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ABSTRACT Three sites with populations of federally endangered golden sedge (*Carex lutea* LeBlond) were sampled to investigate whether circumneutral soil conditions were associated with a species distribution restricted to 208 km^2 within two adjacent counties of the lower North Carolina Coastal Plain. Populations were selected to include different soil series found in a state-owned natural area. Observed golden sedge rhizome and root depths among three specimens, one per site, ranged from 6 to 8 cm below the soil surface, which suggested primarily topsoil influence. A total of 96 soil samples, 48 topsoil and 48 subsoil, were collected in transects and analyzed. Mean pH values within populations were very strongly (4.7) to moderately (5.7) acid for topsoils and moderately (5.8) to slightly (6.5) acid for subsoils. These values did not differ significantly inside versus immediately outside each population, but varied among topsoils and subsoils between populations. Other soil variables associated with marl and limestone parent material influence (i.e., cation exchange capacity, base saturation, calcium, and magnesium) did not exhibit any consistent trends either inside versus outside, or between populations. A prior study found a mean soil pH of 6.7 within golden sedge populations, but choices of sample sites and analysis techniques were questionable. Lack of soil specificity for this species encourages both searches for golden sedge populations outside the known range and restoration or enhancement of local populations.

Key words: Circumneutral, golden sedge, narrow endemic, pH, soil factors.

INTRODUCTION Golden sedge (*Carex lutea* LeBlond) is a perennial graminoid known only from eight sites within a 26 km × 8 km area of two adjacent counties, Onslow and Pender, located in the lower coastal plain of North Carolina (United States Fish and Wildlife Service [USFWS] 2010). Relative to field identification, it is most easily distinguished during the months of May and June when "inflated perigynia (sac which encloses the seed) are bright yellow at flowering and about 4 mm to 5 mm long. The perigynia are outcurved and spreading, with the lowermost in a spike strongly reflexed (turned downward)" (USFWS 2007, p. 7; Weakley 2011). This narrow endemic species (LeBlond 2001) has both federal and state endangered status. The United States Fish and Wildlife Service designated golden sedge as a federally endangered species on 22 February 2002 (USFWS 2002) and North Carolina status also was listed as endangered that year by the North Carolina Plant Conservation Program (Buchanan and Finnegan 2010).

Habitat descriptions for golden sedge populations included: (a) pine savannas—very wet clay variant, a natural community with fewer than 10 occurrences; (b) pine savanna–nonriverine swamp forest ecotones; and (c) very wet to saturated soils adjacent to or in shallow drainage ditches (Schafale and Weakley 1990; Schafale 1994; USFWS 2007, 2010). Associated soils were characterized by a relatively high pH compared to typical acidic series found throughout the species range

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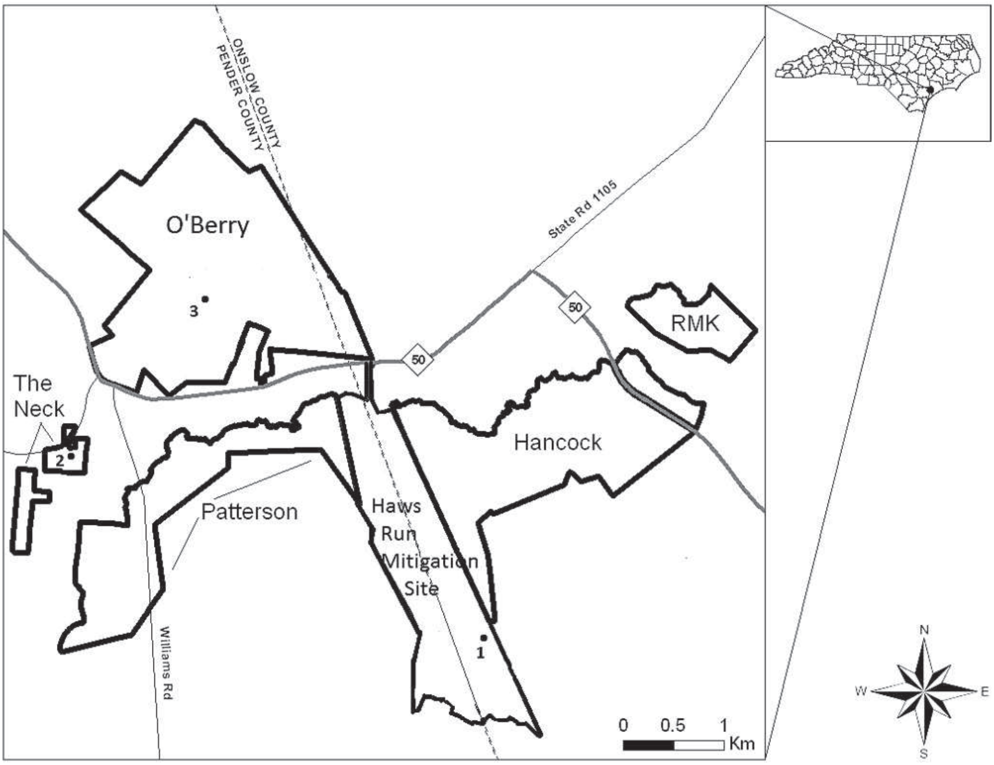

Figure 1. Location of Sandy Run Savannas State Natural Area and its seven constituent tracts in the North Carolina Coastal Plain. Golden sedge populations that were sampled included (clockwise): (1) Haws Run Mitigation Site (34.61349°N, 77.62962°W), (2) The Neck Savanna (34.63033°N, 77.67511°W), and (3) O'Berry Tract (34.64432°N, 77.66257°W).

(LeBlond et al. 1994; USFWS 2007, 2010). The original source of this information was an unpublished study (Glover 1994) that compared soil pH among samples from the type specimen site, The Neck Savanna in Pender County. A mean soil pH of 6.7 was measured within golden sedge populations versus pH 6.3 immediately outside, but sample depth was not specified. Values for pH were determined by the author using a "standard pH electrode" with no mention of buffered standards or quality control procedures.

While the aforementioned type location was associated with an Alfisol in the Grifton series, additional populations were discovered in adjacent tracts mapped as Ultisols, which are typically acidic in soil chemistry (Barnhill 1990, 1992; USFWS 2010). However, the general area of all known populations was underlain by marl and limestone (Barnhill 1990, 1992; Horton and Zullo 1991) that, depending upon depth of occurrence, may have influenced local soil conditions. To resolve this uncertainty, topsoils and subsoils at different golden sedge population locations were sampled to determine if common soil factors were present.

GENERAL STUDY AREA Several golden sedge populations occur within Sandy Run Savannas State Natural Area, which consists of 1,214 ha managed by the North Carolina Division of Parks and Recreation for its floristic diversity and numerous listed species (Taggart 2010). This complex of seven parcels is located between 34.602778° and 34.660556°N and −77.600833° and −77.680556°W in the Cape Fear River Basin (see Figure 1). Geographic center of the constituent tracts is approximately 5.5 km southeast of Maple Hill, North Carolina. All parcels are encompassed by portions of the Folkstone, Haws Run, Maple

Table 1. Soils of golden sedge populations found within Sandy Run Savannas State Natural Area (Barnhill 1990, 1992; USFWS 2010)

Series Name	Taxonomy	Drainage Class
Foreston	coarse-loamy, siliceous, thermic Aquic Paleudult	moderately well drained
Grifton	fine-loamy, siliceous, thermic Typic Ochraqualf	poorly drained
Stallings	coarse-loamy, siliceous, semiactive, thermic Aeric Paleaquult	somewhat poorly drained
Woodington	coarse-loamy, siliceous, thermic Typic Paleaquult	poorly drained

Hill, and Maple Hill SW 7.5 minute quadrangle maps for North Carolina (United States Geological Survey [USGS] 1981). Primary road access is via NC 50 and then by secondary and unpaved roads to the various tracts.

Physical setting was the lower North Carolina Coastal Plain, approximately 25 km from the Atlantic Ocean. Local landscape was comprised of Quaternary sediments underlain by the Castle Hayne formation, an Eocene complex of calcareous marls, fossiliferous limestones, and conglomerates. The formation occurred at variable soil depths, but in some areas within a meter of the soil surface (Miller 1912, Zullo and Harris 1987, Horton and Zullo 1991). Elevations of these properties varied from 1.83 m to 4.27 m above sea level (USGS 1981).

Within Sandy Run tracts, Barnhill (1990, 1992) mapped and described soil series that ranged from very strongly acid, to circumneutral and very poorly drained, to moderately well drained. Four series associated with golden sedge populations (USFWS 2010) found on these properties are detailed in Table 1.

POPULATION SITES Of four soils associated with golden sedge populations at Sandy Run tracts, field assessments determined that three series (i.e., Grifton, Stallings, and Woodington) occurred at sites with healthy plant populations and no evidence of recent soil disturbance. Golden sedge populations selected for sampling are depicted in Figure 1. Areal extent of each soil series mapped at a given site (Barnhill 1990, 1992) was more than adequate to encompass each population plus more than 100 m of buffer before a different series was encountered.

A pine savanna, very wet clay variant (LeBlond 1999), located at the south end of the Haws Run Mitigation Site in Onslow County contained the first population. This locale consisted of approximately 150 flowering-fruiting golden sedge clumps growing an area 20 m × 22 m and mapped as Stallings soil (Barnhill 1992). The site had been cleared and grubbed in the early 1980s, but regenerated to vegetation associated with the aforementioned savanna type (North Carolina Natural Heritage Program [NCNHP] 2011).

The second population was located at The Neck Savanna and encompassed the discovery site of golden sedge (LeBlond et al. 1994) in Pender County, previously sampled by Glover (1994). Only one clump was observed in flower within a 2 m × 12 m former plow line area surrounded by nonriverine swamp forest adjacent to wet pine savanna (Schafale and Weakley 1990, LeBlond 2000). However, Richard LeBlond (species author and retired coastal plain botanist, North Carolina Natural Heritage Program, pers. comm., April 25, 2011), recounted observations of numerous flowering-fruiting plants at that site in past years (NCNHP 2011). The area was underlain by the Grifton series (Barnhill 1990).

Population three was situated on the south side of the main access road within the O'Berry Tract in Pender County. The site contained 13 flowering-fruiting sedge clumps growing in a local depression (10 m × 15 m) with an overstory of shrubs and small trees adjacent to a loblolly pine plantation. This isolated wetland had been bedded, date not available, but not planted (NCNHP 2011). A transition from Foreston to Woodington soil was mapped for this area (Barnhill 1990); however, local relief and profile characteristics indicated the wetter Woodington series (United States Department of Agriculture [USDA] 1999b).

METHODS Golden sedge sample sites were chosen to capture a range of soil series relative to taxonomy and drainage classes (Barnhill 1990, 1992) within the state property. Populations were sampled during May 9, 2010, and April 29 / May 2, 2011, while plants were in flower or fruit. One voucher specimen from each site was collected and deposited in the University of North Carolina at Wilmington Herbarium (WNC). A 1 m soil profile was taken (i.e., using a 7.5 cm in diameter soil auger) adjacent to a given population. Each profile was photographed and examined for comparison to maps and descriptions in county soil surveys (Barnhill 1990, 1992). Four parallel transects, spaced no less than 3 m apart, were established at each population. Within each transect four pairs of topsoil (surface to ca. 20 cm depth) and subsoil (ca. 21 cm to 100 cm depth) core samples were taken: two pairs immediately outside (i.e., ends of each transect) and two pairs inside the population (i.e., no less than 1 m apart). Samples taken per population included 16 topsoil and 16 subsoil with a total number of 96 samples, 48 topsoil and 48 subsoil, from all three populations. Adequate outside sample distances in each transect were determined by lack of golden sedge presence combined with monitoring history for each population (NCNHP 2011). Each sample was obtained by use of a 2.5 cm in diameter soil probe to minimize impacts to sedges and their habitat. Soils were dried and sent to the North Carolina Agronomic Laboratory for analysis. To provide a comparison to state laboratory pH values, 15 random samples (i.e., from soils of the same cores) were analyzed by the lead author at the University of North Carolina at Wilmington using a Vernier LabQuest® unit and pH probe calibrated with a buffered standard (Beaverton, Oregon).

Variables of pH, cation exchange capacity, base saturation, calcium, and magnesium were examined to assess soil reaction and other factors related to potential influence of the underlying Castle Hayne formation (Barnhill 1990, 1992; Brady and Weil 2008). Means were calculated for samples within and immediately outside each of the three populations sampled. A two-way analyses of variance program was used to determine if: (a) soil traits differed inside versus outside golden sedge populations (a location effect), (b) soil traits differed between sites (a site effect), and (c) soil traits were influenced by an interaction among sites and locations (Sokal and Rohlf 1995). A separate analysis was run for each soil variable. When significant differences were found, post hoc comparisons were run using Tukey's Honestly Significant Differences Tests (THSDT) to aid interpretation. All analyses were conducted in R version 2.9.2 (R Development Core Team 2009).

To determine approximate rooting depth for golden sedge, one side of a single sedge clump within each population sampled was excavated to expose rhizomes and roots temporarily. Concern over the endangered status of this species limited more extensive sampling. A measurement was taken from soil surface to rhizome-root maximum depth for each of the three plants. All soil was replaced immediately and water added to minimize impacts.

RESULTS Mean topsoil pH categories (USDA 1998) within the three populations ranged from very strongly acid (4.69) at The Neck to moderately acid (5.66) at O'Berry, while mean subsoil pH ranged from moderately acid (5.79) at The Neck to slightly acid (6.49) at O'Berry (Figures 2 and 3). Spot checks performed at the University of North Carolina at Wilmington on 15 randomly selected residual samples varied no more than three-tenths of a pH unit per sample from the values obtained by the state laboratory.

Two-way analyses of variance gave an array of results among all five soil variables:

1. Topsoil and subsoil pH differed between sites ($p < 0.01$ for both topsoil and subsoil, Figures 2 and 3), but did not differ inside versus outside sedge populations (all $p > 0.21$ for location and the interaction between site and location). Post hoc THSDT indicated that a significant site difference in topsoil and subsoil pH occurred because of differences between The Neck and the other two sites (topsoil: $p < 0.01$ for The Neck versus Haws Run and The Neck versus O'Berry, $p = 0.13$ for O'Berry versus Haws Run; subsoil: $p = 0.02$ for The Neck versus Haws Run and $p < 0.01$ for The Neck versus O'Berry, $p = 0.22$ for O'Berry versus Haws Run).
2. Topsoil cation exchange capacity showed a significant interaction between site and location ($p < 0.01$, Figure 2). According to THSDT, this occurred because cation exchange capacity increased outside The Neck population ($p < 0.01$). This variable was also significantly higher outside pop-

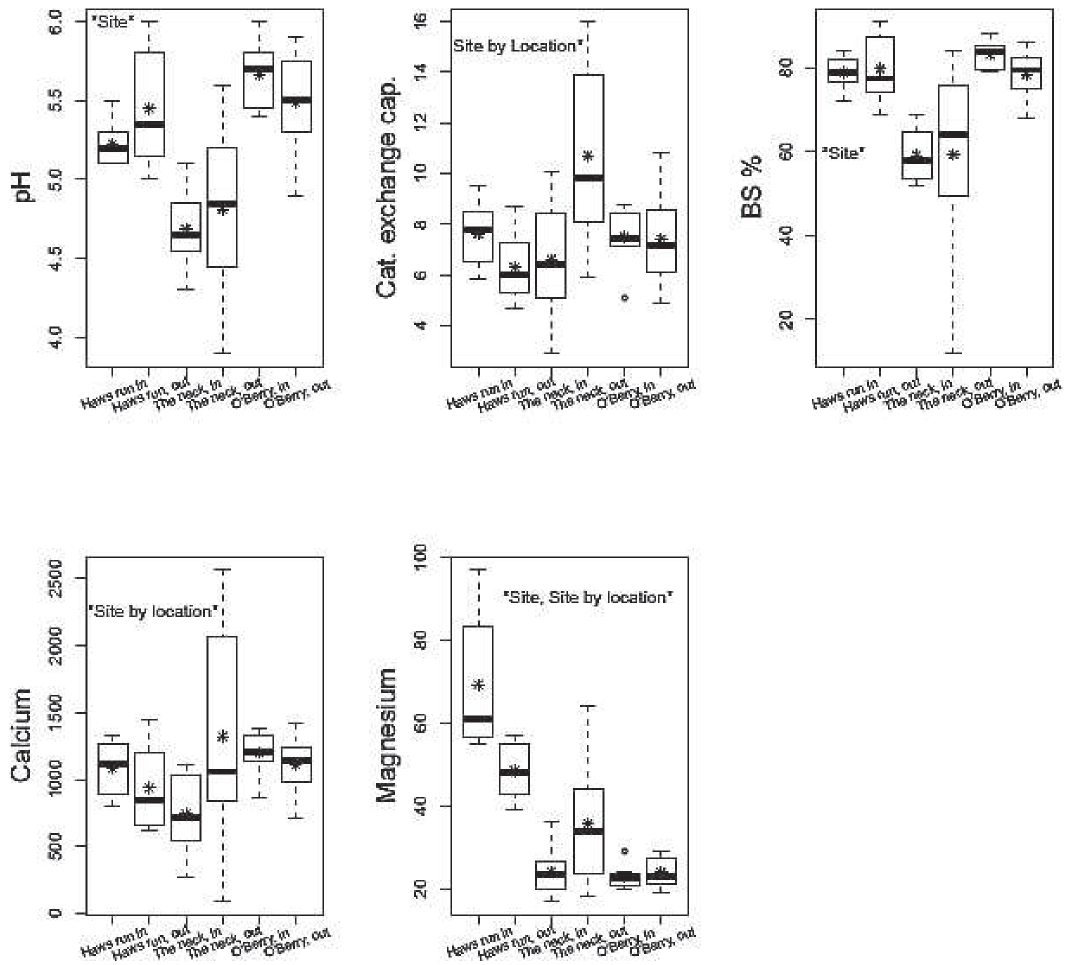

Figure 2. Boxplots for topsoil characteristics within and outside golden sedge populations at three sites investigated. The top and bottom of each box represent 75th and 25th percentiles, the interior dark line is the median, and the star depicts the mean value for each soil variable. Vertical lines above and below boxes represent the smaller of either 1.5 times the interquartile range (difference between values of the 75th and 25th percentiles, approximately two standard deviations), or maximum and minimum values. Circles represent data points that are greater or less than the interquartile range. Significant differences between sites, locations, or their interaction are listed in each panel.

ulations at The Neck than outside populations at Haws Run ($p < 0.01$), and both inside ($p = 0.05$) and outside ($p = 0.04$) populations at O'Berry (p> > 0.05 for all other comparisons). Sites ($p = 0.06$) and the interaction between site and location ($p = 0.09$) showed marginally significant effects on subsoil cation exchange capacity.

3. Base saturation differed between sites for both topsoil and subsoil ($p < 0.01$, Figures 2 and 3), but did not differ significantly among locations ($p = 0.13$ for subsoil and $p = 0.71$ for topsoil). THSDT indicated that The Neck differed from the other two sites in both topsoil ($p < 0.01$ for The Neck versus Haws Run and The Neck versus O'Berry; $p = 0.92$ for O'Berry versus Haws Run) and subsoil ($p = 0.02$ for The Neck versus Haws Run and $p = 0.02$ for The Neck versus O' Berry; $p = 0.99$ for O'Berry versus Haws Run). There was a marginally significant interaction between site and location for base saturation in the subsoil

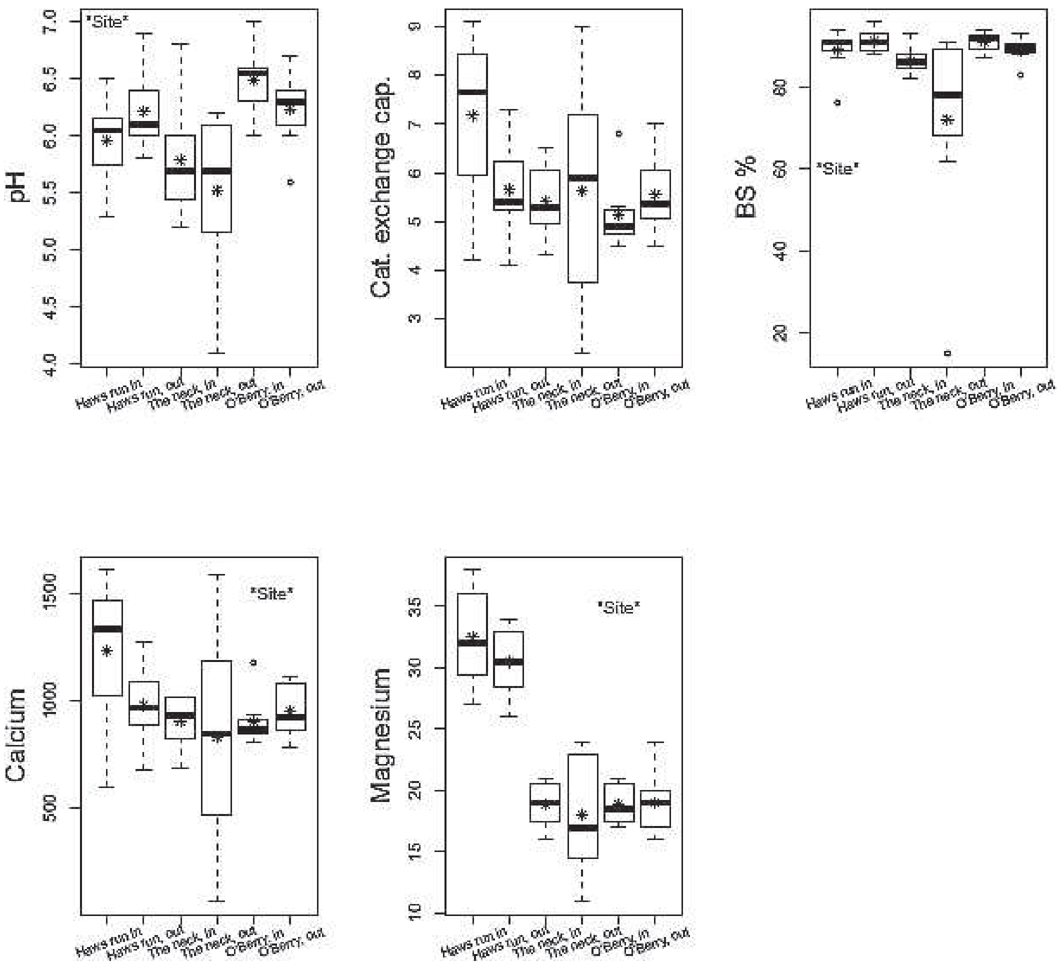

Figure 3. Boxplots for subsoil characteristics within and outside golden sedge populations at three sites investigated. Boxes are as defined in Figure 2. Significant differences between sites, locations, or their interaction are listed in each panel.

($p = 0.09$), but not in the topsoil ($p = 0.74$).

4. Topsoil calcium showed a significant interaction between site and location ($p = 0.03$ for the interaction, $p = 0.59$ for site, and $p = 0.35$ for location, Figure 2) that may have occurred because calcium showed a marginally significant increase outside The Neck population relative to inside the population (THSDT: $p = 0.08$). No other post hoc comparisons were significant (all $p > 0.28$). Subsoil calcium differed between sites ($p = 0.04$), but was not related to location ($p = 0.24$) or the interaction between site and location ($p = 0.30$, Figure 3). A significant site difference occurred because of differences between The Neck and Haws Run populations ($p = 0.04$; $p = 0.16$ for O'Berry versus Haws Run and $p = 0.80$ for The Neck versus O'Berry).
5. While location did not affect topsoil magnesium ($p = 0.36$), there was a significant site effect ($p < 0.01$) and interaction between site and location ($p < 0.01$, Figure 2). This interaction occurred because magnesium decreased outside the Haws Run population relative to inside the population (THSDT: $p < 0.01$), but did not differ between populations, or inside versus outside the populations at The Neck ($p =$

0.23) and O'Berry ($p = 0.99$). THSDT also showed that magnesium inside Haws Run was higher than inside and outside both The Neck and O'Berry populations (all $p < 0.01$). Magnesium outside the Haws Run population was also significantly higher than inside The Neck population and both inside and outside populations at O'Berry (all $p < 0.01$). All other post hoc comparisons did not show significant differences for topsoil magnesium (all $p > 0.13$). Subsoil magnesium differed between sites ($p < 0.01$), but was not affected by location ($p = 0.32$) or the interaction between site and location ($p = 0.64$, Figure 3). This result occurred because magnesium was higher at Haws Run than at the other two sites (both $p < 0.01$), while magnesium did not differ between populations at The Neck and O'Berry ($p = 0.89$).

In summary, these analyses demonstrated no consistent trend of circumneutral soil characteristics either within or between these populations.

Maximum depths of 8 cm, 8 cm, and 6 cm were recorded for three partially exposed golden sedge rhizome and root systems at Haws Run, The Neck, and O'Berry, respectively. Rhizomes were short and produced a cespitose clump of shoots in each plant as described by LeBlond et al. (1994). These measurements suggested that topsoil primarily influenced golden sedges at these sample sites.

DISCUSSION AND CONCLUSION Soil variables sampled at three golden sedge sites did not exhibit circumneutral trends either inside versus outside, or between populations. While our findings were not in agreement with previous botanical literature concerning soil reaction and golden sedge occurrence, they were similar to or slightly higher than established pH and cation exchange capacity characteristics of soil series found within the three Sandy Run populations (Figures 2 and 3; USDA 1999a, 1999b, 2002). Other soil traits sampled (i.e., base saturation, calcium, and magnesium) were not included in official soil series descriptions.

Haws Run mean topsoil and subsoil pH values for the Stallings series were intermediate (5.22 and 5.96) among samples from the three populations. These results were at the high end to slightly above the levels given in the USDA (2002) soil description—3.5 to 5.5 for topsoil and subsoil horizons. Cation exchange capacity means for topsoil and subsoil also were higher (7.61 and 7.16) than expected levels of 1.0 to 6.0 and 1.0 to 3.0.

The Grifton series found at The Neck Savanna was derived from basic parent material, the Castle Hayne formation, but its surface horizons were acidic. The standard profile (USDA 1999a) did not indicate neutral to alkaline soil chemistry until the mid-B horizon, some 80 cm below the surface; however, pH conditions may vary from very strongly acid to neutral (4.5 to 7.3) in the upper horizons (i.e., top 40 cm). Results obtained by Glover (1994) (i.e., pH 6.7 inside versus 6.3 outside populations) at The Neck Savanna were in contrast to our findings at the same site relative to topsoil pH levels and inside versus outside population pH conditions. Mean pH of our samples were acidic both within (4.69) and below (5.79) the observed rooting zone of golden sedge, while topsoil pH was slightly higher immediately outside (4.81) than inside the population. Cation exchange capacity samples were within documented topsoil and subsoil ranges of 5.0 to 15 and 5.0 to 25.0.

Mean topsoil and subsoil pH conditions within the O'Berry tract population were highest of all three sites (5.66 and 6.49—moderately to slightly acid) and beyond the typical Woodington series range of 3.5 to 5.5 (USDA 1999b). Mean cation exchange capacity values of 7.50 (topsoil) and 5.14 (subsoil) within this population were slightly above documented ranges of 2.0 to 7.0 and 1.0 to 4.0.

Shallow depths (i.e., 8 cm or less) of three partially exposed golden sedge rhizome and root systems were consistent with growth forms for cespitose *Carex* species (Bernard 1990). Those observations combined with aforementioned analyses of key soil variables indicated that influence (e.g., unusually high pH) of the underlying Castle Hayne formation on golden sedge occurrence was not consistent or significant within or between these populations.

The disparity between pH results of Glover (1994) and this study for The Neck Savanna was probably due to differences in analyses. The North Carolina State Soils Laboratory analyzed all soil samples in this investigation as a research set with standard quality assurance and quality control protocols, techniques not mentioned in the former study where the investigator determined pH values. Also, lack of samples from other golden sedge populations found in different soil series was a significant difference.

While this study demonstrated that circumneutral soils were not a crucial factor in golden sedge occurrence, the question remained as to why this species was so restricted in distribution. LeBlond (1996) surveyed the status of golden sedge among likely coastal sites (e.g., very wet clay savannas and savanna to swamp forest ecotones during spring-early summer) from North Carolina to Alabama. Target plant populations within those habitats included known golden sedge associates: pineland plantain (*Plantago sparsiflora* Michaux), Thorne's beaksedge (*Rhynchospora thornei* Kral), and Cooley's meadowrue (*Thalictrum cooleyi* Ahles). The latter, a federally endangered species (USFWS 1994), served as an analogous example with an original distribution and habitat preference quite similar to golden sedge. First described over fifty years ago in southeastern North Carolina (Ahles 1959), a disjunct meadowrue population was discovered later in northern Florida (Weakley 2011). However, no golden sedge population outside North Carolina has been found to date.

The known range of this species is only 208 km^2 in two adjacent counties, but its recent (1992) discovery, short flowering-fruiting season, and inconspicuous appearance in the vegetative state could be reasons why it has not been found in other states. The fact that golden sedge does colonize disturbed habitats with acidic soils increases the possibility of occurrence elsewhere. Although highest quality golden sedge populations are found in pristine wet savannas and associated ecotones, populations also occur in drainage ditches, plowlines, and previously bedded sites (USFWS 2010) where light levels and hydrological conditions are presumably conducive for germination and growth. Searches should be made in coastal wet pine savannas, savanna-swamp forest ecotones, and adjacent disturbed wetlands during the late spring to early summer flowering-fruiting season when perigynia are most noticeable. Some time adjustment for anthesis likely will be necessary as one proceeds north or south from the current known range. If additional populations are found, associated environmental conditions can be compared to those in Onslow and Pender counties in North Carolina to further inform life history, distribution, and stewardship of this narrow endemic endangered species.

Finally, these results encourage golden sedge restoration and enhancement possibilities within its known range. Wet savannas and associated ecotones, including those with past soil alterations, in moderately well-drained to poorly drained Alfisol and Ultisol series are likely habitats regardless of soil pH. Overstory control by fire or mechanical means is essential for adequate population maintenance.

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