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The University of West Florida campus ecosystem study: the college/university campus as a unit for study of the ecology of longleaf pine

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Abstract
College and university campuses comprise a unique urban interface. Property used to establish the University of West Florida (UWF) in Pensacola, Florida, contained numerous ecological features, including natural areas with remnant longleaf pine stands that had undergone recovery from extensive regional logging. The two most prominent of these were studied to quantify the effects of chronic fire exclusion on longleaf pine stands. We addressed these questions: (1) how does composition and structure vary between areas? (2) how do soil characteristics vary between areas and change under fire exclusion? (3) what is the size structure of longleaf pine on the UWF campus? (4) how does the status of longleaf pine at the UWF campus compare to campuses of other colleges/universities within the nature range of longleaf pine? Fifteen 0.04 ha circular plots were established in each area to assess composition and structure and sample mineral soil. All live stems ≥2.5 cm diameter at breast height (DBH) in each plot were identified to species and measured for DBH to the nearest 0.1 cm. Mineral soil was taken to a 5-cm depth, air dried, and analyzed for pH, organic matter, cation exchange capacity, extractable macro- and micronutrients, and extractable aluminum. Basal area and density were closely similar between the natural areas, as was canopy dominance (live oak and longleaf pine), but with contrasting sub-dominant species. Soil analyses revealed no significant differences between natural areas, but suggested that fire exclusion decreased soil organic matter and fertility with establishment of hardwood species. Diameter structure of longleaf pine contrasted sharply between natural areas and with the main campus, suggesting different land-use history. The wide array of approaches to longleaf pine ecology by colleges/universities within its natural range indicates the importance of establishing a longleaf pine consortium to coordinate information.

Keywords College campus urban interfaces · Longleaf pine · Fire exclusion · Plant-soil interactions

Introduction

In several respects, the campuses of colleges and universities comprise a unique type of urban interface, considering their array permanent construction—dormitories, administrative buildings, classrooms, academic departments—along with often vast parking lots and green spaces, e.g., quadrangles and gardens (Turner 1984; Roman et al. 2017). Accounts date at least as far back as Charles Dickens, who once remarked upon a visit to Yale University that the campus was something to "…bring about a kind of compromise between town and country…" (Dickens 1842). Although some universities have experimental forested areas (i.e., university forests) for teaching and research, e.g., the Duke Forest of Duke University (Lynch 2006), in the present context we distinguish between those and the sylvan areas of on-campus green spaces (Copenheaver et al. 2014; Roman et al. 2017). For both recreational and educational use, many campuses have established arboreta, e.g., the Coker Arboretum at the University of North Carolina—Chapel Hill (Henderson 1949), typically with tree species native to the region.

Initial construction of the University of West Florida campus in Pensacola in 1963 began on a 405-ha area with numerous ecological features, including a small bayou, wetlands, and hummocks. Most prominently, however, it included second-growth longleaf pine stands that had undergone recovery from extensive logging in that region of the Florida Panhandle (Knight et al. 2011). John E. Jarvis, Jr., campus designer, had been particularly influenced by the architectural

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philosophy of the Scottish landscape architect Ian L. McHarg, and used an approach to this new campus that would eventually be articulated in the title of McHarg's classic book, *Design with Nature*, now in its 25th edition (McHarg 1995). Thus, campus design was originally envisaged to maintain these ecological features to the extent possible. This not only included minimizing the cutting of trees (virtually all of which were native species characteristic of the region, e.g., species of pine, oak, and magnolia), but also maintaining as much of the original contour as possible while creating buildings and paved areas, including roads, sidewalks, and parking lots (Marse 2007; Jarvis 2008).

The UWF campus currently extends just under 1000 ha, most of which is maintained in an undeveloped state. In fact, the vascular plant flora of the campus comprises nearly 900 species (with specimens in the UWF Michael I. Cousens Herbarium), anecdotally the largest flora of any college/university campus in the eastern United States. Contemporaneous with construction was the establishment of natural areas with non-paved, low-impact hiking trails. The two most prominent were the Edward Ball Nature Trail and the Baars-Firestone Nature Trail (now, Baars-Firestone Wildlife Sanctuary).

The intimate relationship between fire and the life history of longleaf pine (*Pinus palustris*), with its natural range closely sympatric with the Coastal Plain of the southeastern United States (Fig. 1), is long established and well understood (Chapman 1932, Heyward 1939, Platt et al. 1988, Gilliam and Platt 2006); early observations date as far back as the travels of eighteenth century naturalist William Bartram (Bartram 1791). Indeed, fire in the southeastern Coastal Plain spanning the past 0.5 to 1 million years has selected for a unique physiognomy composed of numerous species of plants that both are fire dependent and typically produce considerable inflammable aboveground biomass (Kirkman and Jack 2018); longleaf pine is likely the best example of such a fire-adapted species. In their unaltered, frequently-burned state, longleaf pine stands occur as savannas with a simple physiognomy (Noel et al. 1998; Platt 1999; Platt et al. 2006b), comprising the sparse pines in a monospecific overstory along with an often-dense herbaceous ground cover (Platt et al. 1988, 2006a; Gilliam et al. 2006).

Not unlike forest types throughout the eastern United States (Gilliam 2016), old-growth stands of longleaf pine that have avoided anthropogenic alteration are rare (Barton and Keeton 2018). Among the better representations of old-growth longleaf pine are the Wade Tract of southern Georgia (Platt et al. 1988) and vast areas of Eglin Air Force Base in northwest Florida (Provencher et al. 2003; Hiers et al. 2007; Kirkman and Jack 2018), the latter of which is approximately 60 km east of the UWF campus. As already described, these stands display widely open canopies, with occasional clusters of deciduous scrub oaks, such as turkey oak (*Quercus laevis*), post oak (*Q. margaretta*), or blackjack oak (*Q. marilandica*). These species are kept low in importance under frequent fire regimes, but can quickly recover during chronic fire exclusion (Gilliam et al. 1993; Gilliam and Platt 1999). Frequent fire not only maintains the open matrix of longleaf pine stands, but also allows for the proliferation of ground cover species (Fig. 2).

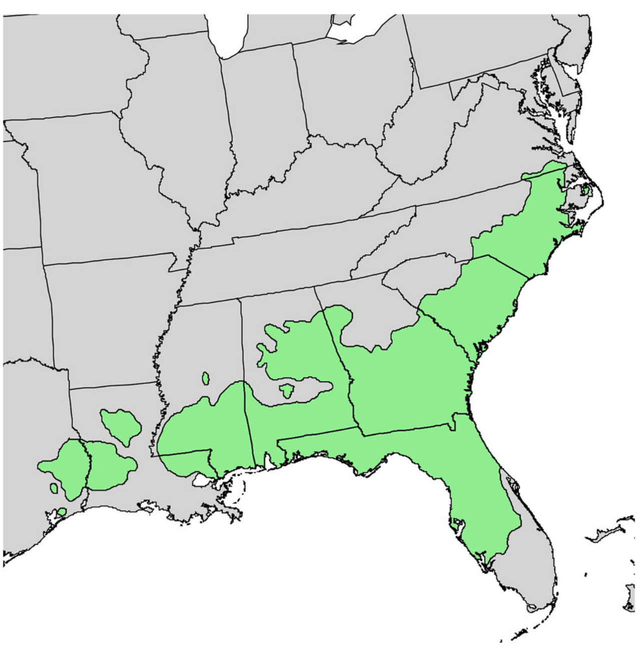

Fig. 1 Geographic range of longleaf pine (www.plants.usda.gov)

Fig. 2 Characteristic physiognomy of a second-growth longleaf pine stand under conditions of frequent fire (annual to biennial) at Weymouth Woods Sandhills Nature Preserve, Moore County, North Carolina. Note the monospecific canopy with wide spacing of longleaf stems

Because urban interfaces, especially those involving college campuses, often necessitate fire exclusion (Francos et al. 2019), the longleaf pine stands occupying the natural areas of the UWF campus have undergone the establishment of hardwood species that have filled their otherwise open matrix (Fig. 3). One facet of the initial phase of the present study investigating the ecology of the UWF campus reported that increased prominence of hardwoods in these longleaf stands has confined populations of gopher tortoise (*Gopherus polyphemus*) to the open areas of powerline right-of-ways (Fig. 4). Gopher tortoises, often a keystone species in longleaf pine ecosystems, require the open physiognomy of frequently burned stands (Berish and Leone 2014; Castellón et al. 2018; Goodman et al. 2018; Knapp et al. 2018). Another facet of the earlier study estimated the age of all longleaf pines (~2200 individual stems) on the main UWF campus (i.e., including areas of permanent structures, roads, parking lots, green spaces, but excluding undeveloped natural areas). Those data yielded an age structure comporting with the land-use history of the region that saw the cessation of widespread logging throughout northwest Florida between 1870 and 1930 (Knight et al. 2011; Gilliam et al. 2020a).

Other colleges and universities within the natural range of longleaf pine have examined longleaf pine in campus settings, though in ways that contrast with the approach of the present study at UWF. Because of the degraded nature of longleaf pine throughout its range from a variety of land-use practices, including fire exclusion (as discussed herein), conversion to agriculture and plantation forestry, and urbanization, many of these studies have focused on restoration, e.g., Stetson University (DeLand, Florida—Cole and Bennington 2017) and Berry College (Mount Berry, Georgia—Cipollini et al. 2019). Fortunately, many of these campuses, including UWF, have received the designation of Tree Campus USA by the Arbor Day Foundation, which shows the commitment of each college/university to maintaining the integrity of campus trees in general and, within its range, longleaf pine in particular. The Foundation has established five standards that must be met for the designation of Tree Campus USA: (1) a Campus Tree Advisory Committee, (2) a Campus Tree Care Plan, (3) a campus tree program with a dedicated annual budget, (4) observance of Arbor Day, and (5) a service learning project.

Fig. 3 Canopies of two longleaf pines in the natural area off of the Edward Ball Nature Trails at the University of West Florida. These pines are part of the second-growth forest landscape within which the UWF campus was constructed. Note the wide spacing of the pines, typical for longleaf stands, but also the hardwoods (principally *Quercus virginiana* here) filling in an otherwise wide canopy opening

Fig. 4 Open area adjacent to the Edward Ball Nature Trails depicting the more typical physiognomy likely present at the time of campus construction. Note individuals of longleaf pine in earlier life history stages

The purpose of this research was to examine further the ecology of the UWF campus to quantify the effects of chronic fire exclusion on longleaf pine stands of its two primary natural areas: Edward Ball Nature Trails and Baars-Firestone Wildlife Sanctuary. In particular, we addressed the following questions: (1) what is the composition and structure of unburned longleaf stands of the two areas? (2) how does soil fertility vary between natural areas and change under fire exclusion? (3) what is the size structure of longleaf pine in each natural area and how does that compare to that previously found on the main UWF campus? (4) how does the status of longleaf pine at the UWF campus compare to campuses of other colleges/universities within the nature range of longleaf pine?

Methods

Study site

This study was carried out at two natural areas on the campus of the University of West Florida (UWF), Pensacola, Florida: the Edward Ball Nature Trails (30° 33′ 8" N, 87° 13′ 29" W) and the Baars-Firestone Wildlife Sanctuary (30° 32' 38" N, 87° 12′ 6" W). Construction of the campus was initiated in 1963 in ~400 ha of second-growth longleaf pine uplands, accompanied by mixed southern hardwood species, e.g., particularly live oak (*Quercus virginiana*) and southern magnolia (*Magnolia grandiflora*). John Jarvis, campus designer, described construction of the campus—buildings, roads, and parking lots—to be "designed to fit into the natural landscape…significant trees were left in place…woven into the natural contours" (Jarvis 2008). In addition, considerable portions of the UWF campus were designated to remain as natural areas through which trails were established for hiking and other outdoor activities, including the areas of this study.

Field sampling

In each of the two sample areas, 15 circular plots were randomly located to assess forest stand composition and structure and sample mineral soil. Each plot was 11.3 m in radius (0.04 ha in area). All live woody stems ≥2.5 cm diameter at breast height (DBH) were identified to species and measured for DBH to the nearest 0.1 cm. Confirmations of plant identifications were made with specimens from the Michael I. Cousens Herbarium of the University of West Florida (UWFP—James R. Burkhalter, curator).

Mineral soil was taken to a 5-cm depth within each plot with a 2-cm diameter soil corer. To capture spatial heterogeneity within each plot, five cores were taken randomly from throughout the plot and combined in sterile polyethylene Whirl-Pak® bags to yield a single composite sample per plot. Soil was air-dried to a constant weight, shipped to the University of Maine Soil Testing Service and Analytical Laboratory, and analyzed for cation exchange capacity (CEC), organic matter (OM—loss on ignition), and pH ($CaCl_2$ buffer). Following KCl extraction, available NH_4^+ and NO_3^- were determined colorimetrically by Flow Injection Analysis. Elemental analyses included P, Ca, Mg, K, Mn, and Al determined via inductively coupled plasma optical emission spectrometry following extraction with NH_4Cl.

Data analysis

To assess variation in plant communities among areas—Nature Trails vs Wildlife Sanctuary—DBH data were converted to basal area and density of each species to construct importance value tables. Means of soil variables were compared among sites and open areas adjacent to the Nature Trails which were occupied by several gopher tortoise burrows (published in Gilliam et al. 2020a) via analysis of variance, followed by least significant difference tests (Zar 2009). These open areas have widely dispersed longleaf pine regeneration, with numerous grass stage juveniles and stem-elongation stage saplings (Fig. 4). Thus, soils of these open areas were assumed to be characteristic of soil of the longleaf pines prior to hardwood establishment. To assess more completely variation in forest composition and soil fertility between sites, tree and soil data were subjected to canonical correspondence analysis using Canoco 5.11, Windows release (5.12) (Šmilauer and Lepš 2014).

In addition to characterizing stand composition and structure, further focus was placed specifically on diameter data for longleaf pine stems, to compare longleaf size structure between natural areas and the main UWF campus, the latter being the subject of the first phase of the broader study (Gilliam et al. 2020a). Size structure was determined by constructing histograms of relative numbers of stems within each of 10-cm size classes, ranging from 0 to 80 cm DBH.

Results and discussion

Stand structure and composition

The two natural areas of the campus of the University of West Florida exhibited numerous patterns of both similarity and contrast with respect to stand structure and species composition. Although these are clearly remnant longleaf pine stands, live oak was the dominant species (based on IV) for both areas and primarily for the same reason—high stem density—well within the range for oak-invaded longleaf stands under chronic fire exclusion (Varner et al. 2005; Hiers et al. 2014). Addington et al. (2015) demonstrated that this process of increased presence of hardwood species can be highly site dependent, not only with fire frequency (lower frequencies yielding greater hardwood cover), but also with soil texture and slope. In addition, the natural areas had nearly identical total basal area and density, approximately 30 m^2/ha and 1200 stems/ha, respectively (Tables 1, 2). Mean species richness (S), evenness (J), and Shannon-Wiener index (H′) also did not vary significantly between areas: 7.6 ± 0.4 species/plot, 0.73 ± 0.02, and 1.46 ± 0.07 for S, J, and H′, respectively. Finally, other than Mn, there were also no differences between natural areas with respect to soil fertility, including organic matter, pH, cation exchange capacity, and extractable nutrients (Table 3).

Thus, both natural areas are characterized as live oak/ longleaf pine communities. In contrast, notable differences were found between the two areas with respect to

Table 1 Importance values (IV) for woody species at the Edward Ball Trails on the campus of the University of West Florida. IV for each species is based on the mean of relative basal area (BA) and relative density (D)

Species	Basal Area m^2/ha	Density stems/ ha	Relative BA %	Relative D %	IV %
Quercus virginiana	13.4	573	44.1	46.8	45.4
Pinus palustris	13.4	175	44.3	14.3	29.3
Q. nigra	1.2	78	3.9	6.4	5.1
Ilex vomitoria	0.1	100	0.4	8.2	4.3
Lagerstroemia indica	0.3	83	0.9	6.8	3.9
Magnolia grandifolia	1.0	43	3.4	3.5	3.5
Vaccinium arboreum	0.1	78	0.5	6.4	3.4
Q. marilandica	0.3	27	1.1	2.2	1.6
Oxydendrum arboreum	0.2	22	0.7	1.8	1.2
I. opaca	<0.1	15	0.1	1.2	0.7
Liquidambar styraciflua	0.1	5	0.2	0.4	0.3
Symplocos tinctoria	<0.1	7	0.1	0.5	0.3
Q. falcata	0.1	3	0.3	0.3	0.3
Magnolia virginiana	<0.1	5	0.1	0.4	0.3
Prunus umbellata	<0.1	3	0.1	0.3	0.2
Hamamelis virginiana	<0.1	3	<0.1	0.3	0.1
Aralia spicata	<0.1	2	<0.1	0.1	0.1
Q. alba	<0.1	2	<0.1	0.1	0.1
Total	30.3	1225	100.0	100.0	100.0

subdominant species. For the Nature Trails, these were water oak (*Quercus nigra*), yaupon (*Ilex vomitoria*), and crape myrtle (*Lagerstroemia indica*), the latter being the only non-native species encountered at either site (Table 1). Crape

Table 2 Importance values (IV) for woody species at the Baars-Firestone Wildlife Sanctuary on the campus of the University of West Florida. IV for each species is based on the mean of relative basal area (BA) and relative density (D)

Species	Basal area m^2/ha	Density stems/ ha	Relative BA %	Relative D %	IV %
Quercus virginiana	10.6	422	36.0	35.2	35.6
Pinus palustris	12.2	113	41.1	9.5	25.3
Magnolia grandifolia	2.6	143	8.9	12.0	10.4
Magnolia virginiana	0.5	190	1.7	15.9	8.8
Vaccinium arboreum	0.7	155	2.4	13.0	7.7
Ilex vomitoria	0.1	55	0.2	4.6	2.4
Q. falcata	0.9	18	3.2	1.5	2.4
Q. marilandica	0.7	20	2.4	1.7	2
Fagus grandifolia	0.1	25	0.4	2.1	1.3
Q. nigra	0.4	12	1.4	1.0	1.2
Nyssa sylvatica	0.3	8	1.1	0.7	0.9
I. opaca	<0.1	15	0.1	1.3	0.7
Q. alba	0.2	3	0.7	0.3	0.5
Oxydendrum arboreum	<0.1	8	0.1	0.7	0.4
P. serotina	0.1	5	0.3	0.4	0.4
Prunus serotina	<0.1	2	<0.1	0.1	0.1
Myrica cerifera	<0.1	2	<0.1	0.1	0.1
Total	29.6	1197	100.0	100.0	100.0

Table 3 Means (± 1 SE) of soil variables for sampling sites (Trails and Sanctuary—see Methods) versus open longleaf matrix adjacent to Trails. Values in bold are for variables exhibiting significant differences (P < 0.05), based on analysis of variance. Means for a given variable with the same superscript are not different at $P < 0.05$. For convenience, arrows indicate significant increases (↑) and decreases (↓) for Trails/Sanctuary means relative to Matrix means

Soil variable	Matrix	Change	Trails	Sanctuary
Organic matter (%)	**2.03 ± 0.13[a]**	↓	**1.50 ± 0.11[b]**	**1.37 ± 0.13[b]**
Cation exchange capacity (meq/100 g)	1.51 ± 0.17		1.31 ± 0.12	1.05 ± 0.10
pH	**5.37 ± 0.08[a]**	↓	**4.67 ± 0.04[b]**	**4.77 ± 0.05[b]**
NH_4-N (μg/g)	2.60 ± 0.43		3.65 ± 0.30	2.69 ± 0.13
NO_3-N (μg/g)	0.23 ± 0.05		0.30 ± 0.02	0.37 ± 0.04
P (μg/g)	**0.37 ± 0.03[b]**	↑	**0.51 ± 0.02[a]**	**0.44 ± 0.01[ab]**
Ca (μg/g)	**175.2 ± 36.1[a]**	↓	**21.9 ± 1.8[b]**	**24.8 ± 7.7[b]**
K (μg/g)	**16.8 ± 1.9[a]**	↓	**7.8 ± 0.4[b]**	**6.0 ± 0.5[b]**
Mg (μg/g)	**22.1 ± 2.5[a]**	↓	**5.6 ± 0.4[b]**	**5.5 ± 0.9[b]**
Mn (μg/g)	**6.42 ± 0.54[a]**	↓	**3.51 ± 0.65[b]**	**0.91 ± 0.18[c]**
Al (μg/g)	**52.0 ± 3.8[b]**	↑	**117.9 ± 6.1[a]**	**112.5 ± 5.6[a]**

myrtle is a common ornamental species and its presence supports the urban interface represented by the UWF campus (Francos et al. 2019; Gilliam et al. 2020a). For the Wildlife Sanctuary, these species were flowering magnolia (*Magnolia grandifolia*), sweet bay (*Magnolia virginiana*), and farkleberry (*Vaccinium arboreum*) (Table 2). Daubenmire (1990) found flowering magnolia and live oak to be prominent components of forests in many regions of Florida.

Multivariate analysis confirms these patterns of similarities and contrasts (Fig. 5). The wide separation of points (plots) in ordination space along with gradients of soil organic matter and nitrogen availability is driven largely by contrasts of subdominant species among plots of the two areas (T and S for Nature Trails and Wildlife Sanctuary, respectively), e.g., the occurrence of southern magnolia and sweet bay (*Magnolia virginiana*) among the S plots, along with numerous species of low relative frequency. There was, however, also considerable overlap among plots, which is further evidenced by the overwhelmingly dominant longleaf pine and live oak that are essentially at the center of ordination space (Fig. 5).

Soil fertility

In addition to comparing soil variables between the Nature Trails and Wildlife Sanctuary, we also compared these data to those of the previous study (Gilliam et al. 2020a) that used identical sampling and analytical methodology for soil in the open matrix (as depicted in Fig. 4) to assess the potential effects of fire exclusion-mediated changes in forest composition and structure on soil fertility. Certainly, this makes the untestable assumption that current soil conditions for the open matrix approximates those of the pre-fire exclusion period. Validity of this assumption is supported, at least in part, by the obviously vigorous regeneration of longleaf pine (Fig. 4) that would have occurred these sites prior to the period of chronic fire exclusion.

As is common in this region, soils of the study areas comprise deep, coarse-textured sand, low in organic matter (OM) and cation exchange capacity (CEC). In their study of soils impacted by gopher tortoises in Florida sandhills communities, Kaczor and Hartnett (1990) reported soil OM of less than 2%. This contrasts with soils of old-growth longleaf pine (3–4%, Gilliam and Platt 1999) and even more sharply with

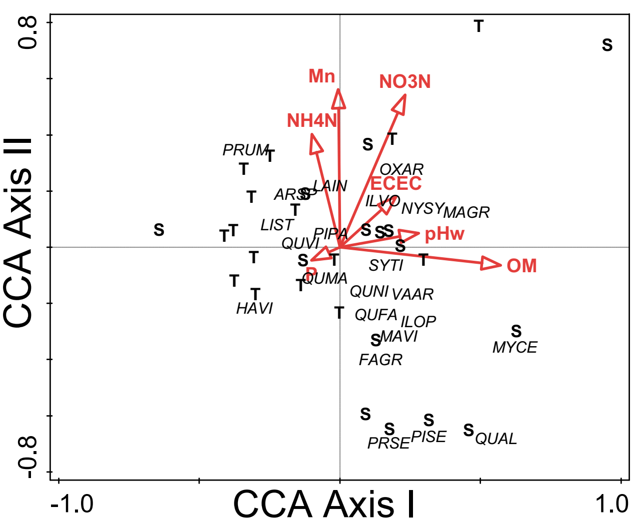

Fig. 5 Canonical correspondence analysis of soil variables and tree species for Nature Trails (T) and Wildlife Sanctuary (S) sites. For vectors, element symbols are extractable concentrations of stated elements, 'ECEC' is effective cation exchange capacity, 'OM' is organic matter, and 'pHw' is H_2O-extractable soil pH. Species are indicated by four-letter codes: *Aralia spicata* (ARSP), *Fagus grandifolia* (FAGR), *Hamamelis virginiana* (HAVI), *Ilex opaca* (ILOP), *Ilex vomitoria* (ILVO), *Lagerstroemia indica* (LAIN), *Liquidambar styraciflua* (LIST), *Magnolia grandifolia* (MAGR), *Magnolia virginiana* (MAVI), *Myrica cerifera* (MYCE), *Nyssa sylvatica* (NYSY), *Oxydendrum arboreum* (OXAR), *Pinus palustris* (PIPA), *Pinus serotina* (PISE), *Prunus serotina* (PRSE), *Prunus umbellate* (PRUM), *Quercus alba* (QUAL), *Quercus falcata* (QUFA), *Quercus marilandica* (QUMA), *Quercus nigra* (QUNI), *Quercus virginiana* (QUVI), *Symplocos tinctoria* (SYTI), *Vaccinium arboretum* (VAAR)

eastern hardwood forests, which typically range between 10 and 15% (Gilliam et al. 2020b). Accordingly, it may have been expected that fire exclusion—which led to extensive establishment of hardwood trees in the remnant longleaf stands—would have led to increases in soil OM from increased litterfall from trees. Quite the contrary, although soil OM was not different between natural areas, it was significantly lower there than in the open matrix (Table 3), suggesting that fire exclusion has led to a decrease in soil OM. This is likely because most OM in these coarse-textured sands arises from turnover of dense fine roots from predominant grass species, such as broomsedge (*Andropogon virginicus*), wiregrass (*Aristida stricta*), and bluegrass (*Poa* spp.) (West et al. 2004), which are prominent in the open matrix and decline rapidly during fire exclusion.

Soil acidity appeared to increase under fire exclusion, with the pH of matrix soil >0.5 unit higher than both natural areas (Table 3), likely resulting from two simultaneous acidifying processes. The first is related to the nature of forest litter, with both longleaf pine and live oak producing acidic litter which accumulates on the forest floor, allowing organic acids to leach into the A horizon. In addition, Moore et al. (2016) found that live oak canopies acidify throughfall by as much as 0.5 pH unit.

The second acidifying process is related to the high nutrient demand of trees relative to herbaceous plants (Muller 2014). Cation uptake by plants occurs via exchange of H^+ for cations on exchange sites and, thus, acidifies the rhizosphere (Marschner 2012). During extensive hardwood establishment under chronic fire exclusion, soil nutrients, especially the base cations Ca, Mg, and K, would have been taken up in great quantity. Furthermore, as demonstrated by Schroth et al. (2007), hardwoods, which currently represent ~55–60% of the basal area for both areas (Tables 1 and 2), have a higher demand for base cations, particularly Ca and Mg, than do conifers. This second mechanism is supported by significantly lower Ca, Mg, and K in forest versus matrix soil (Table 3). Finally, increased acidity is synergistically related to higher Al in forest soils, i.e., in contrast to the base cations, Al is an acid cation, simultaneously acidifying the soil and becoming more mobile under acidic conditions (Gilliam et al. 2020b).

Longleaf pine size-class distributions

Diameter size-class distributions for longleaf pine appeared generally similar among the main campus and the Wildlife Sanctuary and Nature Trails sites. Data for all three exhibited a strong central tendency, with ~40% or more stems occurring in the 30–40 cm class for all three sites (Fig. 6). Closer inspection, however, revealed contrasts between Wildlife Sanctuary and Nature Trails. Whereas >30% of stems were in classes greater than 30–40 cm for the Wildlife Sanctuary, only ~10% were greater than 30–40 cm for the Nature Trails (Fig. 6). Results also suggest a closer similarity of the Wildlife Sanctuary to the main campus than the Nature Trails. Median DBH was 35.0 and 37.1 cm for the main campus and Wildlife Sanctuary, respectively, and 31.2 cm for the Nature Trails (Table 4). Mean DBH did not vary significantly between the main campus and Wildlife Sanctuary (34.4 ± 0.2 and 35.9 ± 1.1 cm, respectively), but means for both were significantly higher ($P < 0.05$) than the Nature Trails (30.9 ± 0.8 cm) (Table 4).

Such patterns of similarity and contrast yields two conclusions. The general overall similarities (e.g., Fig. 6) support the findings of Gilliam et al. (2020a), which was based on DBH measurements of 2165 stems, that the pines throughout the UWF campus are remnants of the cessation of wide-spread harvesting of longleaf pine in this region over a century ago (Knight et al. 2011). Sharp contrasts between the Sanctuary and Trail sites (Table 4), however, suggest that the two natural areas, which occur on opposite sides of the campus and are ~2 km apart, were likely originally property of different ownership and contrasting land-use history.

Longleaf pine at other colleges/universities in its range

Like UWF, numerous other college and university campuses occur within the natural range of longleaf pine. The following is an overview of the status of longleaf pine of several of these. This is intended to neither be an exhaustive account of all campuses, nor of all available information for a given campus. Rather, this is intended to provide a general picture of campuses within this range.

The campus of Berry College is vast (10,900 ha), with small areas containing a variant of longleaf stands—mountain longleaf pine (Cipollini et al. 2019). Most of these remnant longleaf stands are either fire suppressed or have undergone plantation forestry. Thus, on-campus efforts are largely focused on restoration, not only for longleaf pine itself, but also for herbaceous plants and birds associated with these stands (Cipollini et al. 2012, Kronenberger et al. 2014). Among several plots sampled, basal area and density of

Table 4 Median and mean (±1SE) diameter at breast height for longleaf pine stems on main campus and in study sites: Baars-Firestone Wildlife Sanctuary and Edward Ball Nature Trails. Means subjected to analysis of variance and least significance difference test. Means with the same superscript are not significantly different at $P < 0.05$

Site	N stems	Median cm	Mean cm
Main campus	2165	35.0	34.4 ± 0.2[a]
Wildlife Sanctuary	68	37.1	35.9 ± 1.1[a]
Nature Trails	105	31.2	30.1 ± 0.8[b]

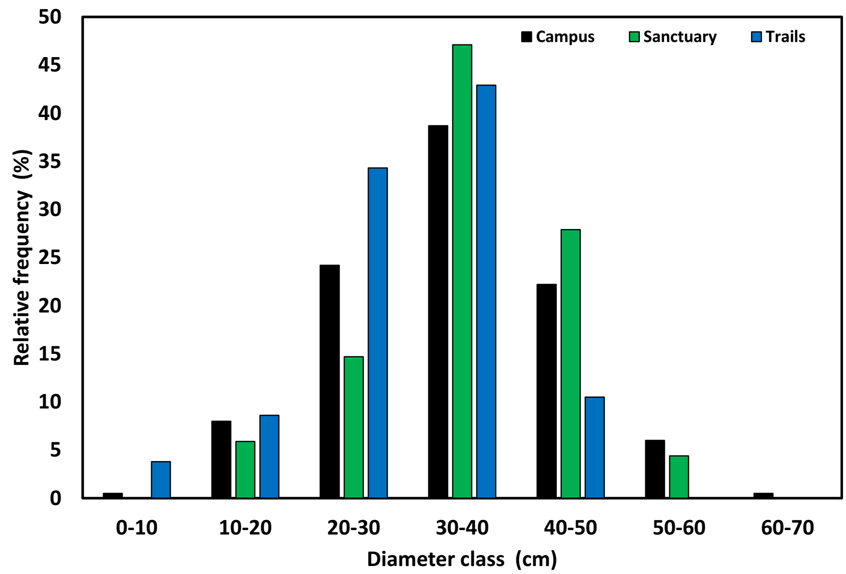

Fig. 6 Diameter size-class frequency distributions for two UWF natural areas (Ball Trails and Wildlife Sanctuary) and the UWF main campus. Data for main campus taken from Gilliam et al. 2020a)

longleaf pine is low relative to values commonly found in the literature (1.4 m^2/ha and 54 stems/ha, respectively). Work within these and other forest stands is often the focus of outdoor laboratory investigations. Also in Georgia, Valdosta State University maintains via its plant operations a list of campus plants, with longleaf pine as a main component. To accompany this, it provides an aerial photo map indicating locations of species on campus.

The campus of Stetson University has very few longleaf pine trees pre-dating adjacent university buildings. Similar to the surrounding region, longleaf pines have been replaced by oaks, native cabbage palms (*Sabal palmetto*), and ornamental species throughout campus (Cole and Bennington 2017). In 2011, through the on-campus Gillespie Museum, Stetson began a longleaf restoration effort and now have numerous longleaf stems between 2 and 15 yr old. This site is used in a variety of ways, including community outreach and outdoor laboratory activities (Cole and Bennington 2017). Despite a red-headed sawfly infestation in 2018, planted stems are exhibiting healthy growth, with basal area increasing threefold and height growth increasing two-fold over the past 5–6 yr (Bennington, personal communication).

Among the two major public universities in Florida's capital city of Tallahassee, Florida A&M University has identified distinct land/vegetation types on its 170-ha campus. These include the following: (1) urban land (terrestrial grasses, live oak and sweet gum), (2) agricultural field (target crops, terrestrial grasses and weeds), (3) mesic forest (sweet gum, laurel oak, and longleaf pine) and (4) forested swamp (mesic oaks, cypress, black gum, red maple, and sweet gum). The other school—Florida State University—is working with Tall Timbers Research Station and Land Conservancy to reintroduce fire to longleaf-dominated stands on university property.

Florida's land-grant university—University of Florida (Gainesville)—has a vast 809 ha campus supporting numerous trees, most notably large, old live oaks. These were actually planted since the construction of the campus in the mid-nineteenth century. The longleaf pines that were originally part of the landscape are largely gone, with few of the original stems remaining.

Campuses of other colleges and universities within the longleaf range in Florida have preserves, botanical gardens, and arboreta of which longleaf pine is a prominent component. Although not on the main campus, the Genius Preserve gives faculty and students of Rollins College (Winter Park, Florida) access to a variety of ecological scenarios. There is a complete flora and fauna associated with the Preserve, including native, exotic, and ornamental species, along with restoration efforts. University of South Florida (Tampa) maintains the USF Botanical Gardens, a 6.1 ha area used extensively for research and teaching. There is also the USF Species Catalog with a map of Tampa campus and a record of all plants geolocated. University of Central Florida (Orlando) has the 32.4-ha UCF Arboretum, with numerous plant community types, including longleaf pine in mesic flatwoods. University of North Florida (Jacksonville) has both a list of campus plant species via the UNF Landscape and Grounds Department, but also maintains the Sawmill Slough Preserve, a 154-ha tract with diverse habitats, including longleaf pine/turkey oak woodlands.

Synthesis

The remnant longleaf pine stands of two disjunct natural areas of the University of West Florida campus currently exhibit numerous characteristics of chronic fire exclusion, supporting earlier studies that include old-growth stands and the effects of fire exclusion on fire-dependent longleaf pine ecosystems (Gilliam and Platt 1999, Varner et al. 2005, Gilliam et al. 2006, Hiers et al. 2014). For longleaf pine alone, basal area and density were not only closely similar between the campus natural areas (13.4 versus 12.2 m^2/ha and 175 versus 113 stems/ha for Nature Trails and Wildlife Sanctuary, respectively), they were also similar to other longleaf sites, e.g., the Boyd Tract in the Sandhills of North Carolina (17.2 m^2/ha and 121 stems/ha; Gilliam et al. 2006). Soil data suggest that fire exclusion-mediated establishment of hardwood species in remnant pine stands also may have greatly altered soil fertility, with the general pattern being lower organic matter, greater acidity, and lower availability of nutrient cations. This likely arose from the acidifying nature of cation uptake, coupled with the high demand of hardwood trees for nutrient cations, and the elimination of deep-rooted herbaceous species by closed canopy-mediated reductions in light availability (Neufeld and Young 2014).

Questions remain regarding the future of these stands. With an ever-increasing human population, frequent fire is unlikely to be a part of any management strategy, e.g., toward restoration. Furthermore, although Hiers et al. (2014) suggested use of flammable oaks as a strategy toward longleaf restoration via prescribed burning, two of the more predominant oak species of the UWF natural areas (live oak and water oak) are mesic, rather than pyrogenic, in nature. These oak species would be less likely to sustain requisite fire conditions. Although the future of these natural areas is necessarily speculative, what is certain is that <5% of these stems are in the regeneration size class (0–10 cm DBH, Fig. 6). Among the other southern pine species, longleaf pine is the most long-lived, with at least one stem at the old-growth Boyd Tract in North Carolina >400 yr old (Gilliam et al. 1993). The current longleaf stems, therefore, will continue to grow, both on the main campus of UWF and its natural areas, and do so for many years to come. Lacking successful regeneration in the chronic absence of fire, however, longleaf pine likely will eventually be lost from these stands.

There appears to be widespread awareness of the importance of longleaf pine among colleges and universities within its natural range (Fig. 1). Virtually all have been granted Tree Campus USA status by the Arbor Day Foundation; this indicates their commitment to maintaining their campuses as suitable habitat for trees, especially longleaf pine. Also, each school uses its campus for various activities that include research and teaching. At UWF, ecology classes study the variety of habitat types originally targeted for preservation by John Jarvis, who designed the campus nearly 60 years ago. What is lacking among schools is a unified effort in intercampus communication regarding the status of longleaf pine. Accordingly, we suggest the establishment of a longleaf pine consortium to address this.

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