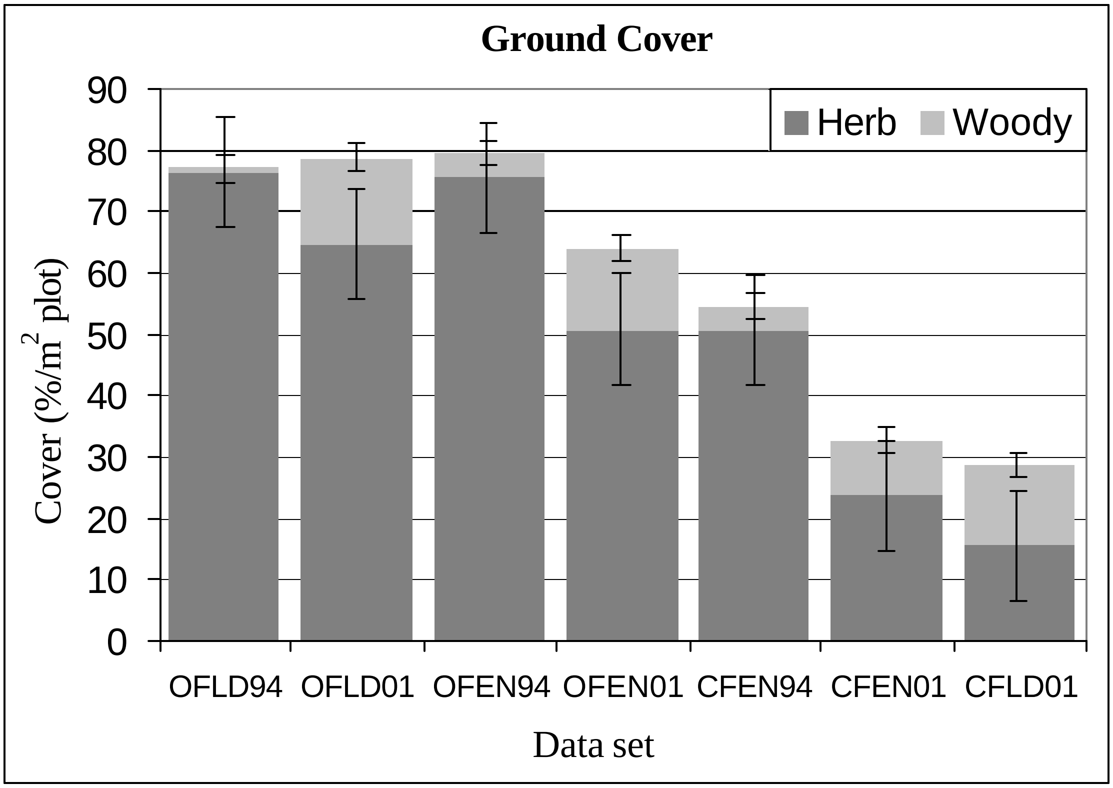

Figure 6. Ground cover per plot, with herbaceous and woody components in the Tulula wetland complex: open floodplain (OFLD), open fen (OFEN), closed fen (CFEN) and closed floodplain (CFLD).

Table 5. Means ± S.E. of ground-layer species richness per plot, and overall species richness of the ground-layer. Letters in each column indicate the significance of post-hoc multiple comparisons (α = 0.05).

	Species richness (per plot)	Overall species richness		
Data set	Ground-layer	Total	Herb	Woody
1994 open floodplain	10.0 ± 1.1a	40	35	5
2001 open floodplain	9.5 ± 0.7ab	46	36	10
1994 open fen	9.5 ± 0.8ab	32	24	8
2001 open fen	8.6 ± 1.0abc	9	23	16
1994 closed fen	7.5 ± 1.0bcd	9	21	18
2001 closed fen	6.5 ± 1.1cd	4	15	19
2001 closed floodplain	6.2 ± 0.7d	2	20	12

Seven uncommon herbaceous species occurred at Tulula (Table 6). Four of these species (small-leaved witchgrass, *Dichanthelium ensifolium* var. *ensifolium;* ten-angled pipewort, *Eriocaulon decangulare;* green arrow arum, *Peltandra virginica;* and clustered beaksedge, *Rhynchospora glomerata*) are uncommon in the southern Appalachian Mountain region. The other three (fescue sedge, *Carex festucacea;* short-leaved witchgrass, *Dichanthelium ensifolium* var. *curtifolium;* and rough bedstraw, *Galium asprellum)* are on the N.C. Natural Heritage Program Watch List (1999). All species are OBL except fescue sedge, which is FACW (see Appendix C).

Each of the open canopy areas contained 4 uncommon species in both 1994 and 2001 (Table 6). In forested areas, uncommon species were present only in 1994, when there were 2 species in the closed fen. All of the documented uncommon species are relatively small heliophytes that likely succumbed to light stress with increasing canopy closure.

Table 6. Percent cover per plot for seven uncommon plant species at Tulula: open floodplain (OFLD), open fen (OFEN), closed fen (CFEN) and closed floodplain (CFLD).

Species	OFLD 1994	OFLD 2001	OFEN 1994	OFEN 2001	CFEN 1994	CFEN 2001	CFLD 2001
Coverage							
C. festucacea[a]	0.72	0.06	0.11	0.06	0.05	0	0
D. ensifolium var. *ens*.[b]	0	2.50	0	0	0	0	0
D. ensifolium var. *curt*.[a]	0	0.31	0	4.30	0	0	0
E. decangulare[b]	0	0	0.48	0.10	0	0	0
G. asprellum[a]	0.01	0.04	1.40	1.40	0.29	0	0
P. virginica[b]	0.27	0	0	0	0	0	0
R. glomerata[b]	2.10	0	0.14	0	0	0	0
Total Coverage 3.1	2.9	2.1	5.8	0.4	0	0	
Number of species	4	4	4	4	2	0	0

[a]N.C. Watch List – N.C. Natural Heritage Program (1999).
[b]Rare in mountains – Weakley (2000).

Overall, the ground-layer of the open floodplain was dominated by forbs in both years, perhaps reflecting the relatively dry conditions, which led to succession by field herbs (Table 7). The open fen, which was the wettest area, was dominated by sedges in both years. The closed fen and the closed floodplain were dominated by ferns, which are often associated with forested wetlands (Weakley and Schafale 1994).

Table 7. Percent cover of ground-layer vegetation types for all data sets.

Data Set	Tree	Shrub	Forb	Sedge	Grass	Rush	Fern
1994 open floodplain	<1	>1	45	>1	23	6	<1
2001 open floodplain	5	6	55	4	3	2	2
1994 open fen	<1	4	16	33	13	4	9
2001 open fen	<1	7	14	21	5	<1	11
1994 closed fen	<1	4	17	12	<1	<1	22
2001 closed fen	<1	4	5	7	<1	0	12
2001 closed floodplain 2	4	3	<1	<1	0	11	

2. Red maple dynamics

Methods

Density, frequency, mean DBH and basal area were calculated for red maples in the 1994 and 2001 open and closed fen, and in the 2001 closed floodplain. T-tests ($p \leq 0.05$) were used to compare differences between 1994 and 2001. Linear regressions were performed for age-diameter relationships. In order to determine the best size distribution model for red maple growth, linear, exponential and quadratic regressions of stem frequency-size class relationships were tested for significance ($p \leq 0.05$).

Results and Discussion

Red maple was the dominant canopy tree in all forested sites (I.V. = 82 to 98), and a dominant component of the shrub-layer in the open and closed fen (I.V. = 82 to 96). The mean age of red maple trees in the closed fen was 34 yrs, compared with a mean age of 45 years in the closed floodplain.

In the open fen, which was last cleared in the late 1980s, the diameter distribution of red maple suggested that recruitment had not slowed between 1994 and 2001 (Fig. 7). In both years, there were many stems with a DBH < 1.6 in, suggesting a high level of seedling recruitment. The diameter distribution of red maple in the closed fen, which was last cleared approximately 30 years ago, suggested that recruitment was about half of that of the open fen.

Red maple recruitment had essentially ceased by 2001 in the closed floodplain, which may be about a decade older than the closed fen (based on tree age core data) and had about 27% more basal area. The dominance of canopy trees in the closed floodplain may have created too much shade for the germination of additional red maple seedlings.

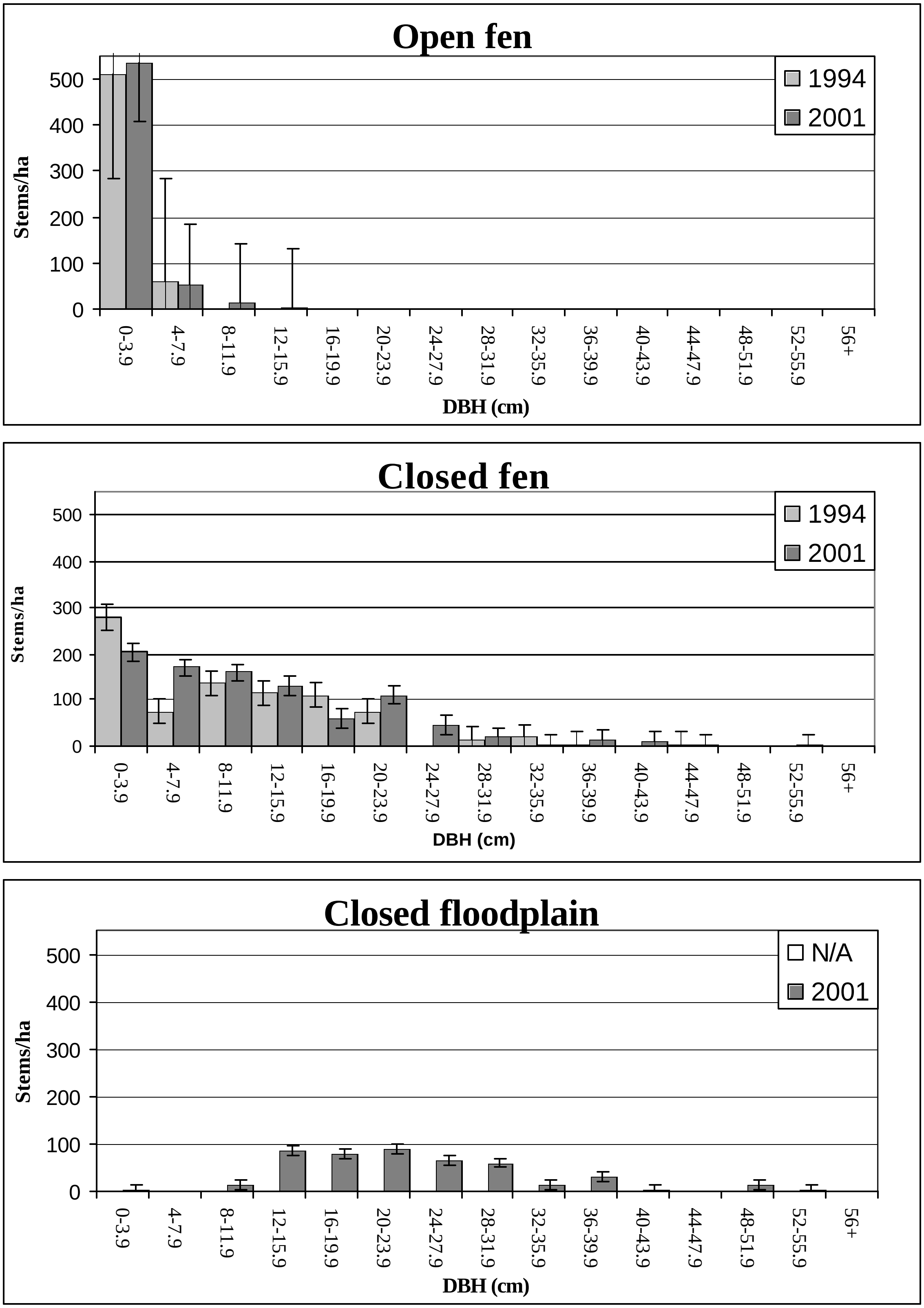

Fig. 7. Structural profiles of red maple saplings and trees across all sites.

Age-diameter regressions suggested that red maple grew faster in the closed floodplain than closed fen (Fig. 8). In addition, the closed fen had a strong contingent of small and intermediate trees, which were nearly absent from the closed floodplain. Fast growth of intermediate-sized trees could lead to a relative depletion of the smaller classes (Harcombe 1987), perhaps explaining the unimodal diameter distribution and age-diameter distribution of the closed floodplain. In addition, inundation stress may account for slower growth of red maple in the fen than in the floodplain.

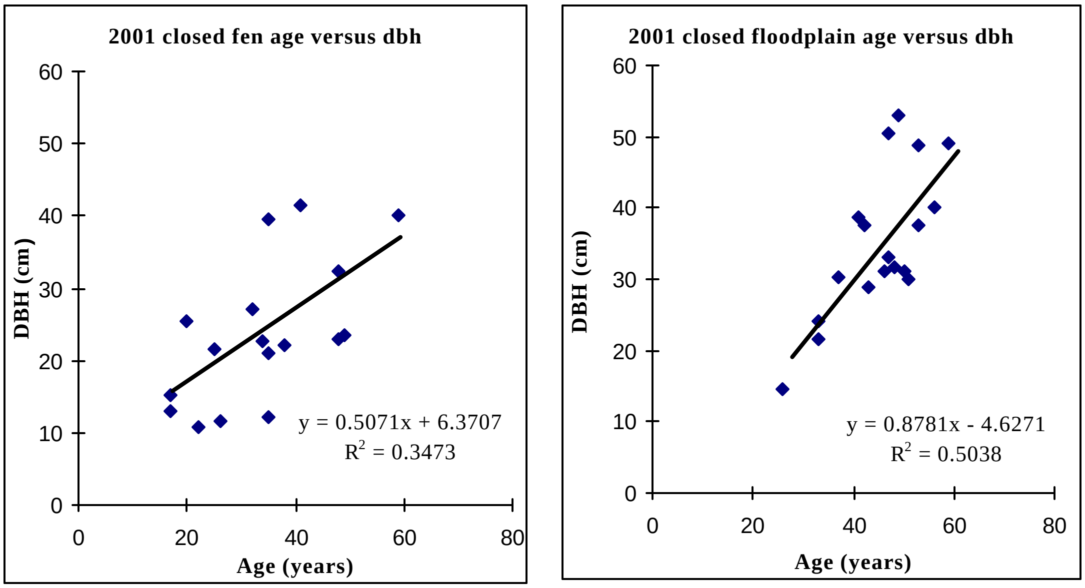

Fig. 8. Age-diameter regressions for red maple trees in the 2001 closed fen and floodplain. The steeper curve in the closed floodplain suggests a faster growing rate than in the closed fen.

3. Naturally-regenerating woody plants

Methods

To examine the success of naturally-regenerating woody plants at Tulula, we inventoried all woody plants (trees and shrubs) occurring in 4, 65.6 ft x 98.4 ft plots in the fairways surrounding the fen. The inventory was done during the fall and winter (2001-2002), when tall herbaceous vegetation had died back. All woody stems were identified to species, and placed into one of four height categories (<3.3 ft, 3.3 – 6.6 ft, 6.6 – 9.9 ft, >9.9 ft).

Results and Discussion

Our study showed that substantial natural regeneration of woody plants is occurring in the fairways at Tulula. We counted 7,077 stems in our four plots. Of this total, 42% were shrubs, and 58% were sapling trees. Species richness for shrubs and trees was approximately equal, but species diversity was higher for shrubs than for trees. Twelve species of shrubs were documented, with 6 species accounting for almost 95% of all shrub stems (Table 8). For trees, 14 species were documented, but red maple accounted for 93% of all tree stems. Although some woody plants exceeded 9.9 ft in height, the majority (68%) were < 3.3 ft in height (Table 9). Clearly, red maple is the dominant overstory species at Tulula, and it is aggressively reclaiming the disturbed fairways. It is also clear that reforestation with woody plants is not necessary in the fairways at Tulula.

Table 8. Naturally-regenerating woody plants occurring in disturbed fairways surrounding Tulula Fen, fall and winter 2001.

Shrubs

Species	Common name	Number	Percent of all shrubs
Aronia melanocarpa	Black chokeberry	843	28.1
Sorbus arbutifolia	Red chokeberry	572	19.0
Sambucus canadensis	Elderberry	478	15.9
Lyonia ligustrina	Maleberry	449	15.0
Cornus amomum	Silky dogwood	300	10.0
Alnus serrulata	Tag alder	194	6.5
Ilex verticillata	Winterberry	80	2.7
Kalmia angustifolia	Mountain laurel	33	1.1
Salix sericea	Silky willow	27	0.9
Leucothoe axillaris	Doghobble	16	0.5
Vaccinium sp.	Blueberry	11	0.4
Rhus sp.	Sumac	1	0.03
Total shrubs		3004	100.1

Trees

Species	Common name	Number	Percent of all trees
Acer rubrum	Red maple	3791	93.0
Pinus strobus	White pine	89	2.2
Nyssa sylvatica	Black gum	82	2.0
Oxydendrum arboreum	Sourwood	46	1.1
Malus angustifolia	Crabapple	34	0.8
Amelanchier sp.	Serviceberry	7	0.2
Liriodendron tulipifera	Tulip poplar	7	0.2
Prunus americana	Wild plum	5	0.1
Ilex opaca	American holly	4	0.1
Pinus rigida	Pitch pine	3	0.1
Prunus serotina	Black cherry	2	0.1
Diospyros virginiana	Persimmon	1	0.02
Pinus virginiana	Virginia pine	1	0.2
Quercus alba	White oak	1	0.2
Total trees		4073	100.3

Table 9. Heights of naturally-regenerating woody plants occurring in disturbed fairways surrounding Tulula Fen, fall and winter 2001.

Shrubs

Heights	Number	Percent of all shrubs
< 3.3 ft	1627	54.2
3.3 – 6.6 ft	1042	34.7
6.7 – 9.9 ft	278	9.3
> 9.9 ft	57	1.9
Total shrubs	3004	100.1

Trees

Heights	Number	Percent of all trees
< 3.3 ft	3169	77.8
3.3 – 6.6 ft	745	18.3
6.7 – 9.9 ft	125	3.1
> 9.9 ft	34	0.8
Total trees	4073	100.0

4. Vegetation dynamics and hydrology of a recently restored fairway.

Methods

We examined the emergence and establishment of vegetation in a golf fairway that NCDOT restored to its original wetland state during summer 2000. Restoration of this area included recontouring the floodplain to remove spoil that was deposited during golf course construction in the 1980's. As the floodplain was recontoured, the original hydric soils (and its seed bank) were exposed.

In August 2000, 6, 32.8 ft x 32.8 ft plots were established in this area. Three were placed in a low, wet area of the fairway, and three were placed in a drier area at a slightly higher elevation. Each plot was divided into two 16.4 ft x 32.8 ft subplots, and five random points were selected within each subplot (total of 60 random points). Vegetation occurring at each random point was inventoried during the last 2 weeks of August in 2000 and 2001 by centering a 0.3 yd^2 quadrat around the random point. The percent of the quadrat occupied by each species of plant was visually estimated.

Because the data were not normally distributed, variables were analyzed using nonparametric statistics. We classified all species as belonging to one of five plant types (forb, grass, sedge, rush, or woody plant), and summed the cover of each plant type in each plot. We then used Wilcoxon Rank Sum Tests (alpha=0.05) to determine whether the cover of any plant type differed between years in either of the two zones.

Twelve manual water-table wells were installed in the vegetation plots established in the recently restored floodplain (six in dry and six in wet plots). Water-table wells installed for plant community plots established for previous studies were also used. Soil chemical and physical properties were determined here and in other areas across the site (open and closed floodplain, open and closed fen) using standard methods of soil analysis (see Page et al. 1982). Soil samples were collected with a soil probe from 12 to 15 random points in each plot, collecting the top eight inches of soil at each point. The soil samples were consolidated, air dried, and sieved to remove debris and inorganic material > 0.078 in.

Results and discussion

Over the 2-year period, taxonomic richness decreased in both zones (declining from 31 to 24 in the dry zone, and from 27 to 20 in the wet zone) (Table 10). In the wet zone, coverage by rushes increased significantly (P = 0.02), from 14% in 2000 to 44% in 2001. This supports the results of a seed bank study that was conducted at Tulula in 1995, in which very large numbers of rush seedlings emerged from fen soils that were kept in a greenhouse (Rossell and Wells 1999). It also supports the work of McGraw (1987), who found that up to 95% of the seedlings emerging from bog soils were rushes. The other plant type that changed significantly in our study was grass, for which coverage in the dry zone decreased from 85% in 2000 to 58% in 2001 (P = 0.04). This decrease was due to the decline of redtop grass (*Agrostis stolonifera*), which was planted by NCDOT in 2000.

Arrowhead (*Sagittaria latifolia*), an OBL species that was not common at Tulula before restoration, flourished in the restored wet zone. Cattail (*Typha latifolia*) was also established in the wet zone in 2001. It remains to be seen whether cattail will become invasive at this site. Clearly, some wetland species have been able to establish in the restored wetland on their own, whether through the seed bank, or by seed dispersal into the area.

Table 10. Mean percent cover (per plot) of plants emerging from seed bank plots in wet and dry zones of a restored fairway, August 2000 and 2001.

	Dry Zone		Wet Zone	
	2000	2001	2000	2001
Forbs				
Ambrosia artemisiifolia	0.2	0.6	0.1	-
Apios americana	3.6	10.6	-	0.4
Bidens tripartita	0.03	-	0.3	-
Boehmeria cylindrica	0.03	-	-	-
Chamaecrista nictitans	0.1	0.5	-	-
Clematis virginiana	-	0.2	-	-
Conyza canadensis	0.3	0.3	-	-
Eupatorium fistulosum	0.4	1.4	-	-
Eupatorium perfoliatum	-	0.3	-	-
Galium asprellum	-	-	-	0.2
Hypericum mutilum	0.4	2.8	0.2	0.7
Impatiens capensis	-	0.03	-	-
Kummerowia striata	0.4	-	-	-
Lespedeza cuneata	-	0.5	-	-
Lindernia dubia	-	-	1.7	-
Ludwigia alternifolia	-	-	0.1	0.2
Ludwigia palustris	-	-	3.3	0.3
Oxalis stricta	0.03	-	-	-
Persicaria pensylvanica	-	0.7	-	-
Plantago rugelii	0.03	-	-	-
Polygonum cespitosum	0.1	-	-	-
Polygonum punctatum	0.8	-	0.2	-
Polygonum sagittatum	0.2	1.0	0.6	1.8
Polygonum scandens	0.3	-	0.2	-
Sagittaria latifolia	-	-	27.4	13.7
Solidago gigantea	-	6.3	-	-
Solidago rugosa	0.3	-	-	-
Solidago spp.	0.2	-	-	-
Sparganium americanum	-	-	2.0	1.7
Trifolium repens	11.6	0.5	1.9	-
Typha latifolia	-	-	-	0.3
Viola cucullata	-	0.2	-	-
Unknown forbs	1.4	0.2	0.5	0.2
Total cover by forbs	20.4	26.1	38.5	19.5
Grasses				
Agrostis perennans	0.4	-	-	-
Agrostis stolonifera	80.6	57.8	32.0	20.6
Calamagrostis cinnoides	0.2	-	-	-
Secale cereale	3.4	-	0.1	-
Total cover by grasses	84.6	57.8	32.1	20.6

Table 10 (con't)

Sedges				
Carex bullata	-	0.1	-	0.1
Carex lurida	-	1.7	-	4.2
Carex stricta	-	0.8	-	-
Carex spp.	0.7	-	1.2	-
Cyperus strigosus	-	-	0.03	0.7
Dulichium arundinaceum	-	-	0.5	0.2
Eleocharis obtusa	0.03	-	6.1	-
Schoenoplectus purshianus	-	-	0.3	-
Scirpus cyperinus	-	0.2	-	8.0
Scirpus polyphyllus	-	-	2.5	4.4
Total cover by sedges	0.7	2.8	10.6	17.6
Rushes				
Juncus debilis	-	-	-	8.5
Juncus effusus	-	9.2	-	35.5
Juncus spp.	0.8	-	7.8	-
Juncus subcaudatus	0.2	-	5.8	-
Juncus tenuis	0.03	-	0.3	-
Total cover by rushes	1.0	9.2	13.9	44.0
Woody plants				
Acer rubrum	0.03	-	0.03	-
Alnus serrulata	-	0.2	-	-
Rubus argutus	-	4.3	-	0.5
Rubus spp.	0.6	-	0.03	-
Salix spp.	-	-	0.1	-
Sambucus canadensis	0.2	-	-	-
Total cover by woody plants	0.8	4.5	0.2	0.5

Soil properties in the recently restored floodplain differed considerably from soils in the open and closed floodplain or fen areas (Table 11). In the restored area, regardless of a high or low water table, the percent of sand was lower, silt was higher, and pH and exchangeable cations were higher. The cation exchange capacity (CEC) of the recently restored floodplain was much lower. Disturbance in general has been shown to impact soil properties and an increase of exchangeable cations is similar to responses seen for fire (Wilbur and Christensen 1983, Binkley et al. 1992). Odum et al. (1984) found decreasing exchangeable cations in soils as plant community succession proceeds. The closed floodplain plots have the oldest plant community (40-50 year old maple forest) of the vegetation plots and also have the lowest exchangeable cations and pH.

Table 11. Soil physical and chemical properties of plant vegetation plots. Samples were collected in 2001. Means sharing the same letter in each column are not significantly different (*P* > 0.05).

Vegetation Plots	Sand	Silt	Clay	OC	pH	CEC	Ca	Ma
	-------------%---------------					------cmol(c)/kg-----		
open floodplain	67.5a	25.1b	7.3b	6.7c	4.64b	40.3a	0.76b	0.24b
open fen	62.6ab	26.2b	11.2ab	9.3a	4.26c	50.5a	0.78b	0.39ab
closed fen	69.5a	23.1b	7.4b	8.5ab	4.35bc	47.5a	0.46b	0.43ab
closed floodplain	58.7ab	31.1ab	10.3ab	7.2bc	4.13c	50.3a	0.30b	0.25b
2001 restored fairway – wet	55.5bc	34.2a	10.2ab	7.0a	4.88a	23.7b	1.59a	0.44a
2001 restored fairway – dry	48.7c	38.2a	13.0a	3.3b	4.88a	18.4b	1.73a	0.55a

The water table of Tulula Fen and the adjacent floodplain (open floodplain plant community plots) was described in the section on hydrology. The water table of plots located in the recently restored fairway is shown in Fig. 9. The plots of lower elevation (wet plots) had a much higher water table and stream restoration decreased the depth of the water table for both wet and dry plots.

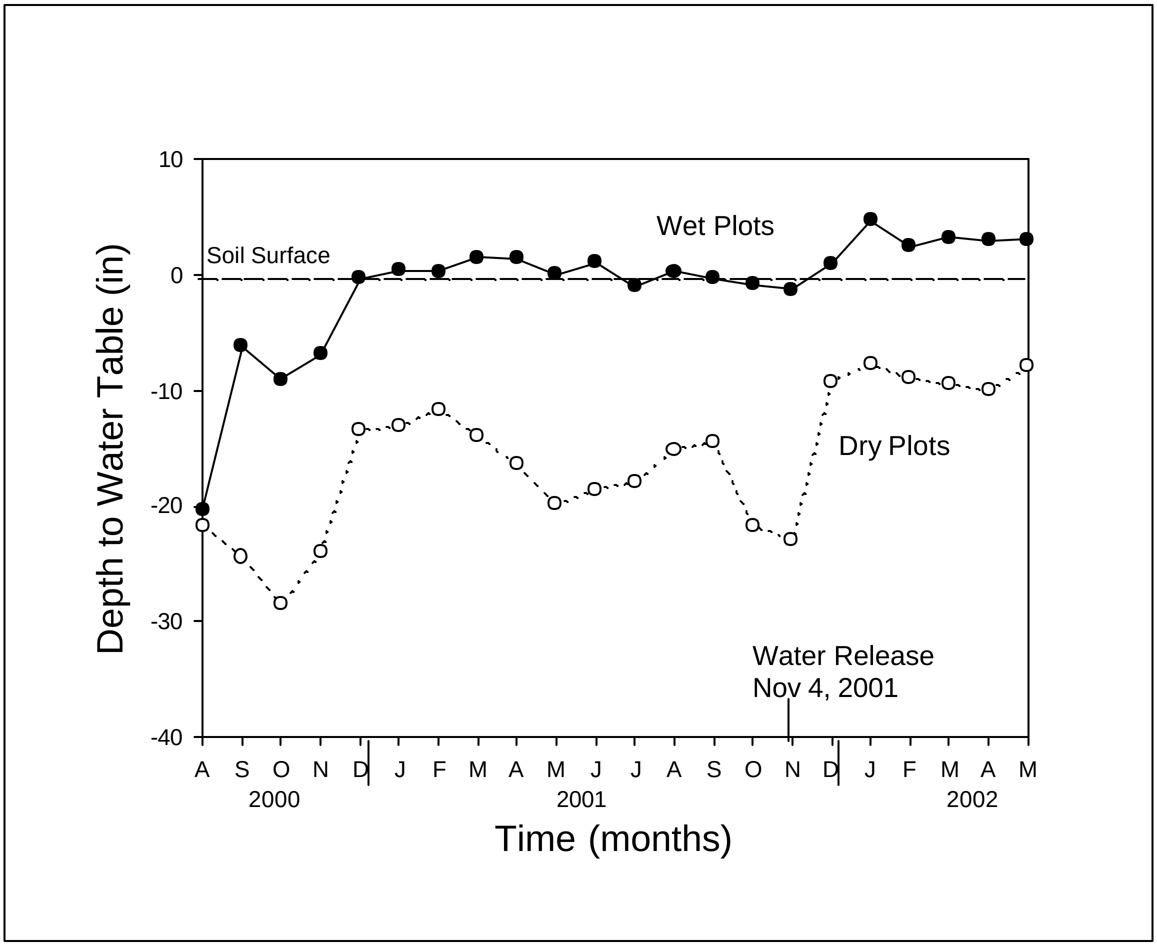

Fig. 9. Average monthly water table of vegetation plots in a recently restored fairway.

C. Amphibian Use of Tulula

Introduction

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 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.

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). 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 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 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. Permanent ponds 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.

Monitoring of temporary habitats during 1994-1995 indicated that most breeding sites 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. 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. 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. At seven sites small standing water habitats existed prior to the construction of ponds. We selected 10 of the largest existing breeding sites as reference ponds to compare hydrological, physiochemical, and biotic characteristics. Three reference ponds were destroyed in 2001 in conjunction with reconstruction of the stream channel.

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 in 2001. Additional pools were formed in conjunction with stream restoration in 2001 and 2002. In February 2002 the site contained 40 primary breeding sites (Fig. 10).

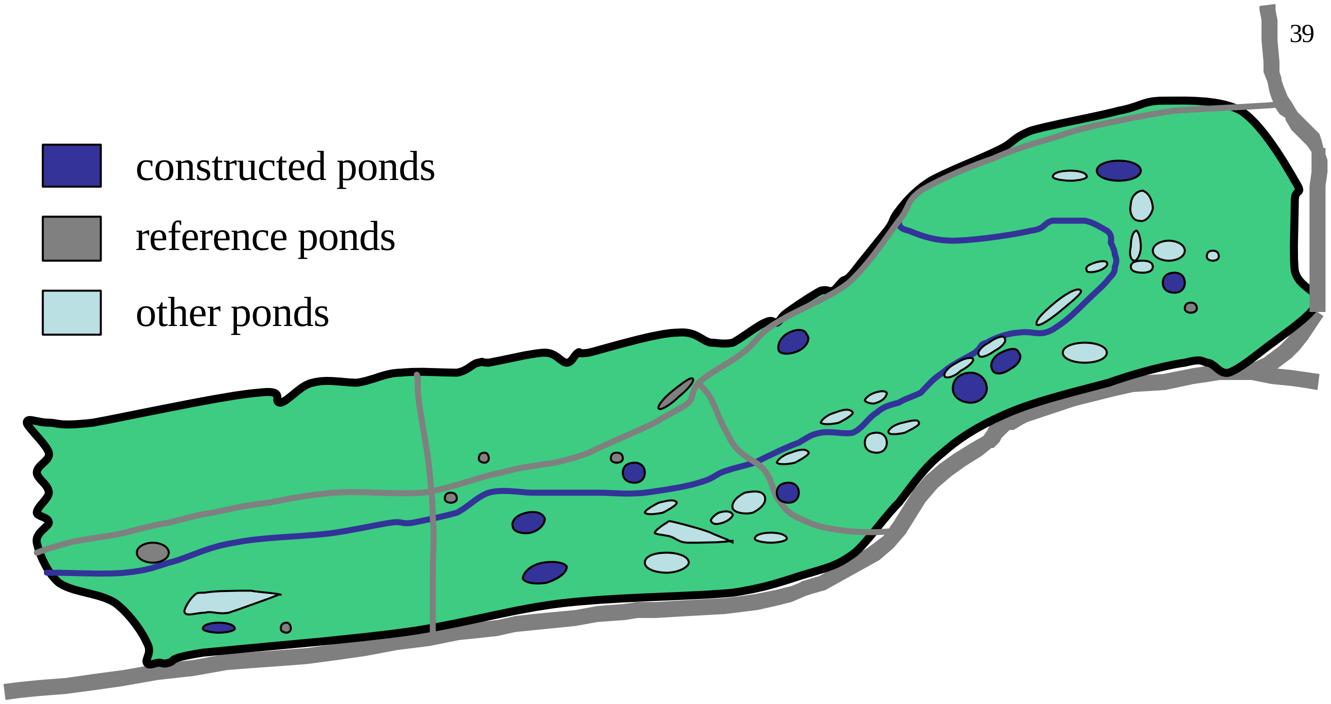

Fig. 10. Location of standing water habitats within the study site (winter 2002).

1. Physiochemical characteristics of ponds.

Methods

Physiochemical characteristics of the 10 constructed and 10 reference ponds were compared by sampling at 1-4 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. 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 on 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

Reference ponds were smaller and shallower than constructed ponds, which could influence physiochemical characteristics. At full capacity, surface areas of reference ponds averaged 888 ft^2 (range = 145-2367 ft^2) versus 5165 ft^2 (range = 2421-9931 ft^2) for constructed ponds. Respective values for maximum depths were 13.4 inches (range = 5.1-23.6 inches) and 24.4 inches (range = 15-34 inches). Comparisons of physiochemical characteristics of constructed and reference ponds from 1996-2001 are in Fig. 11. Comparable data for 2002 are still being collected and are not shown.

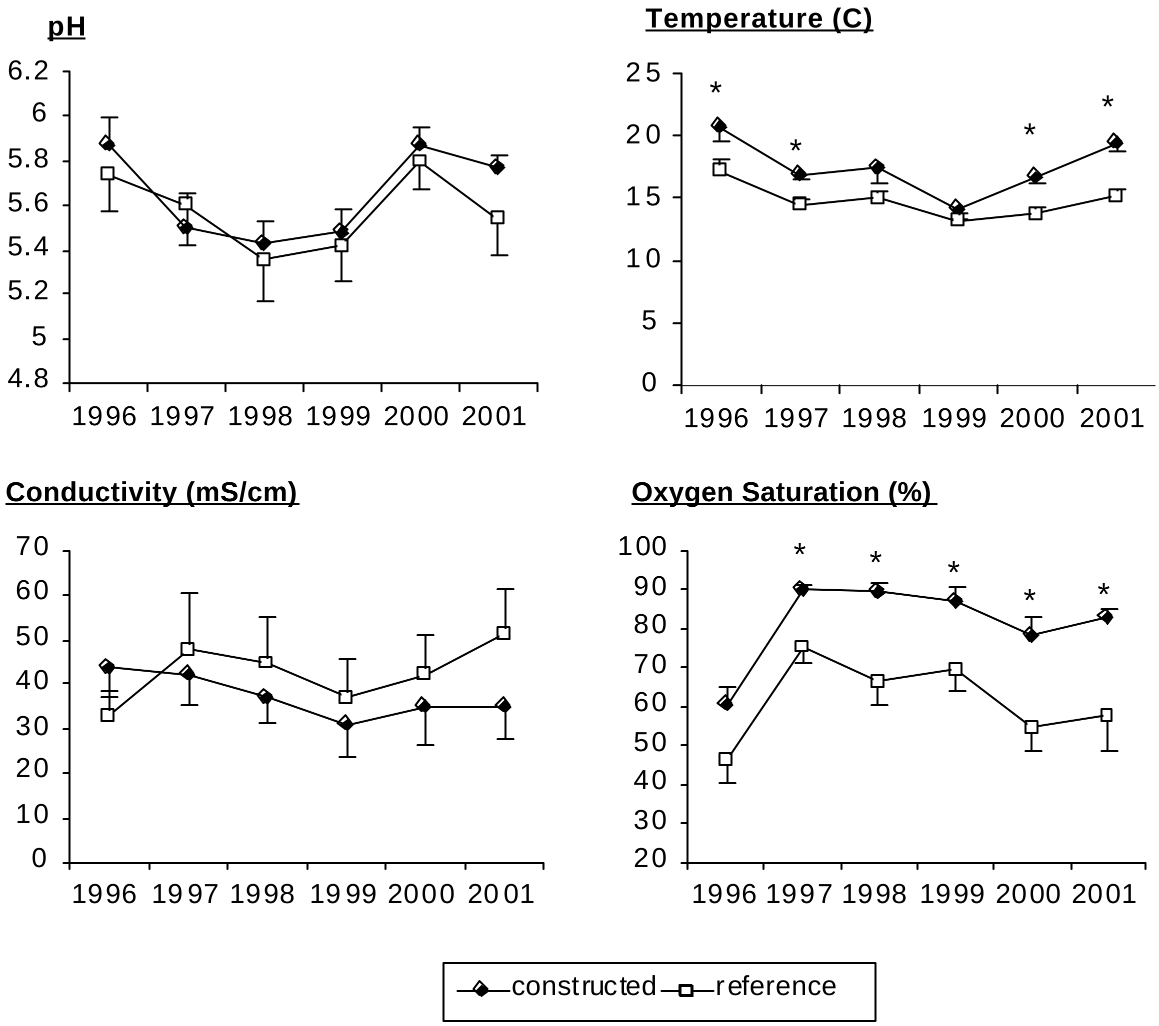

Fig. 11. Physiochemical characteristics of reference and constructed ponds. Symbols are annual means based on 3-19 seasonal samples per year. Vertical bars are 1 SE. Asterisks indicate means that differed significantly within years.

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) ? S/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.

Methods

All constructed ponds filled with water before amphibians began breeding in February 1996. We monitored all constructed and reference 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

Resident amphibians rapidly colonized constructed ponds that first filled in 1996 (Fig. 12). Eight species of amphibians bred in the constructed ponds within 1 year of construction and 10 species have used the ponds through 2002. 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 F). The only species unique to constructed ponds was the bullfrog, which prefers permanent or semipermanent habitats. 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).

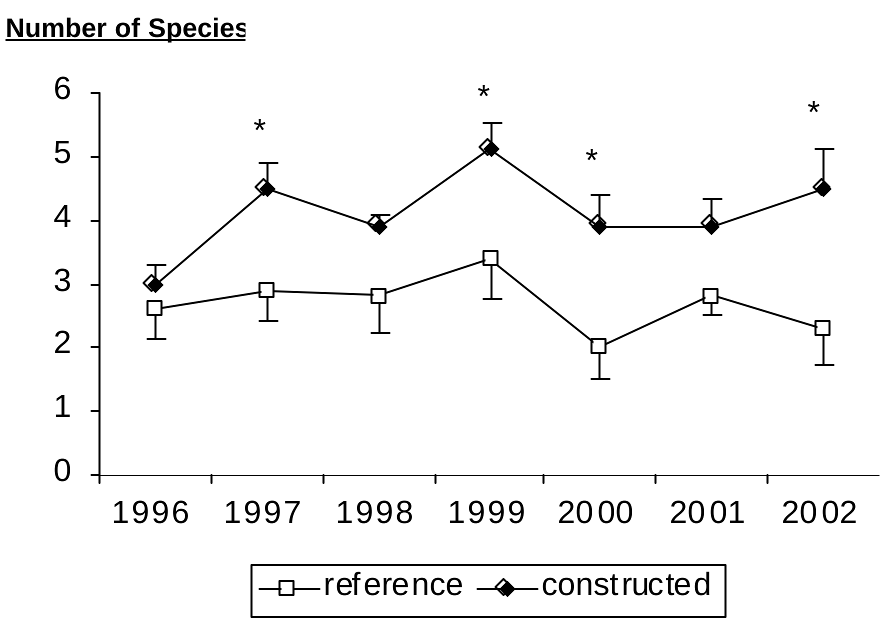

Fig. 12. Mean number of species that bred in reference and constructed ponds. Symbols are means and bars are + 1 SE. Years with asterisks are significantly different.

Overall, constructed ponds contained a significantly greater number of breeding species (mean + 1 SE = 4.10 + 0.25 species) than reference ponds (2.68 + 0.17 species) during the 7-year period (paired t-test; $P < 0.001$). For individual years, the mean number of species per pond was significantly higher in constructed ponds for four of seven years and approached significance ($P < 0.10$) for two other years (Fig. 13). Regression analysis indicates that the mean number of species using ponds annually did not increase between 1996-2002 (P values for reference and constructed ponds = 0.47 and 0.44, respectively). The latter suggests that constructed ponds quickly reached saturation levels within one year of construction.

3. Response of focal species to constructed ponds.

Methods

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, and serve as an index of the size of the female breeding population.

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 (1996-2002), reference ponds, and all additional breeding sites.

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 blowtorch (approximate area of can bottom = 1.2 ft^2). When sampling, the can was pushed into the pond substrate to trap larvae. Repeated sweeps of the can were made with 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

The responses of breeding populations of wood frogs and spotted salamanders to pond construction are shown in Fig. 13. These data exclude two constructed ponds (7X; 10X) that occurred on the western end of the site and three small reference ponds for 2002 that were destroyed in association with stream restoration efforts. 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, a short-term decline in the use of constructed ponds occurred from 2000-2002 when animals shifted to new breeding sites that were formed during stream reconstruction. 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. Additional ponds created in 2001-2002 in association with stream reconstruction were used by both species (146 *Rana* masses; 63 *Ambystoma* masses).

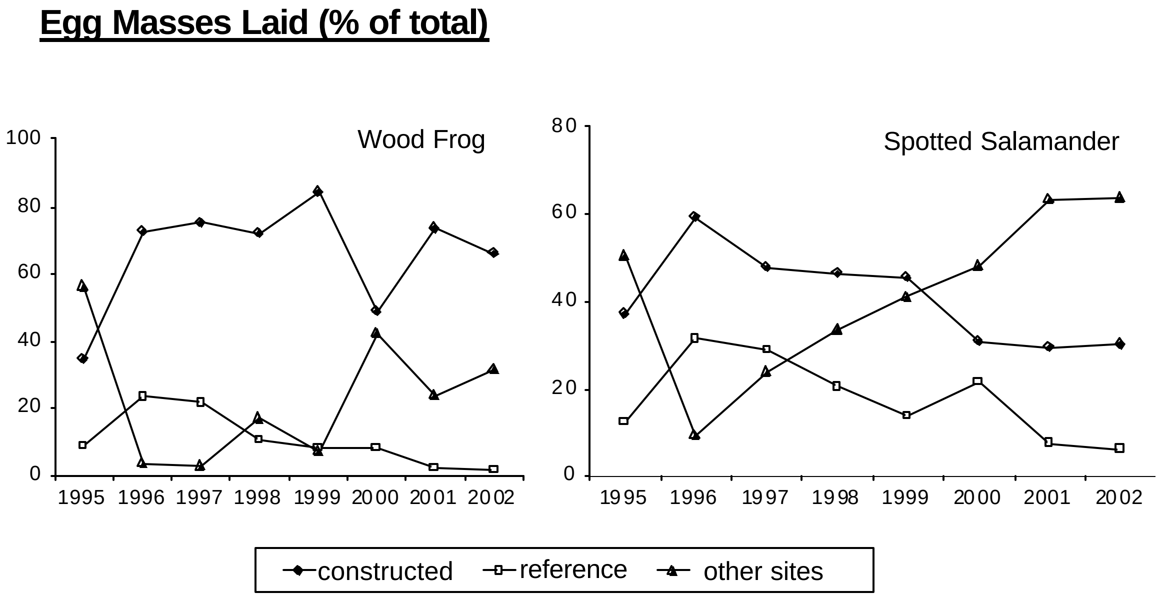

Fig. 13. Response of female wood frog and spotted salamanders to pond construction. Symbols are the number of egg masses laid on the eastern half of the site in constructed ponds, reference ponds, and all remaining breeding sites. Numbers are expressed as a percentage of all masses laid in the eastern half of the site. 'Other" includes all sites other than reference and constructed ponds, including sites that were created during stream channel restoration. Data for 1995 'constructed' are masses laid in preexisting sites where ponds were constructed.

Fig. 14 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 was exceptionally high during 1996 (N = 253,696 wood frogs; 30,831 spotted salamanders), but progressively declined in later years. A similar trend 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 (Fig. 15) indicate that the decline in juvenile output was primarily due to increased larval mortality rather than increased embryonic mortality between 1996-2002. 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 during the study period for both species and both sets of ponds. 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 a pathogen that caused larval die-offs, and (3) the accumulation of predators in constructed ponds after 1996.

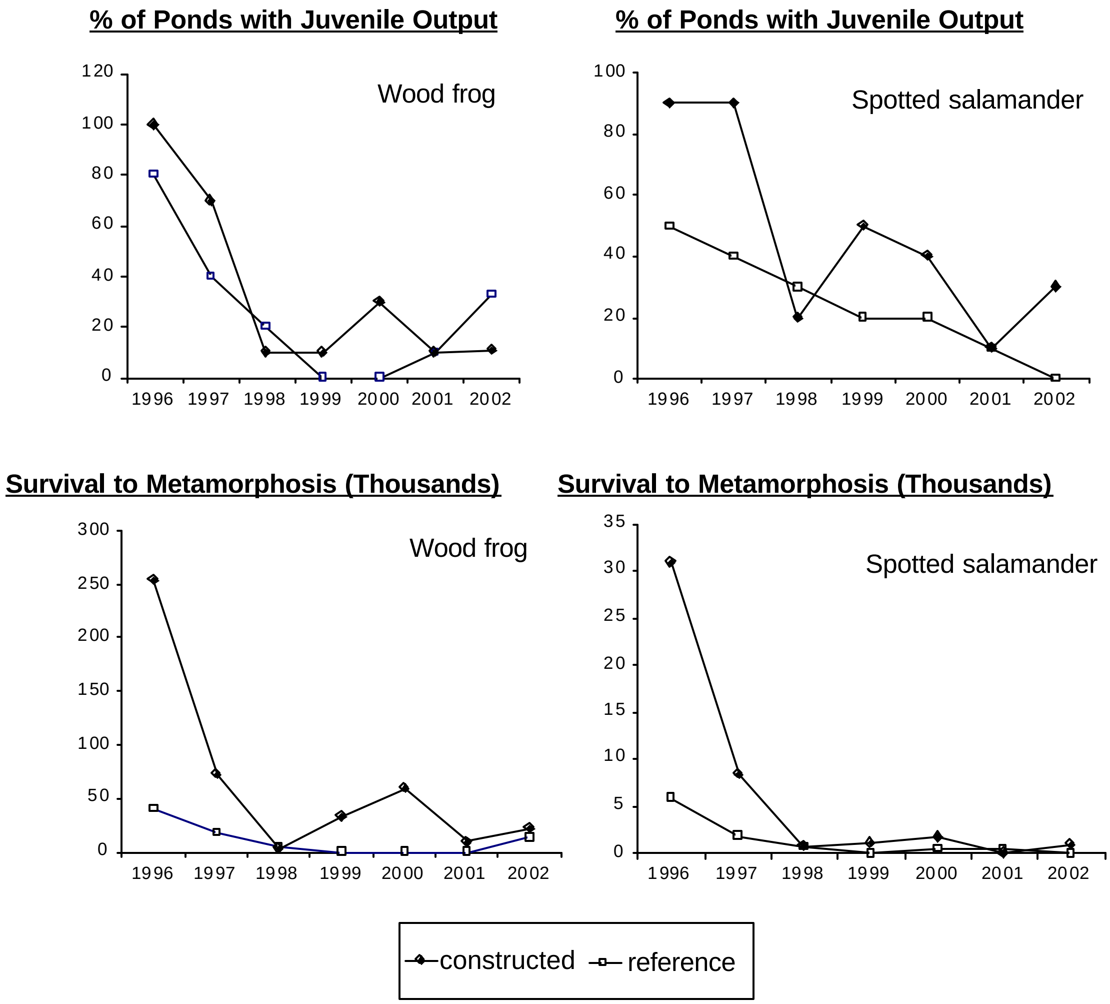

Fig. 14. Estimates of the percentage of ponds that produced juveniles, and total juvenile recruitment from 10 constructed and 10 reference ponds during 1996-2002. Symbols for upper panels are the percentage of ponds that produced juveniles annually, whereas those in the lower panels are the estimated number of larvae surviving to the initiation of metamorphosis.

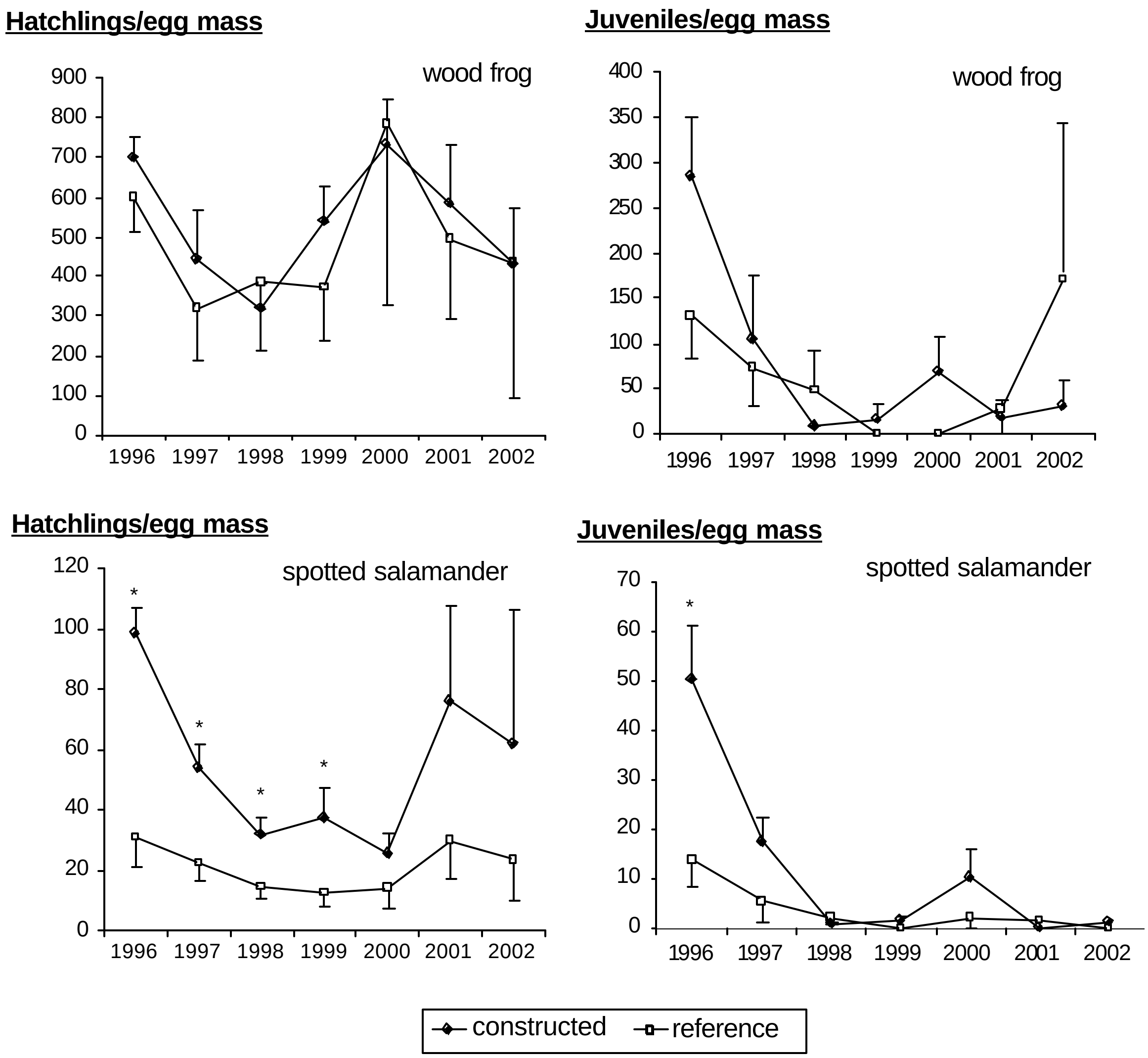

Fig. 15. Estimates of number of hatchlings and juveniles produced per egg mass for the wood frog and spotted salamander based on yields from open-bottom samplers. Symbols and bars are means and 1 SE, and asterisks indicate means that differed significantly within years.

Fig. 16 shows the percentage of ponds that either did not fill or that filled and dried prematurely between 1996-2002. 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

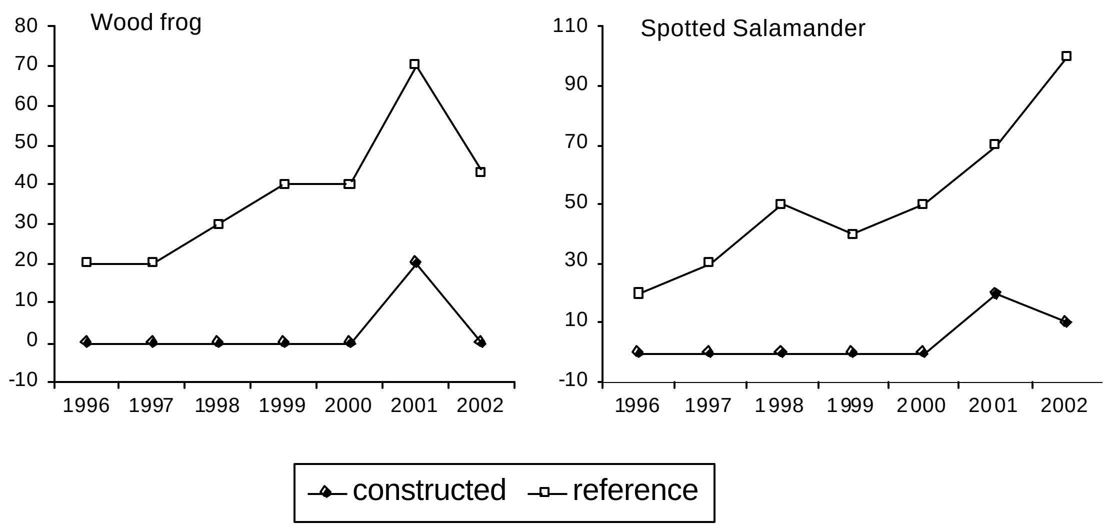

Fig. 16. Changes in the percentages of reference and constructed ponds that either did not fill seasonally or that dried before larvae could metamorphose.

In contrast, the more shallow reference ponds tended to progressively deteriorate with respect to hydroperiod between 1996-2002. During 2002, 43% and 100% of the reference ponds either did not fill or dried prematurely for *Rana* and *Ambystoma*, respectively. This pattern may in part reflect a regional drought that occurred during 1998-2002.

Disease is a second factor that contributed strongly to the decrease in juvenile output between 1996-2002. 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 is 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 mid- to latter half of the larval stage. Catastrophic mortality typically occurs within 1-2 weeks after the first infected individuals are detected. Typically, outbreaks result in 100% mortality of larvae in a pond.

The extent to which the disease has impacted local populations in reference and constructed ponds at Tulula is shown in Fig. 17. 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 1998-2002 reflects the fact that many reference ponds dried prematurely (e.g., prior to the time when the disease normally develops).

Egg and larval predation was the third significant source of premetamorphic mortality that contributed to the decline in juvenile output between 1996-2002. 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. 18. The size of the wood frog population declined from 1995-1998, but increased dramatically (366%) through 2000 and has declined 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. The decline since 2000 presumably reflects the impact of *Ranavirus* and premature pond drying on the adult population.

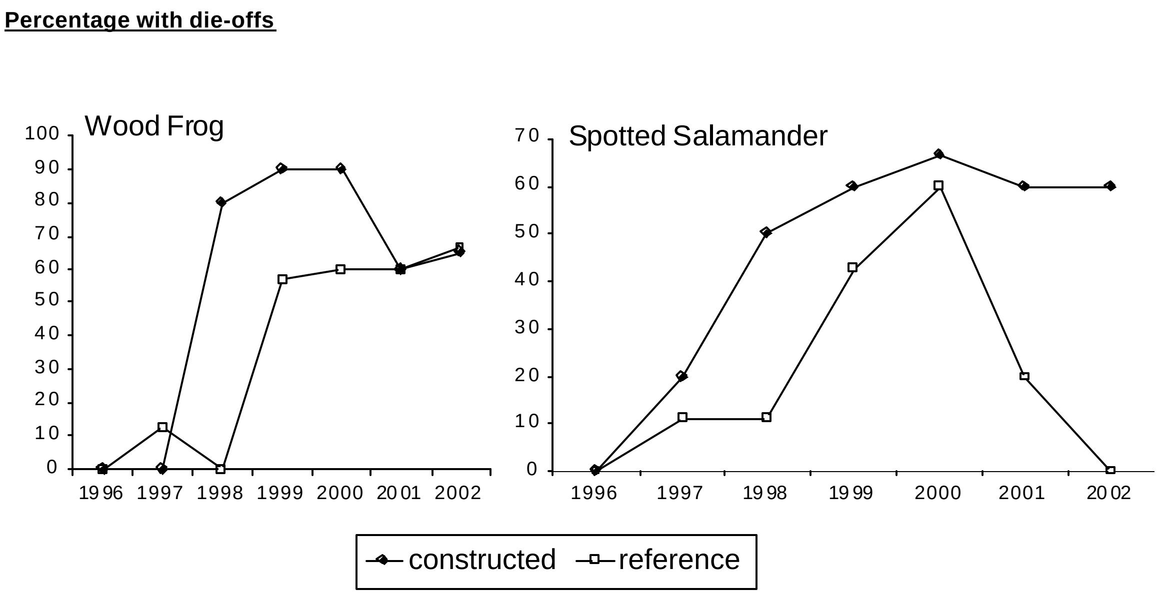

Fig. 17. Changes in the percentage of reference and constructed ponds in which catastrophic die-offs of larvae occurred from *Ranavirus* infections.

Number of Egg Masses

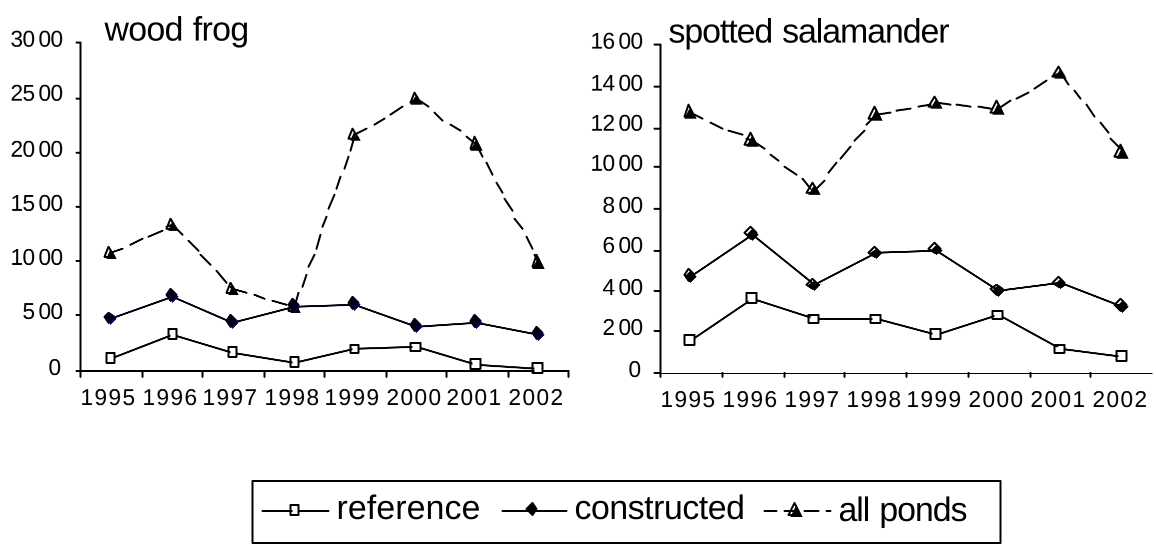

Fig. 18. Changes in adult breeding population size based on annual egg mass counts.

The population of spotted salamanders has not changed as markedly. The size of the breeding population slowly increased from 1995-2001. 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. The decline in 2002 may reflect the impact of *Ranavirus* outbreaks that began in 1997-1998.

Summary

Data collected from 1996-2002 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 1996-2002 with respect to seasonal hydroperiod. In 2002 the majority either did not fill or dried prematurely, resulting in catastrophic mortality of pond populations. 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. Because of delays in the final construction phase of the project, we were unable to document the response of amphibians to altered site hydrology associated with stream reconstruction and the filling of ditches. These data will become available after construction is terminated in August 2002.

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, it is unknown 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. Preliminary studies that we have conducted suggest that humans do not play a major role in spreading the disease via mud or water on field gear and that healthy tadpoles rapidly become infected when confined with sick animals. 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 that do not dry prematurely. The latter could result in resident 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 stream restoration is completed in summer 2002. 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.

D. Bird Use of Tulula

Birds are a commonly used indicator for assessing changes in habitat attributes (Morrison 1986). We conducted breeding bird surveys and measured habitat characteristics of the Tulula floodplain in 1994, 1998, and 2000 (Moorhead et al. 2001). This section reports the results of breeding bird surveys and habitat analyses conducted during the spring of 2002, and compares the results to the previous surveys. This is the fourth year of data that will serve as a baseline for evaluating how bird populations and habitat respond to post-restoration of the site.

1. Bird Surveys

Methods

Breeding bird surveys were conducted from 22 May to 31 May 2002, at 65, 82-ft radius plots located across Tulula floodplain (Fig. 19). Thirty-two plots were separated by at least 328 ft for sample independence between plots and reducing the likelihood of double-counting birds (Pendelton 1995). An additional 33 plots were separated by at least 164 ft and surveyed because habitat data have been collected at these plots since 1994 (see Bird-Habitat Relations below). Surveys were conducted from sunrise until 1000 hrs. After a 1-min quiet time, all birds heard or seen within 82 ft of the plot center were recorded for 3 min. Birds that flushed within 82 ft of the plot center during the approach also were recorded. Plots were sampled three times during the survey period (Rossell et al. 1999). 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.

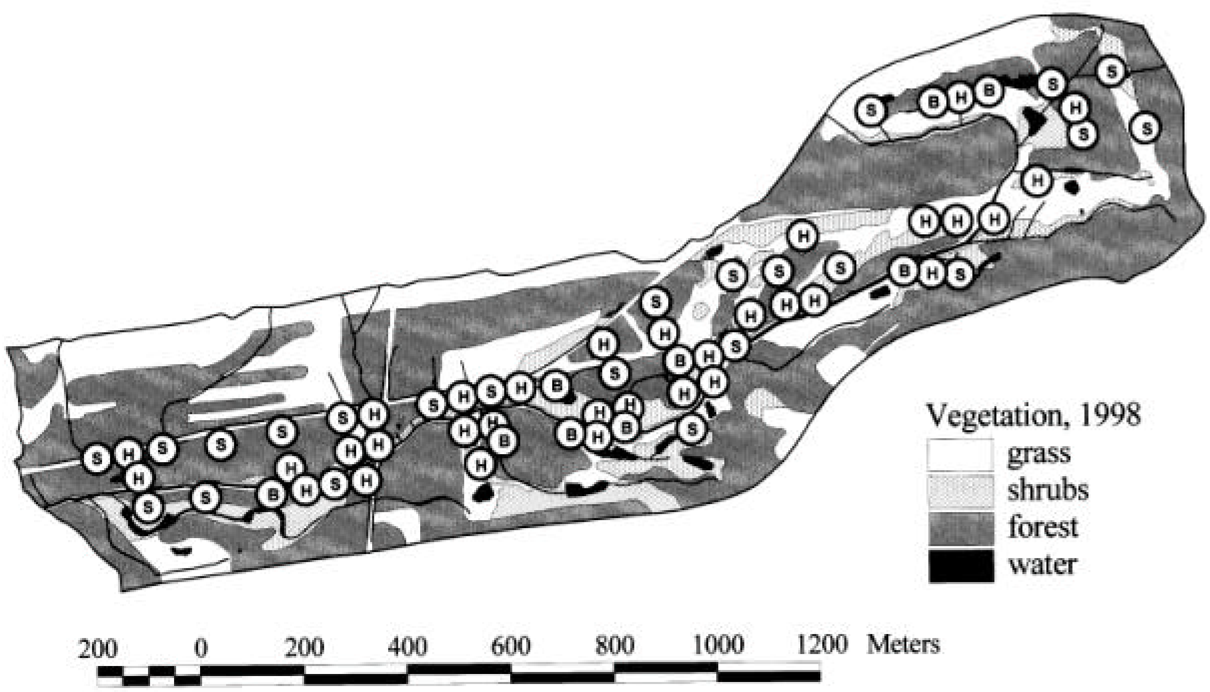

Fig. 19. Location of bird survey and habitat plots. S = survey plots, H = habitat plots, and B = survey and habitat plots.

Results and Discussion

Results of the breeding bird surveys are presented in Table 12. Species richness in 2002 was the highest of the four years that surveys have been conducted, with 39 species recorded. The Blue-headed Vireo, Brown-headed Cowbird, Eastern Phoebe, Red-winged Blackbird, and Wood Duck were new species recorded during surveys. Of these, the Blue-headed Vireo was probably the only species not breeding on site. The Eastern Phoebe and Prairie Warbler (which was not recorded during surveys) were entirely new species at Tulula (see Appendix G for complete list of birds and scientific names). The Eastern Phoebe is common in the mountains and often is associated with water (Hamel 1992). The Prairie Warbler probably was not breeding on site, but one male was observed singing in the powerline right-of-way at the west end of Tulula. Prairie Warblers are uncommon in the mountains and prefer habitats dominated by saplings and shrubs (Hamel 1992).

Relative bird abundance increased 49% (215 to 321 birds) from 2000 to 2002. Four species, American Robin, Red-winged Blackbird, Northern Cardinal, and Song Sparrow, increased in relatively large numbers, accounting for 50% (53 birds) of the total increase in relative abundance in 2002. Other species with notable increases included the Chestnut-sided Warbler and Northern Parula. Both species increased by at least 100% from 2000 levels (Chestnut-sided Warbler: 7 to 14 birds; Northern Parula: 10 to 26 birds). Two other neotropical migrants, Golden-winged Warbler and Yellow-breasted Chat, continued to decline in abundance. Of particular concern is the Golden-winged Warbler. This species is currently under status review for federal listing by the U.S. Fish and Wildlife Service. Since 1994, the Golden-winged Warbler has decreased 81% (31 to 6 birds) at Tulula. Golden-winged Warblers are considered habitat specialists, requiring a variety of seral stages for breeding, including patches of herbaceous cover, shrub thickets, and a forested edge (Klaus and Buehler 2001). As a result of stream construction and backfilling the old stream channel during the spring of 2002, most of the herb and shrub layers were eliminated from the interior of Tulula. This area in the past has encompassed a substantial portion of many Golden-winged Warbler territories (Rossell et al., in prep), including many song perches that defined territory boundaries (Rossell 2001).

The positive trends in bird richness and relative abundance may be attributed to disturbance, changes in habitat, and natural population fluctuations. Disturbance of the interior of Tulula has been extremely high for the past few years, with active construction of the new stream channel and filling of the old stream channel. Other studies have demonstrated that after a disturbance, bird species diversity and abundance increase, as generalists and exotic species colonize the area (Noss 1983, Mooney 1988). A similar pattern occurred in 2002 at Tulula, where many generalist species such as American Robin, Northern Cardinal, and Song Sparrow dramatically increased in abundance. Brown-headed Cowbirds also were more numerous. This species probably bred on site for the first time in 2000, although they were not recorded during bird surveys (Moorhead et al. 2001). In 2002, two individuals were recorded during surveys, constituting a relative increase of 200%. Brown-headed Cowbirds are a pest species and tend to invade areas that have been fragmented (Franzreb and Phillips 1996).

As a result of vernal pond construction, stream restoration, and backfilling of drainage ditches, there appeared to be substantially more standing water on site than in past years. This change in habitat is reflected by the addition of the Red-winged Blackbird and the Wood Duck to the breeding avian fauna at Tulula. Both species are closely associated with standing water. Red-winged Blackbirds have quickly become one of the most abundant species at Tulula, ranking fifth in relative abundance (Table 12).

Table 12. Relative abundance and migratory status of birds recorded during breeding bird surveys in 65, 82-ft radius (0.5 ac) plots during 1994, 1998, 2000, and 2002.

Species	1994	1998	2000	2002	Migratory Status
	Number				
Acadian Flycatcher	2	14	3	1	N
American Goldfinch	19	13	7	5	Y
American Robin	0	1	0	12	D
Belted Kingfisher	0	1	0	0	Y
Blue-gray Gnatcatcher	11	13	10	9	N
Blue-headed Vireo	0	0	0	1	N
Brown-headed Cowbird	0	0	0	2	D
Brown Thrasher	1	0	0	4	D
Black-and-White Warbler	1	3	1	0	N
Blue Jay	0	2	0	0	Y
Carolina Chickadee	15	4	7	10	Y
Carolina Wren	3	6	3	2	Y
Common Yellowthroat	7	1	0	2	N
Chestnut-sided Warbler	23	2	7	14	N
Cedar Waxwing	9	10	4	9	D
Downy Woodpecker	6	1	2	3	Y
Eastern Phoebe	0	0	0	1	D
Golden-winged Warbler	31	21	8	6	N
Gray Catbird	4	0	0	0	Y
Hooded Warbler	11	21	6	12	N
Indigo Bunting	83	55	15	17	N
Kentucky Warbler	17	9	9	2	N
Mourning Dove	0	2	0	1	Y
Northern Bobwhite Quail	0	0	2	7	Y
Northern Cardinal	8	3	4	12	Y
Northern Flicker	1	0	0	1	Y
Northern Parula	17	24	10	26	N
Northern Rough-winged Swallow	0	2	0	4	N
Ovenbird	2	6	2	5	N
Pileated Woodpecker	0	2	1	2	Y
Red-eyed Vireo	21	28	28	25	N

Ruby-throated Hummingbird		6	5	6	7		N
Rufous-sided Towhee		22	24	14	26		Y
Red-winged Blackbird	0	0	0	13		D	
Scarlet Tanager		0	1	1	0		N
Song Sparrow		4	11	11	31		Y
Swainson's Warbler		1	4	0	0		N
Tufted Titmouse		3	5	8	11		Y
White-breasted Nuthatch		1	0	1	1		Y
White-eyed Vireo		22	26	29	20		N
Wood Duck		0	0	0	1		D
Wood Thrush		0	1	0	3		N
Yellow-breasted Chat		18	23	12	7		N
Yellow-throated Vireo	4	1	3	3		N	
Yellow-throated Warbler		3	4	1	3		N
Yellow Warbler		0	1	0	0		N
Total Species		31	36	29	39		
Total Individuals		378	350	215	321		

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

2. Bird-Habitat Relations

Methods

Habitat data were collected from 41 permanent plots from 15 June to 9 July 2002. Bird-habitat plots were selected in 1994 based on the criteria that they had at least one bird species recorded in two of three surveys. Similar data were collected in the same plots during 1998 and 2000. Within each plot, herbaceous cover, shrub thickness, and canopy cover were estimated at 16 points along two perpendicular transects. Understory (1-4 in dbh) and overstory (>4 in dbh) tree densities also were estimated in each plot using the closest individual method (Bonham 1989). Herbaceous cover was estimated for vegetation < 20 in tall using a 100-in^2 quadrat. Shrub thickness was estimated for vegetation 20 in – 6.5 ft tall using a shrub profile board (Hays et al. 1981). Canopy cover was estimated using a spherical densiometer (Hays et al. 1981).

Bird richness and relative bird abundance were calculated for each plot. 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 (ANOVA) tests were used to compare differences among years for bird diversity, relative bird abundance, and the habitat variables. If a significant difference was found with ANOVA, then Tukey's Studentized Range test was used to determine between year differences.

Results and Discussion

Means of bird richness, relative bird abundance, and habitat variables for the 41 habitat plots are summarized in Table 13. Both bird richness and relative bird abundance were significantly higher in 2002 than in 2000 ($P < 0.05$). In addition, herbaceous cover and shrub thickness were significantly lower in 2002 than in 2000 ($P < 0.05$). All other habitat variables were similar among the four 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 -0.07 and 0.05).

The positive trends in bird richness and relative bird abundance found in the habitat plots support the results of the breeding bird surveys. Possible explanations for the significant increases in bird richness and relative bird abundance are discussed in the Results and Discussion of the Bird Survey section of this report. The extremely low associations between bird richness and relative abundance and the habitat variables may reflect the highly diverse structure of the habitat among sample plots, which is indicated by the large standard deviations of the habitat variables (Table 13).

The significant reductions in herbaceous cover and shrub thickness reflect the high levels of disturbance of the interior of Tulula that occurred during restoration activities. Interestingly, canopy cover, understory tree density, and overstory tree density have not significantly changed in the habitat plots during the four years of study. This may be explained by the fact that many of the plots that have been disturbed by restoration activities were devoid of a canopy prior to the start of this study in 1994. Many of these plots are located in areas that were cut as fairways during golf course construction.

Table 13. Mean (SD) bird richness, relative bird abundance, and habitat variables for 41, 82-ft radius (0.5 ac) plots during 1994, 1998, 2000, and 2002.

	Year			
Variable	1994	1998	2000	2002
Bird Richness	4.6 (2.1)a	4.0 (1.8)a	2.8 (1.9)b	3.7 (2.2)a
Relative Bird Abundance	6.6 (3.0)a	5.2 (2.8)a	3.4 (2.3)b	4.4 (2.7)bc
Herbaceous Cover (%)	60.0 (17.5)a	53.9 (20.6)a	52.4 (17.9)a	28.1 (15.6)b
Shrub Thickness (%)	35.2 (15.9)a	28.5 (14.7)b	38.9 (17.7)a	25.9 (16.7)b
Canopy Cover (%)	59.2 (23.8)	45.4 (21.8)	51.7 (25.0)	45.6 (26.5)
Understory dens. (no./0.5 ac)	11.5 (15.3)	6.3 (18.8)	21.7 (27.1)	18.5 (30.2)
Overstory dens. (no./0.5 ac)	7.1 (13.9)	7.6 (13.8)	10.8 (20.5)	8.9 (16.0)

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

E. GIS Support of Project

We continued our efforts to use GIS/GPS to assess wildlife response to plant community succession. For example, since 1994 bird data have been analyzed in relation to digitized vegetation files derived from aerial photographs of the site every two years. Other studies of the golden-winged warbler (Rossell 2001) and eastern box turtle (Rossell et al. 2002) also involved using GIS/GPS to record animal locations. GIS/GPS also was used to document the location of vernal ponds and the footprint of restored channel segments in support of the geomorphology studies. Many ongoing studies require the use of the digital 2002 aerial photography, which was not obtained prior to July 2002.

DISCUSSION

Tulula continues to change as restoration proceeds and as natural processes respond to changing site conditions. The opportunity to conduct long-term research at a mitigation bank, partially as a result of delays in construction, has provided UNCA and NCDOT with a more comprehensive understanding of annual and seasonal variability in the structural and functional attributes of a restoration project.

The restored stream channel should improve overall site hydrology. Western North Carolina continues to receive below average precipitation that has kept water in the new channel near baseflow for most of the six to eight months of water flow. Although low flow and lack of precipitation have made assessment of site hydrology more challenging, the net effect has been improved channel bank stability. The channel banks restored in 2001 have been completely colonized by vegetation. A few adjacent areas of the new channel did experience localized overbank flooding in the winter of 2002, particularly during a one-week period of 7 inches of rainfall.

The network of manual and electronic wells will provide information to assess the relative changes in water table across the site. We are fortunate to have water-table data from the period between June 1994 and June 1998 (a period of frequent above average precipitation) to assess site hydrology. This is one of several examples of how the long-term database established for Tulula has given UNCA and NCDOT a more thorough understanding of site ecology.

Natural succession is well underway across most of Tulula. The basal area and ground-layer cover of woody species have increased, and woody species richness has increased in open areas. These changes have been accompanied by decreased coverage of herbaceous plants in forested areas. Without active management (e.g., bush-hogging, burning), the site will revert to a forested floodplain, eliminating the pockets of habitat that currently support small populations of unique and uncommon wetland plants.

One benefit of natural succession in open areas at Tulula is that there has been substantial emergence of woody shrubs and trees in the fairways, making it unnecessary for NCDOT to reforest the site with nursery-grown stock. In addition, the seed bank in the fairway that NCDOT restored appears to be responding to this disturbance and the altered hydrology, and a number of typical wetland species have emerged.

Constructed ponds are currently functioning as high-quality habitats for resident amphibians and also support a wide array of aquatic invertebrates. Reference ponds underwent progressive deterioration between 1996-2002 with respect to seasonal hydrology. Most either did not fill or dried prematurely in 2002. During this same period the hydroperiods of constructed ponds were sufficient to allow most resident species to complete the larval stage. The extent to which seasonal hydroperiods will be altered in the future in response to stream restoration, the filling of ditches, the return to more normal annual precipitation, and the recolonization of the site by beavers will be assessed in 2003 and subsequent years.

The outbreak of a pathological virus at the site was unexpected and provides an opportunity to determine how the design of a wetland mitigation site influences the ability of populations to weather outbreaks of disease. We used a metapopulation design in which we constructed an array of breeding sites on site. Despite the catastrophic nature of local die-offs from *Ranavirus*, our goal is to have a subset of ponds that successfully produce juveniles each year. Although outbreaks of *Ranavirus* have reduced the output of juveniles from both constructed and reference ponds, current juvenile output from constructed ponds appears to be at a level that will sustain the adult populations of resident amphibians. The extent to which *Ranavirus* will ultimately impact adult populations of the wood frog and spotted salamander will become more clear as we continue to track changes in breeding population size in 2003 and beyond. Because of the long-term data that has been collected at the site, this study is the only in the country to provide meaningful insights into the population consequences of *Ranavirus* infections.

The changes in the avian fauna seen in 2002 reflect the response of birds to disturbance and to some extent an increase in standing water on site. Overall, a general shift has occurred from early-successional specialists, many of which are neotropical migrants of high conservation value, to generalist species of low conservation value. As post-restoration proceeds, and the herbaceous and shrub layers become re-established in the interior of the site, there may be a resurgence of early-successional specialists. However, once the vegetation becomes re-established, periodic vegetation management will be required to maintain the early-successional habitat attributes of the site. In addition, species associated with standing water and wetland systems may increase. This, however, will depend on how much the hydrology of the site changes over time. To date, the information obtained on the birds and the habitat at Tulula provides valuable insight into how an avian fauna responds to disturbance from wetland restoration activities in a mountain ecosystem.

Tulula is the first wetlands mitigation bank in the Blue Ridge Province of North Carolina. Most mitigation banks in North Carolina are located in the Coastal Plain, and are considerably different from Tulula in terms of their hydrology and ecology. Our database on hydrology, soils, flora, and fauna continues to provide a framework for documenting the success of restoration at Tulula. These data were important in the development and design of restoration strategies, and have influenced considerations for site management. Tulula has provided research experience to more than 50 undergraduates at UNCA, including numerous senior research projects.

RECOMMENDATIONS

1. NCDOT should use manual wells if water table data are expressed as monthly averages. If a more thorough understanding of hydrology is needed, NCDOT should use electronic wells.

2. An evaluation of restored site hydrology requires an assessment of several years and conditions of average precipitation.

3. Site management of Tulula should include options to retain portions of Tulula in an early successional stage (for example, using bush-hogging or burning). This would enhance habitat for unique and uncommon plants, and animals such as the Golden-winged Warbler.

4. Large-scale plantings of nursery-grown woody plants should be discouraged for Tulula. We have documented more than adequate natural regeneration of both trees and shrubs.

5. Now that restoration of Tulula is nearing completion, monitoring of floral and faunal communities should continue, to document how they respond to the hydrologic changes.

6. Beavers should be allowed to use the restored channel and floodplain of Tulula Creek. The beaver is a natural community element in many mountain wetland systems and was present on site prior to stream restoration. The population at Tulula was eliminated via trapping in 2001-2002 to allow work on the stream channel. This species will likely reappear in 2003 unless trapping continues. The beaver is a keystone species that will be an important community member in the future. Recolonization by beavers will alter site hydrology and the composition of aquatic communities. Post-restoration monitoring to determine ecosystem function and hydrologic dynamics will be more realistic and meaningful if beavers are present on site.

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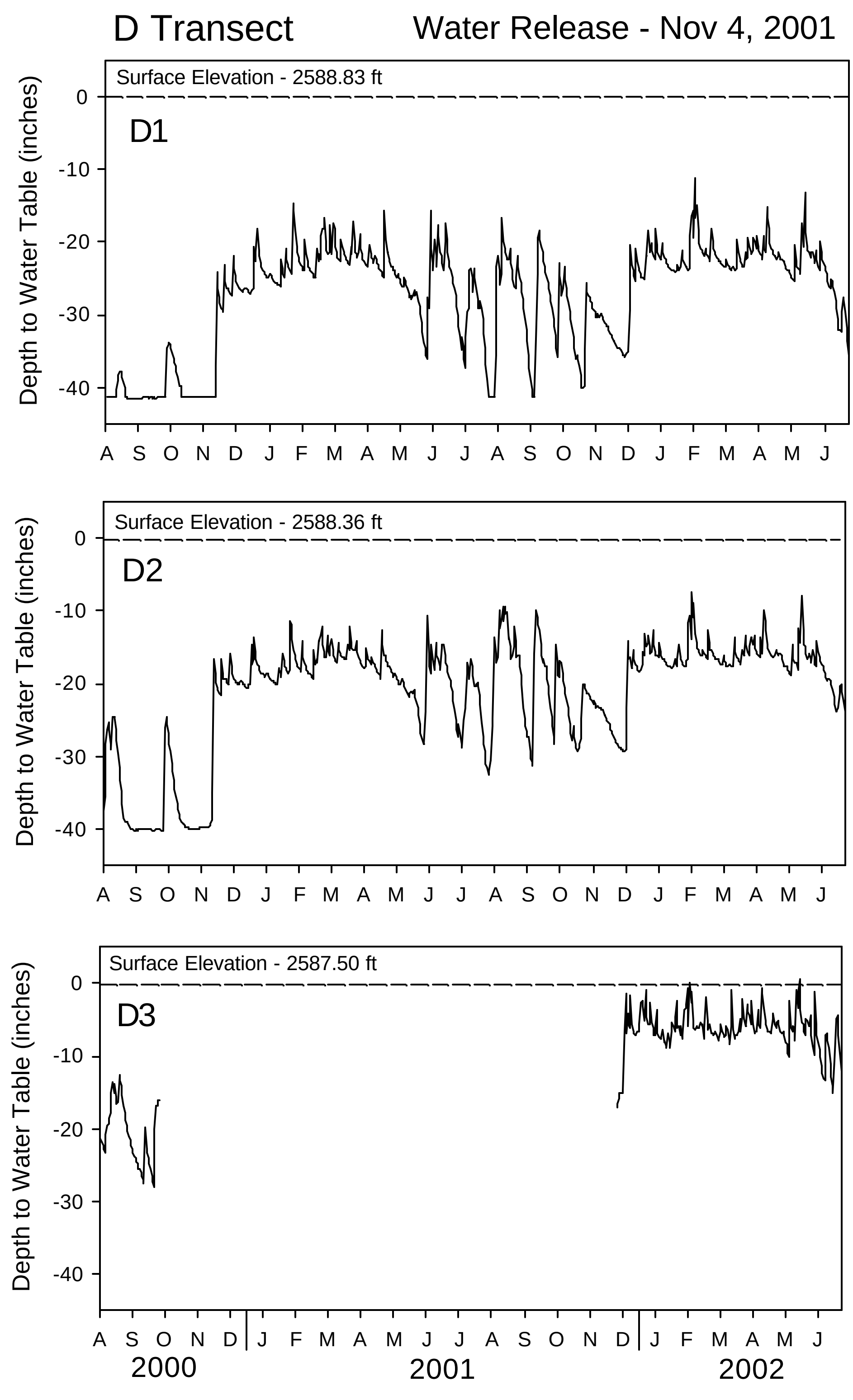
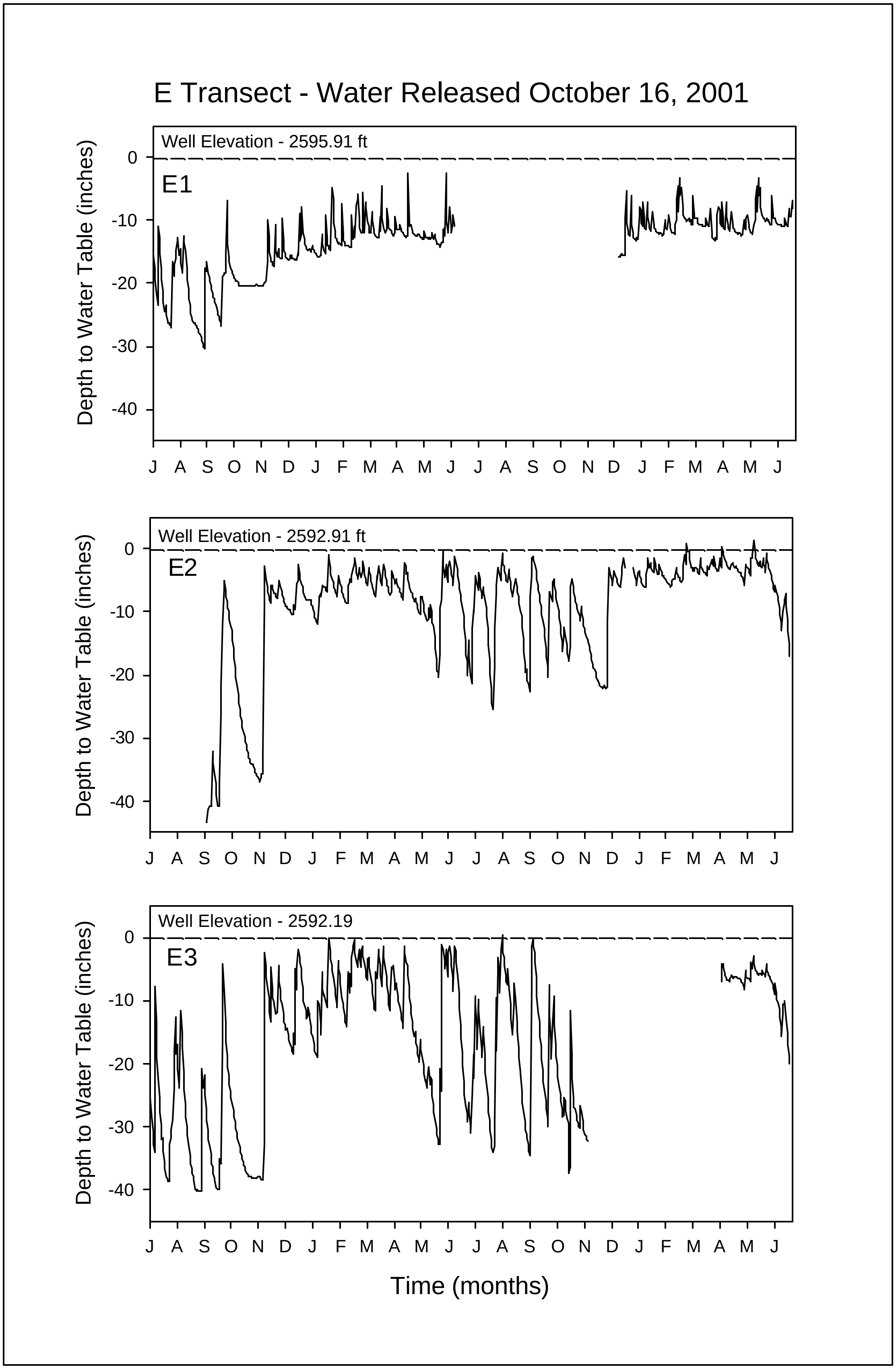
Appendix A-1. Daily water-table levels of electronic wells on the D transect.

A

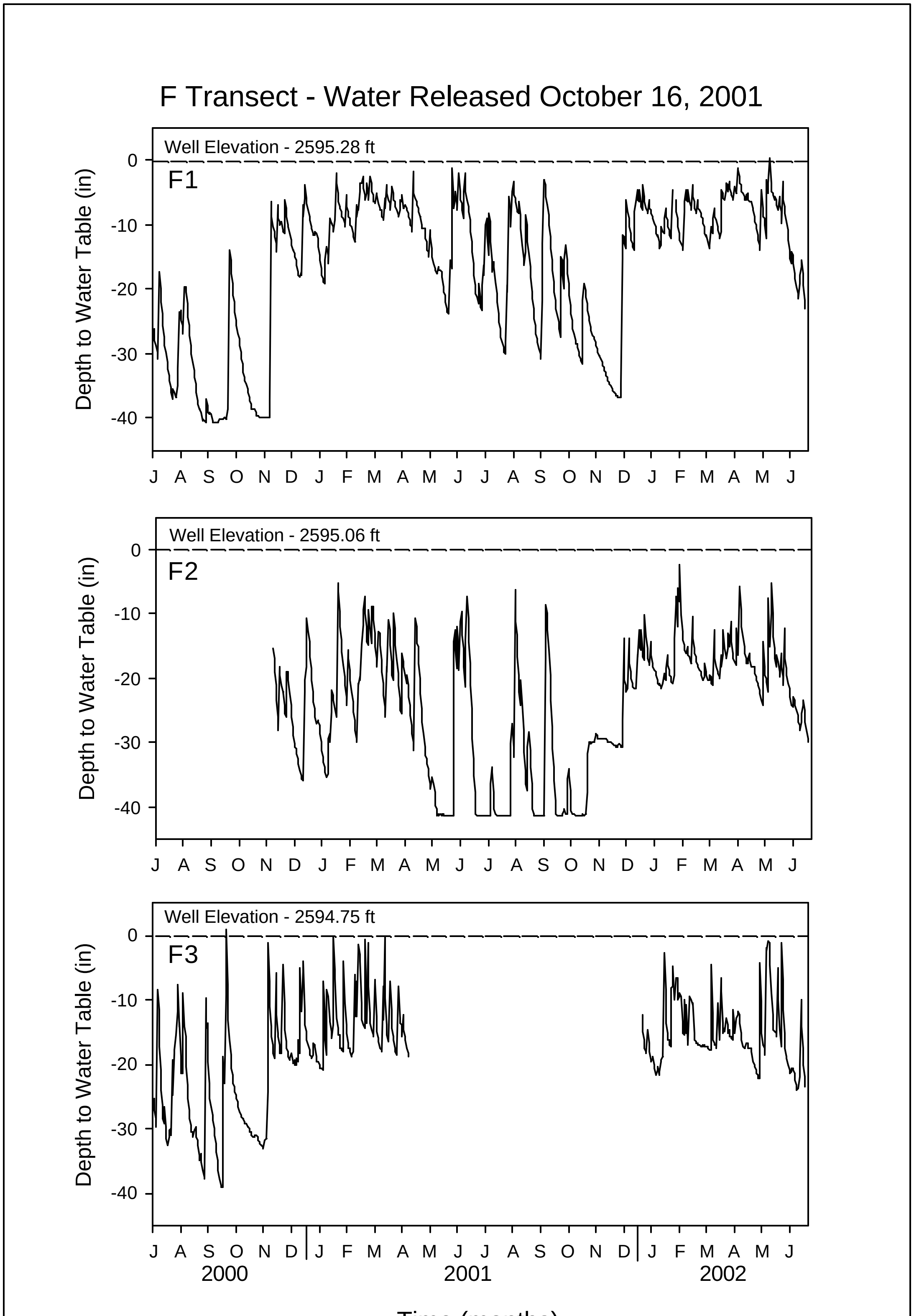
A



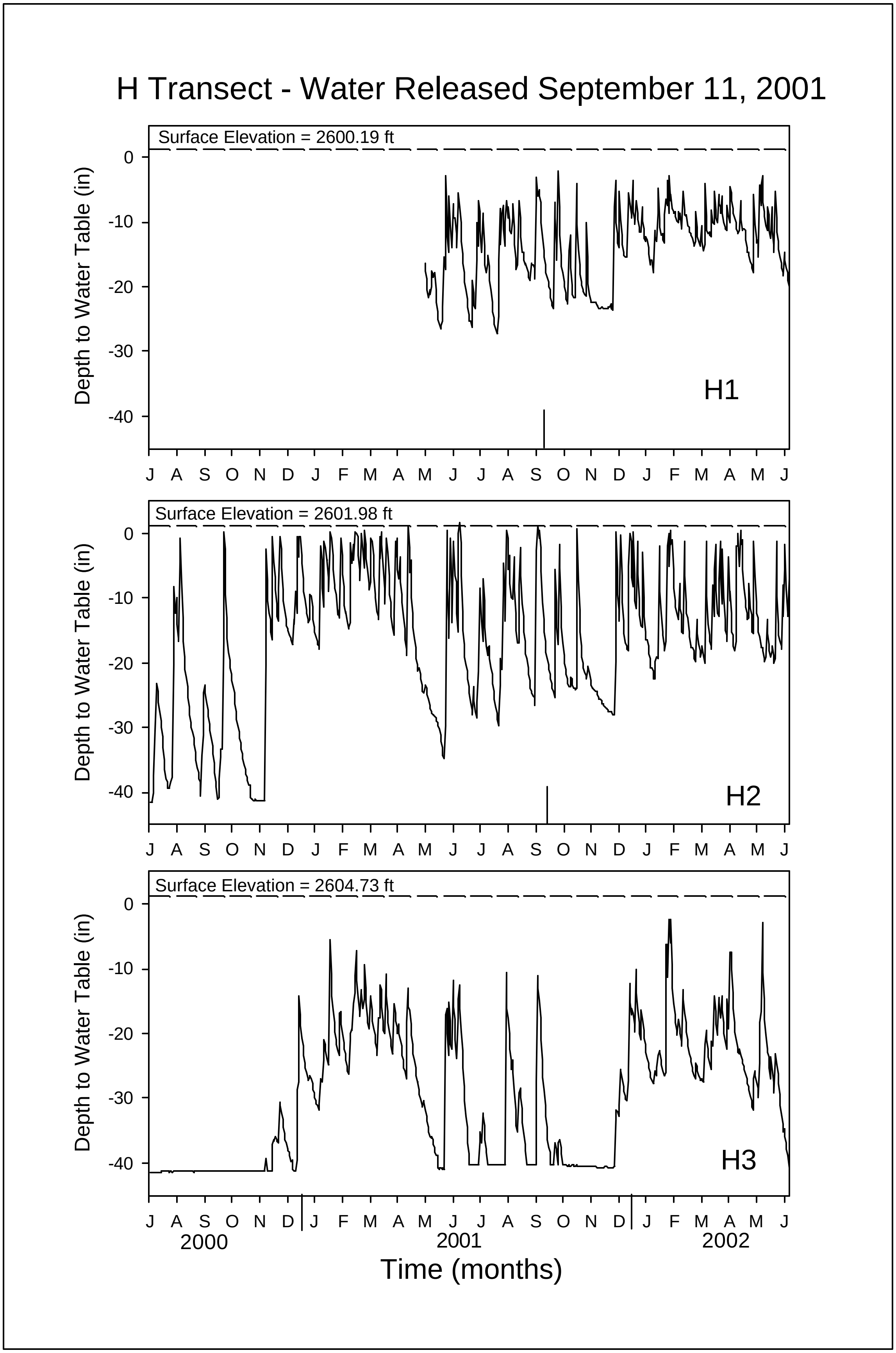
Appendix A-2. Daily water-table levels of electronic wells on the E transect.



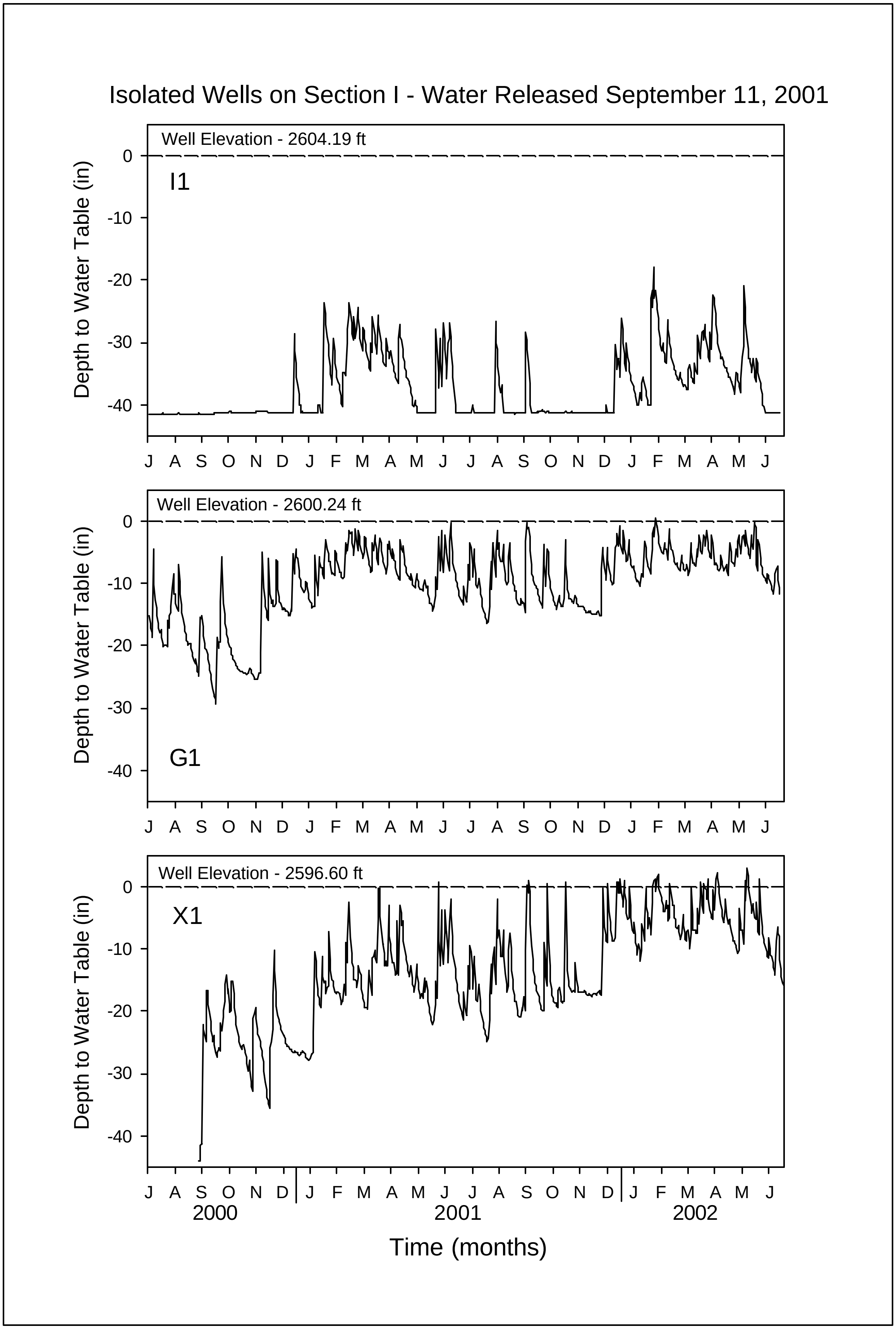
Appendix A-3. Daily water-table levels of electronic wells on the F transect.



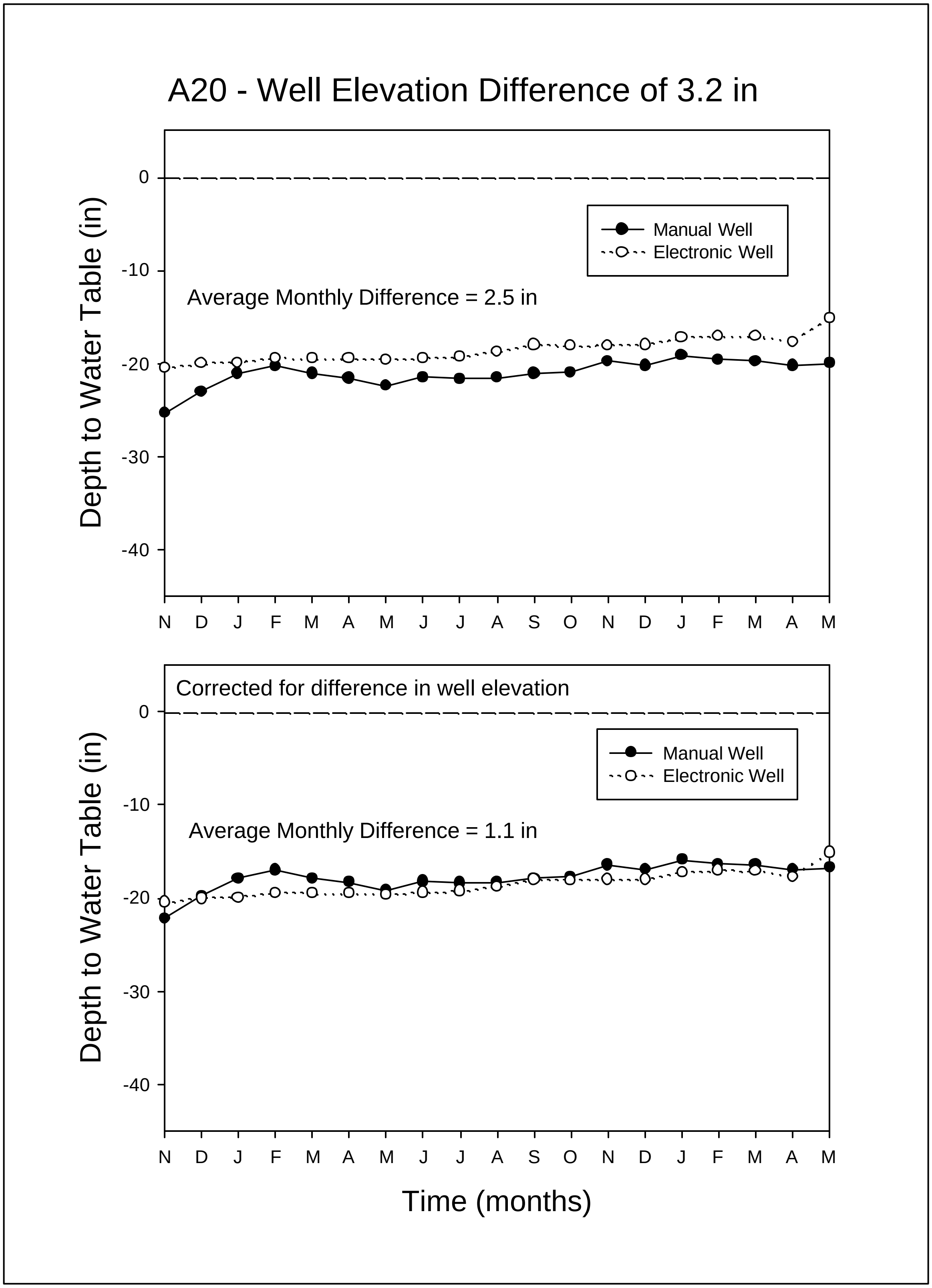
Appendix A-4. Daily water-table levels of electronic wells on the H transect.



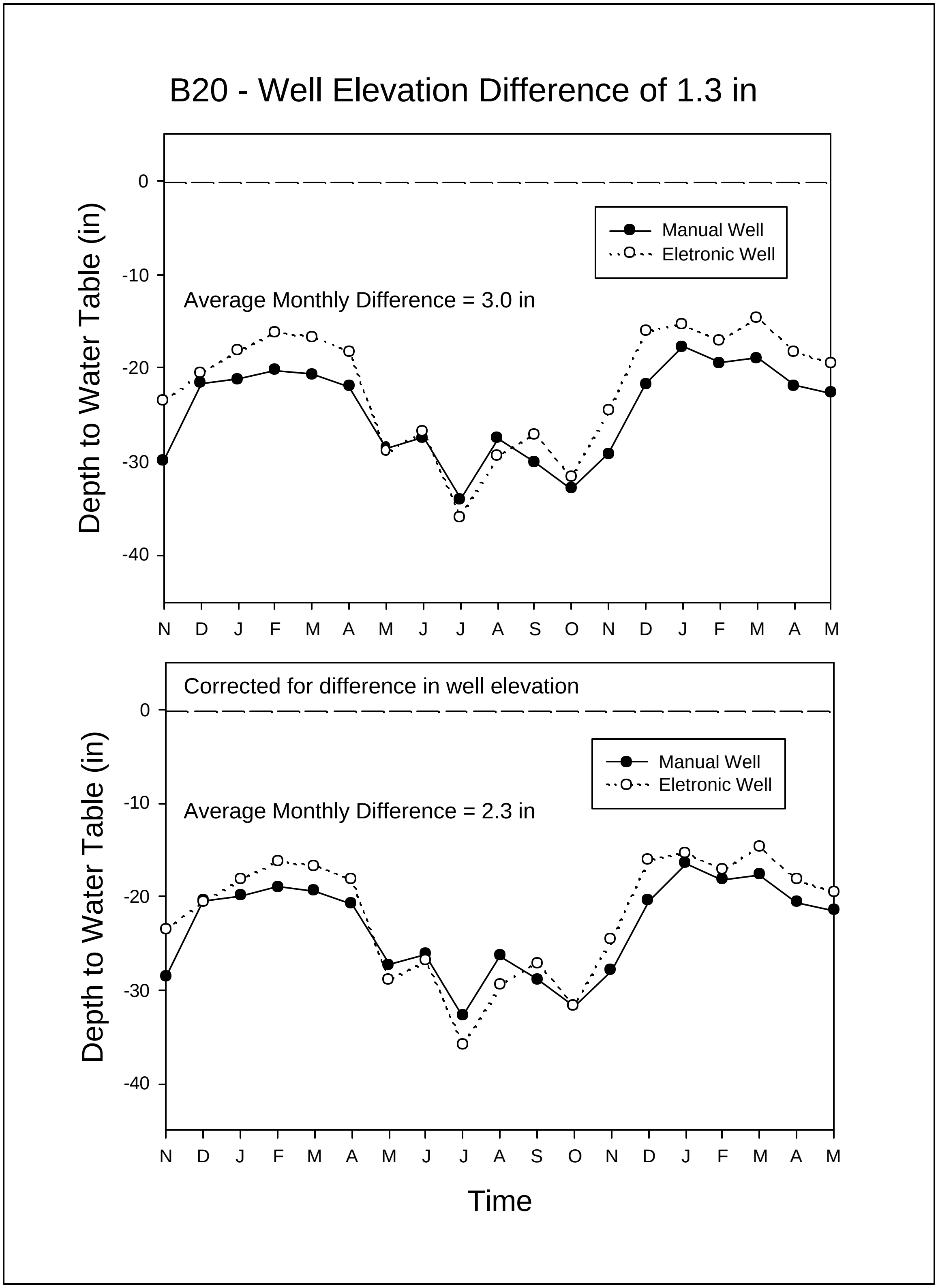
Appendix A-5. Daily water-table levels of isolated electronic wells on Section I.



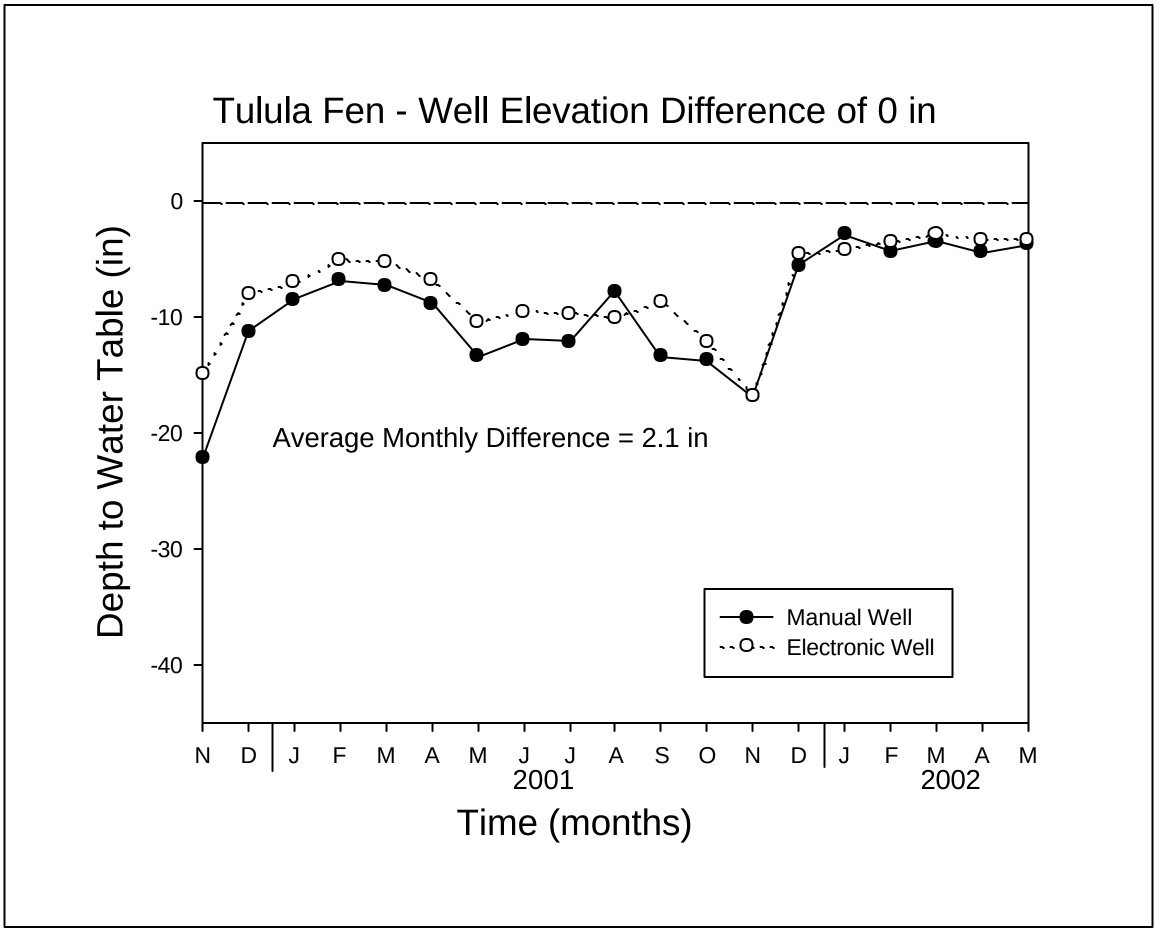
Appendix B-1. Monthly water table averages of manual and electronic wells located at A20.



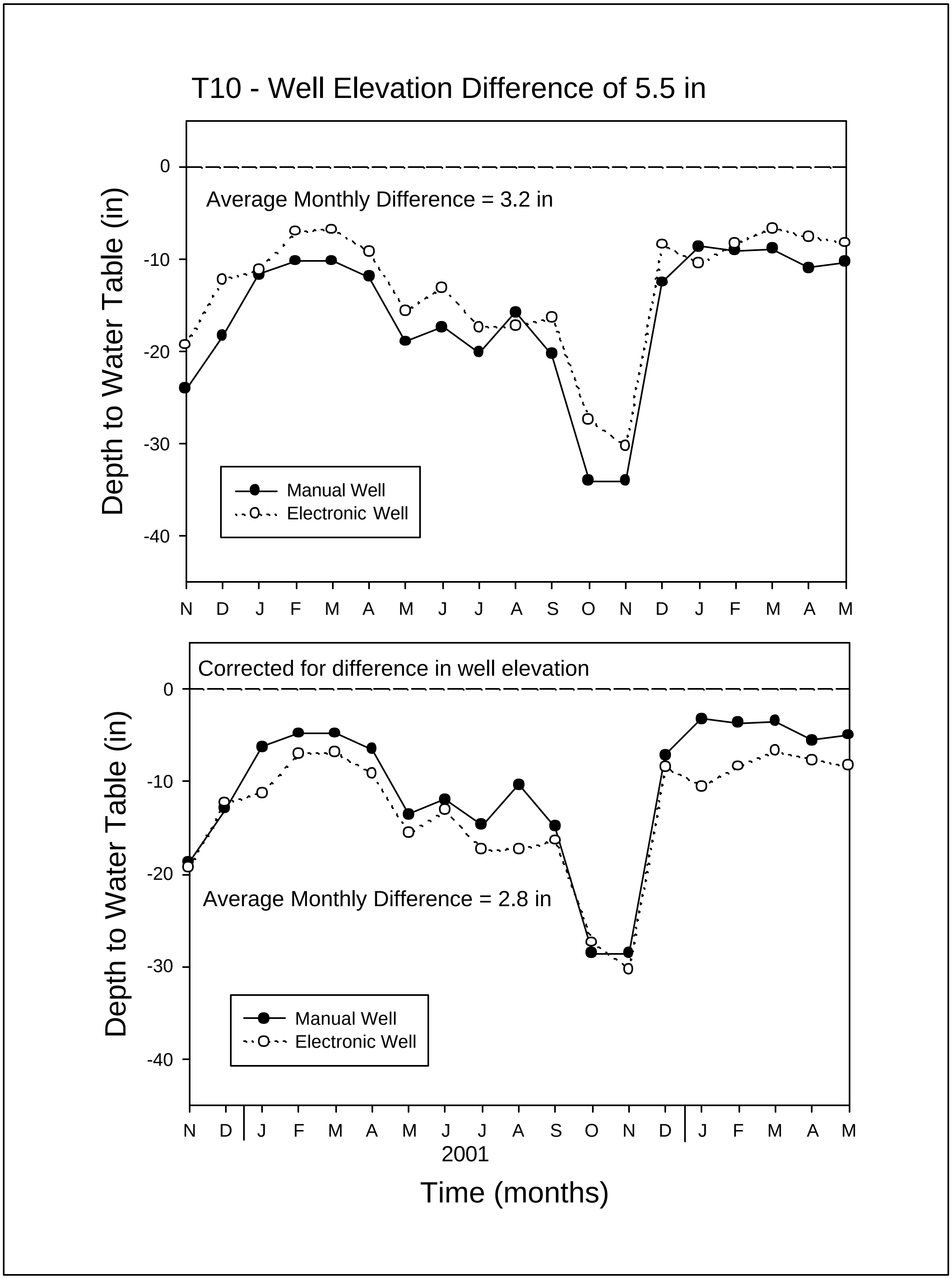
Appendix B-2. Monthly water table averages of manual and electronic wells located at B-20.



Appendix B-3. Monthly averages of manual and electronic wells located in Tulula Fen.



Appendix B-4. Monthly averages of manual and electronic wells located at T-10.



Appendix C. List of vascular plants recorded in 1994 and 2001 in open and closed fen and floodplain areas of the Tulula Creek wetland complex with wetland indictor status.

Species	**Common name**	**Family**	**Wetland status**
Acer rubrum L var. *rubrum*	Red maple	Aceraceae	FAC
Agalinis purpurea (L.) Pennell	Foxglove	Schrophulariaceae	FACW
Ageratina altissima King & H.E. Robins. *var. altissima*	White snakeroot, milksick	Asteraceae	FACU
Alnus serrulata (Ait.) Willd.	Tag alder	Betulaceae	FACW
Apios americana Medik.	Groundnut	Fabaceae	FACW
Ambrosia artemisiifolia L.	Ragweed	Asteraceae	FACU
Amelanchier laevis Wieg.	Smooth serviceberry	Rosaceae	NA
Aralia spinosa L.	Hercules club	Araliaceae	FAC
Arisaema triphyllum L.	Jack-in-the-pulpit	Araceae	FACW
Aronia arbutifolia (L.) Pers.	Red chokeberry	Rosaceae	FACW
Aronia melanocarpa (Michx.) Ell.	Black chokeberry	Rosaceae	FAC
Aster puniceus L.	Purple-stem aster	Asteraceae	OBL
Aster pilosus Willd. var. *pilosus*	Old-field hairy aster	Asteraceae	FAC
Athyrium asplenioides (Michx.) A.A. Eat.	Southern lady fern	Dryopteridaceae	NA
Calamagrostis coarctata (Torr.) Eat.	Reed-grass	Poaceae	OBL
Carex atlantica Bailey	Prickly bog sedge	Cyperaceae	FACW
Carex bullata Schkuhr ex Willd.	Button sedge	Cyperaceae	OBL
Carex communis Bailey	Fibrousroot sedge	Cyperaceae	NA
Carex debilis Michx.	White edge sedge	Cyperaceae	FACW
Carex festucacea Schkuhr ex Willd.	Fescue sedge	Cyperaceae	FACW
Carex intumescens Rudge var. *intumescens*	Greater bladder sedge	Cyperaceae	FACW
Carex stricta Lam.	Upright sedge	Cyperaceae	OBL
Chamaecrista nictitans (L.) Moench var. *nictitans*	Common sensitive-plant	Caesalpinianceae	FACU
Clematis virginiana L.	Virgin's bower	Ranunculaceae	FAC
Cornus amomum P. Miller	Silky dogwood	Cornaceae	FACW
Danthonia spicata (L.) Beauv. ex Roemer & J.A. Schultes	Poverty oat-grass	Poaceae	NA
Dichanthelium clandestinum (L.) Gould	Deer tongue, witch grass	Poaceae	FACW
Dichanthelium commutatum (J.A. Shultes) Gould	Variable witch grass	Poaceae	FAC
Dichanthelium dichotomum (L.) Gould	Witch grass, panic grass	Poaceae	FAC
Dichanthelium dichotomum (L.) Gould var. *ramulosum*	Barbed witch grass	Poaceae	NA
Dichanthelium ensifolium (Baldw.) Gould *var. curtifolium*	Short-leaved witch grass	Poaceae	NA
Dichanthelium ensifolium (Baldw.) Gould *var. ensifolium*	Small-leaved witch grass	Poaceae	NA
Dryopteris intermedia (Muhl. Ex Willd.) A. Gray	Fancy fern	Dryopteridaceae	FACU
Eleocharis obtusa (Willd.) J.A. Shultes	Blunt spikerush	Cyperaceae	OBL
Euonymus americana L.	Strawberry bush	Celastraceae	FAC
Eriocaulon decangulare L. var. *decangulare*	Ten-angle pipewort	Eriocaulacaea	OBL
Eupatorium fistulosum Barratt	Hollow-stem joe-pye-weed	Asteraceae	FAC
Eupatorium purpureum L. var. *purpureum*	Purple-node joe-pye-weed	Asteraceae	FAC
Fallopia scandens (L.) Holub	Climbing buckwheat	Polygonaceae	FAC

Species	Common name	Family	Wetland status
Galium asprellum Michx.	Rough bedstraw	Rubiaceae	OBL
Hypericum mutilum L. var. *mutilum*	Dwarft St. John's wort	Clusiaceae	FACW
Ilex opaca Ait. var. *opaca*	American Holly	Aquifoliaceae	FAC
Ilex verticillata (L.) A. Gray	Winterberry	Aquifoliaceae	FACW
Impatiens capensis Meerb.	Jewelweed	Balsaminaceae	FACW
Juncus debilis A. Gray	Weak rush	Juncaceae	OBL
Juncus effusus L.	Common rush	Juncaceae	FACW
Juncus tenuis Willd.	Path rush	Juncaceae	FAC
Kalmia latifolia L.	Mountain laurel	Ericaceae	FACU
Lactuca canadensis L.	Canada lettuce	Asteraceae	FACU
Lindera benzoin (L.) Blume	Spicebush	Lauraceae	FACW
Liriodendron tulipifera L.	Tulip poplar	Magnoliaceae	FAC
Ludwigia alternifolia L.	Altemate-leaf seedbox	Onagraceae	OBL
Lycopodium obscurum L.	Common ground-pine	Lycopodiaceae	FACU
Lyonia ligustrina (L.) DC var. *ligustrina*	Northern maleberry	Ericaceae	FACW
Lysimachia lanceolata Walt.	Lanceleaf loostrife	Primulaceae	FAC
Malus angustifolia (Ait.) Michx.	Wild crab apple	Rosaceae	NA
Muhlenbergia schreberi J.F. Gmel.	Nimblewill, dropseed	Poaceae	FAC
Nyssa sylvatica Marsh.	Sour gum, black gum	Nyssaceae	FAC
Osmunda cinnamomea L.	Cinnamon fern	Osmundaceae	FACW
Osmunda regalis L. var. *spectabilis* (Willd). A. Gray	Royal fern	Osmundaceae	OBL
Oxalis stricta L.	Wood sorrel	Oxalidaceae	UPL
Oxydendrum arboreum (L.) DC	Sourwood	Ericaceae	UPL
Parthenocissus quinquefolia (L.) Planch.	Virginia creeper	Vitaceae	FAC
Peltandra virginica (L.) Schott	Green-arrow alum	Araceae	OBL
Persicaria hydropiper (L.) Opiz	Common smartweed	Polygonaceae	OBL
Phytolacca americana L.	Common pokeweed	Phytolaccaceae	FACU
Pinus strobus L.	Eastern white pine	Pinaceae	FACU
Polygonatum biflorum (Walt.) Ell.	Solomon's seal	Convallariaceae	FAC
Polygonum sagittatum L.	Arrowleaf tearthumb	Polygonaceae	OBL
Potentilla simplex Michx.	Old-field five fingers	Rosaceae	FACU
Prunella vulgaris L.	Self-heal	Lamiaceae	FAC
Prunus serotina Ehrh.	Black cherry	Rosaceae	FACU
Pycnanthemum muticum (Michx.) Pers.	Mountain-mint	Lamiaceae	FAC
Quercus rubra L. var. *rubra*	Red oak	Fagaceae	FACU
Quercus velutina Lam.	Black oak	Fagaceae	UPL
Rhexia mariana L. var. *mariana*	Maryland meadow beauty	Melastomataceae	FACW
Rhus copallinum L.	Dwarf sumac	Anacardiaceae	FACU
Rhynchospora glomerata (L.) Vahl. var. *glomerata*	Clustered beaksedge	Cyperaceae	OBL
Rosa palustris Marsh.	Swamp rose	Rosaceae	OBL
Rubus argutus Link	Southern blackberry	Rosaceae	FACU
Rubus hispidus L.	Swamp dewberry	Rosaceae	FACW
Sabatia campanulata (L.) Torr.	Slender marsh pink	Gentianaceae	FACW
Sagittaria latifolia Willd. Var. *pubescens* (Muhl. ex Nutt.) J.G. Sm.	Duck potato	Alismataceae	OBL
Sambucus canadensis L. var. *canadensis*	Elderberry	Adoxaceae	FACW
Salix sericea Marsh.	Silky willow	Salicaceae	OBL
Scirpus expansus Fern. Strong	Woodland bulrush	Cyperaceae	OBL
Sisyrinchium mucronatum Michx.	Blue-eyed grass	Iridaceae	FACW

Species	**Common name**	**Family**	**Wetland status**
Smilax glauca Walt.	Whiteleaf greenbrier	Smilaceae	FAC
Solanum carolinense L. var. *carolinense*	Horse-nettle	Solanaceae	FACU
Solidago patula var. *patula* Muhl. ex Willd.	Bog goldenrod	Asteraceae	OBL
Solidago rugosa P. Miller	Goldenrod	Asteraceae	FAC
Thelypteris noveboracensis (L.) Nieuwl.	New York fern	Thelypteridaceae	FAC
Toxicodendron radicans (L.) Kuntze	Poison ivy	Anacardiaceae	FAC
Trifolium repens L.	White clover	Fabaceae	FACU
Trillium undulatum Willd.	Painted trillium	Trilliaceae	FACU
Vaccinium corymbosum L.	Smooth highbush blueberry	Ericaceae	FACW
Vernonia novaborcensis (L.) Michx.	Ironweed	Asteraceae	FAC
Viburnum cassinoides L.	Viburnum	Adoxaceae	FACW
Viola cucullata Ait.	Bog violet	Violaceae	OBL
Viola primulifolia L.	Primrose-leaf violet	Violaceae	FACW
Vitis labrusca L.	Fox grape	Vitaceae	FAC
Woodwardia areolata (L.) T. Moore	Netted chain fern	Azollaceae	OBL
Xanthorhiza simplicissima Marsh.	Yellowroot	Ranunculaceae	FACW
Xyris torta J.M. Smith	Mountain yellow-eyed grass	Xyridaceae	OBL

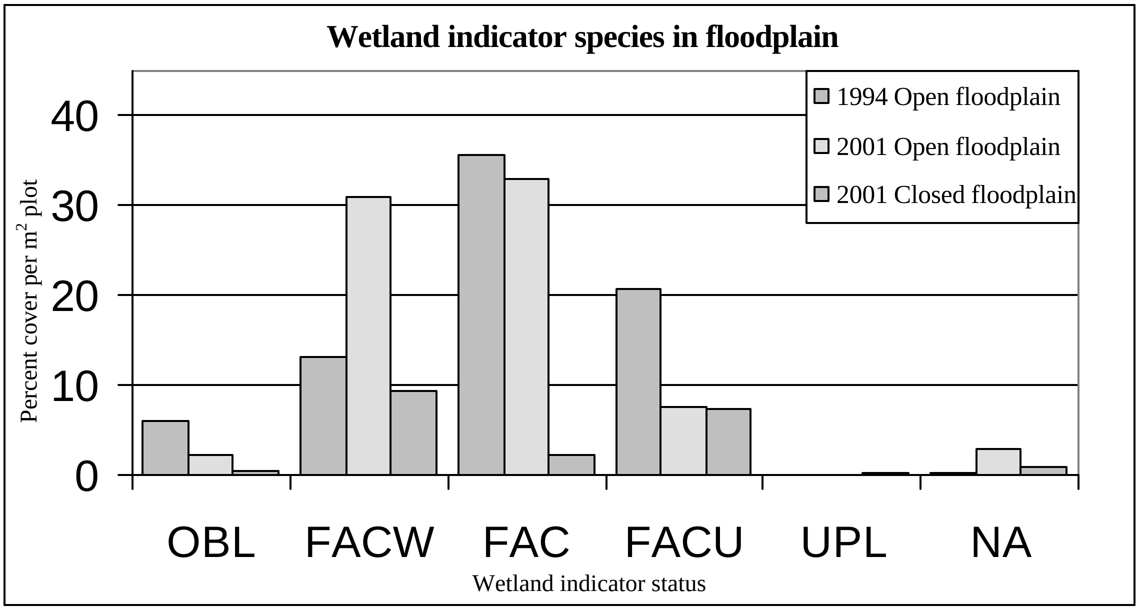
Appendix D. Percent cover (per m^2 plot) of vascular plants recorded in 1994 and 2001 in open and closed fen and floodplain areas of the Tulula Creek wetland complex.

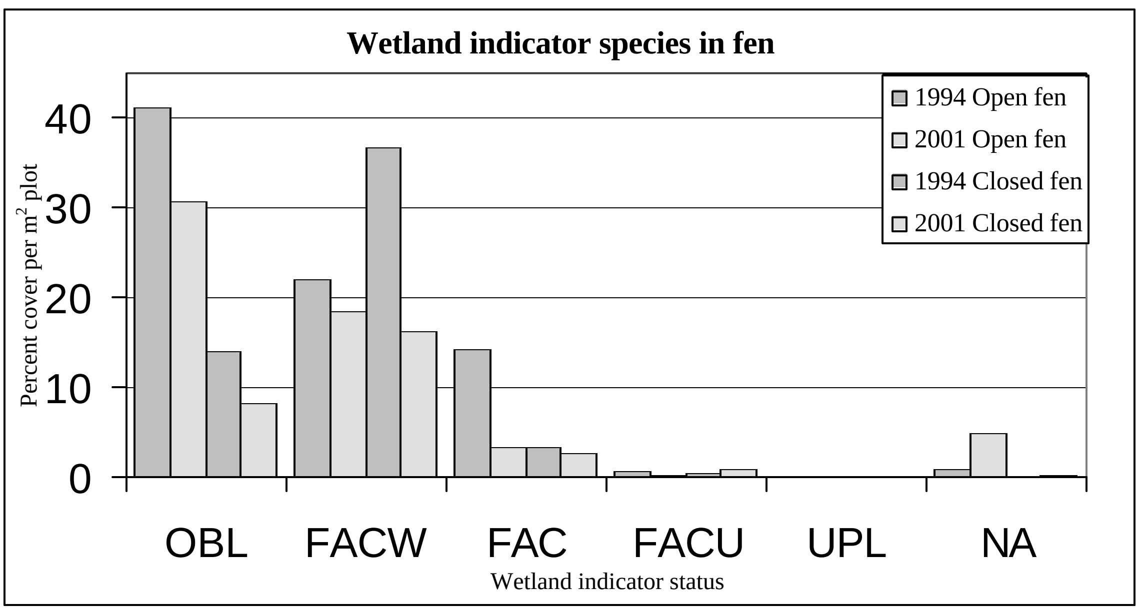
Species	O. floodplain		Open fen		Closed fen		C. floodplain
	1994	2001	1994	2001	1994	2001	2001
Ground Cover							
Acer rubrum L. var. *rubrum*	29	54	20	35	15	5	5
Agalinis purpurea (L.) Pennell	8	0	0	0	0	0	0
Ageratina altissima King & H.E. Robins var. *altissima*	95	0	0	0	0	0	5
Ambrosia artemisiifolia L.	4	0	0	0	0	0	0
Amelanchier laevis Wieg.	0	0	0	0	10	0	20
Apios americana Medik.	4	25	0	0	20	5	0
Arisaema triphyllum L.	0	0	0	0	0	0	5
Aronia arbutifolia (L.) Pers.	0	4	35	45	45	20	25
Aronia melanocarpa (Michx.) Ell.	0	0	20	50	65	75	40
Aster puniceus L.	75	4	5	10	0	0	0
Aster pilosus Willd. var. *pilosus*	71	21	0	0	0	0	0
Aster spp.	4	0	0	0	0	0	0
Athyrium asplenioides (Michx.) A.A. Eat.	0	0	5	10	0	0	0
Calamagrostis coarctata (Torr.) Eat.	0	0	0	5	0	0	0
Carex atlantica Bailey	0	4	5	10	0	0	0
Carex bullata Schkuhr ex Willd.	0	0	10	10	0	0	0
Carex communis Bailey	0	0	0	0	0	0	10
Carex debilis Michx.	0	58	0	0	5	5	0
Carex festucacea Schkuhr ex Willd.	63	4	20	15	5	0	0
Carex intumescens Rudge var. *intumescens*	0	4	0	0	0	0	0
Carex stricta Lam.	4	79	100	100	100	95	20
Chamaecrista nictitans (L.) Moench var. *nictitans*	0	4	0	0	0	0	0
Clematis virginiana L.	0	4	0	0	0	0	0
Cornus amomum P. Miller	4	0	0	0	5	0	0
Cuscuta spp.	4	0	0	0	0	0	0
Cyperinus spp.	8	0	0	0	0	0	0
Danthonia spicata (L.) Beauv. ex Roemer & J.A. Schultes	0	0	0	0	0	5	10
Dichanthelium dichotomum (L.) Gould	96	0	95	0	25	10	5
Dichanthelium clandestinum (L.) Gould	0	4	0	0	0	0	0
Dichanthelium commutatum (J.A. Shultes) Gould	0	0	0	10	0	0	0
Dichanthelium ensifolium (Baldw.) Gould *var. ensifolium*	0	4	0	90	0	0	0
Dichanthelium ensifolium (Baldw.) Gould *var. curtifolium*	0	75	0	0	0	0	0
Dryopteris intermedia (Muhl. Ex Willd.) A. Gray	0	0	0	0	0	0	20
Eleocharis obtusa (Willd.) J.A. Shultes	0	0	10	0	0	0	0
Euonymus americana L.	0	0	0	0	5	15	0
Eriocaulon decangulare L. var. *decangulare*	0	0	5	5	0	0	0
Eupatorium fistulosum Barratt	0	25	0	0	0	0	0

Species	O. floodplain 1994	O. floodplain 2001	Open fen 1994	Open fen 2001	Closed fen 1994	Closed fen 2001	C. floodplain 2001
Eupatorium purpureum L. var. *purpureum*	8	0	0	0	0	0	0
Eupatorium spp.	21	0	0	0	0	0	0
Fallopia scandens (L.) Holub	0	4	0	0	0	0	0
Galium asprellum Michx.	4	4	65	55	25	0	0
Hypericum mutilum L. var. *mutilum*	29	0	10	0	0	0	0
Ilex opaca Ait. var. *opaca*	0	0	0	0	0	0	10
Ilex verticillata (L.) A. Gray	0	0	0	5	0	10	0
Impatiens capensis Meerb.	0	0	0	0	10	0	0
Juncus debilis A. Gray	4	0	15	0	0	0	0
Juncus effusus L.	92	38	65	10	10	0	0
Juncus tenuis Willd.	0	33	0	0	0	0	0
Kalmia latifolia L.	0	4	0	0	0	5	0
Lactuca canadensis L.	0	4	0	0	0	0	0
Lindera benzoin (L.) Blume	0	0	0	0	0	0	40
Liriodendron tulipifera L.	0	0	0	0	0	0	5
Ludwigia alternifolia L.	4	0	0	0	5	0	0
Lycopodium obscurum L.	0	0	0	0	0	0	10
Lyonia ligustrina (L.) DC var. *ligustrina*	0	0	30	40	15	0	25
Lysimachia lanceolata Walt.	29	0	0	0	0	0	0
Muhlenbergia schreberi J.F. Gmel.	0	8	0	0	0	0	0
Nyssa sylvatica Marsh.	0	0	0	0	0	5	0
Osmunda cinnamomea L.	17	21	45	45	95	95	55
Osmunda regalis L. var. *spectabilis* (Willd). A. Gray	0	0	10	15	10	15	15
Oxalis stricta L.	4	4	0	0	0	0	0
Oxydendrum arboreum (L.) DC	0	4	0	0	0	0	0
Parthenocissus quinquefolia (L.) Planch.	0	0	0	0	0	0	5
Peltandra virginica (L.) Schott	49	0	0	0	0	0	0
Persicaria hydropiper (L.) Opiz	0	4	0	0	0	0	0
Phytolacca americana L.	0	0	0	0	0	0	5
Pinus strobus L.	0	4	5	5	10	10	5
Polygonum sagittatum L.	17	4	70	55	25	0	0
Polygonum spp.	4	0	0	0	0	0	0
Polygonatum biflorum (Walt.) Ell.	0	0	0	0	0	0	10
Potentilla simplex Michx.	88	54	0	0	5	0	0
Prunus serotina Ehrh.	0	0	0	0	10	20	65
Pycnanthemum muticum (Michx.) Pers.	0	4	0	0	0	0	0
Quercus rubra L. var. *rubra*	0	0	0	0	0	5	5
Quercus velutina Lam.	0	0	0	0	10	5	20
Rosa palustris Marsh.	0	0	25	30	0	10	0
Rhexia mariana L. var. *mariana*	58	63	0	0	0	0	0
Rhus copallinum L.	0	4	0	0	0	0	0
Rhynchospora glomerata (L.) Vahl. var. *glomerata*	63	0	5	0	0	0	0
Rubus argutus Link	25	33	30	20	30	0	25
Rubus hispidus L.	54	83	95	80	100	100	75
Sabatia campanulata (L.) Torr.	4	0	0	0	0	0	0
Sagittaria latifolia Willd. Var. *pubescens* (Muhl. ex Nutt.) J.G. Sm.	4	0	5	5	0	0	0
Sambucus canadensis L. var. *canadensis*	4	4	15	10	10	10	0

Species	O. floodplain 1994	O. floodplain 2001	Open fen 1994	Open fen 2001	Closed fen 1994	Closed fen 2001	C. floodplain 200
Scirpus expansus Fern. Strong	0	0	0	5	0	0	0
Sisyrinchium mucronatum Michx.	25	21	0	0	0	0	0
Smilax glauca Walt.	0	8	0	0	20	20	50
Solanum carolinense L. var. *carolinense*	0	4	0	0	0	0	0
Solidago rugosa P. Miller	0	63	10	0	5	0	0
Solidago patula var. *patula* Muhl. ex Willd.	0	0	0	30	15	10	0
Toxicodendron radicans (L.) Kuntze	0	0	0	0	0	0	15
Thelypteris noveboracensis (L.) Nieuwl.	0	0	20	15	5	10	0
Trifolium repens L.	0	0	0	0	0	0	5
Trillium undulatum Willd.	0	0	0	0	0	5	10
Vaccinium corymbosum L.	4	0	0	0	0	20	0
Vernonia novaboracensis (L.) Michx.	4	13	0	0	0	0	0
Viburnum cassinoides L.	0	0	0	0	5	0	0
Viola cucullata Ait.	0	0	10	0	10	5	0
Viola primulifolia L.	0	21	15	10	0	0	10
Vitis labrusca L.	29	33	0	25	10	10	0
Woodwardia areolata (L.) T. Moore	0	0	0	5	0	0	0
Xanthorhiza simplicissima Marsh.	0	0	0	0	5	5	0
Xyris torta J.M. Smith	8	4	0	0	0	0	0
Shrub-Layer							
Acer rubrum L. var. *rubrum*	0	x	40	60	55	55	0
Alnus serrulata (Ait.) Willd.	0	x	15	20	5	10	0
Amelanchier laevis Wieg.	0	0	0	5	0	0	0
Aralia spinosa L.	0	0	0	5	0	0	0
Aronia arbutifolia (L.) Pers.	0	0	0	25	0	5	0
Aronia melanocarpa (Michx.) Ell.	0	0	0	10	0	0	0
Ilex opaca Ait. var. *opaca*	0	0	0	0	0	15	30
Ilex verticillata (L.) A. Gray	0	0	0	0	10	15	0
Lindera benzoin (L.) Blume	0	0	0	0	0	0	30
Liriodendron tulipifera L.	0	0	0	5	0	0	5
Malus angustifolia (Ait.) Michx.	0	0	0	0	5	5	0
Nyssa sylvatica Marsh.	0	0	0	5	15	15	0
Oxydendrum arboreum (L.) DC	0	0	0	0	5	5	0
Pinus strobus L.	0	0	5	15	20	30	15
Prunus serotina Ehrh.	0	0	0	5	0	0	5
Rhus copallinum L.	0	x	0	0	0	0	0
Rosa palustris Marsh.	0	0	0	5	0	0	0
Sambucus canadensis L. var. *canadensis*	0	x	0	15	5	0	0
Salix sericea Marsh.	0	0	0	5	0	0	0
Vaccinium corymbosum L.	0	0	0	0	0	5	0
Viburnum cassinoides L.	0	0	0	0	15	10	0
Trees							
Acer rubrum L. var. *rubrum*	0	0	0	10	90	90	95
Ilex opaca Ait. var. *opaca*	0	0	0	0	0	5	25
Malus angustifolia (Ait.) Michx.	0	0	0	0	5	5	0
Pinus strobus L.	0	0	0	0	10	20	45
Prunus serotina Ehrh.	0	0	0	0	0	0	30

Appendix E. Percent ground-layer coverage per m^2 plot of wetland indicator species. Wetland indicator categories are Obligate (OBL), Facultative Wetland (FACW), Facultative (FAC), Facultative upland (FACU), Upland (UPL) and not available (NA).





APPENDIX F. 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 G. Bird Species at Tulula Wetland (1994-2002).
(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*
Eastern Phoebe (1)	*Sayornis phoebe*
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*
Prairie Warbler (1)	*Dendroica discolor*
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*