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Vegetation and Environment in Adjacent Post Oak (Quercus stellata) Flatwoods and Barrens in Indiana

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ABSTRACT.—To compare adjacent post oak flatwoods and barrens communities in southwestern Indiana, we used vegetational, environmental and fire history data in multivariate analyses. Barrens had greater dominance by post oak and lower tree species richness, but variation in tree species composition was not strongly related to soil moisture, litter depth or other environmental gradients measured. Tree growth has been slow and variable, with little difference between the barrens and flatwoods. Barrens and flatwoods differ in herb species composition, but with considerable overlap. In the barrens, herbaceous vegetation composition was correlated with tree basal area, litter depth and soil moisture; in the flatwoods, it was correlated with soil moisture and microelevation. The barrens and flatwoods differed only slightly but significantly in environment: barrens soils were drier in June 1986 than flatwoods soils. Data from fire-scarred trees show no clear evidence of differences in frequency or extent of fire between the flatwoods and barrens. Multistemmed post oaks in the barrens indicate that past cutting may have contributed to these openings within the closed canopy flatwoods matrix.

INTRODUCTION

Flatwoods are forests growing on level surfaces over nearly impervious subsoil layers. They are wet in spring with ponded depressions, dry in summer and typically lack a well-developed shrub layer (Marks and Harcombe, 1981; Aldrich and Homoya, 1984; Nelson 1985). Flatwoods dominated by red maple, beech, sweetgum, pin oak and other mesic species in Indiana and Illinois have received study (McCoy, 1938; Potzger and Liming, 1953; Stearns, 1956; Jackson and Barnes, 1974) but little is kown of vegetation and environment of flatwoods dominated by post oak. In particular, the origin and maintenance of barrens areas (open, savannah-like areas of widely scattered trees within the flatwoods) and the role of fire [important in maintaining post oak savannas further S (Dyksterhuis, 1948; Scifres, 1982)] are not known.

We studied the plant communities, environment and fire history of The Nature Conservancy's 120-acre Post Oak Barrens Nature Preserve (also known as Chrisney Flats) in Spencer County, S-central Indiana. This preserve is located on unglaciated alluvial lacustrine terraces of the Ohio River and is associated with McGary silt loam soil type. Major goals of our study were: (1) to characterize and compare the flatwoods and barrens based on species composition and environmental parameters such as microtopography, soil moisture and texture, and (2) to investigate the role of fire and human disturbance in the maintenance of the flatwoods and barrens.

METHODS

Sampling took place using a permanent grid system that facilitated mapping and resampling. Surveying equipment was used on 7–8 May 1986, to establish a 32-point 8 × 4 rectangle of grid points, each 25 m apart, in the flatwoods, an area with a nearly complete

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tree canopy dominated by post oak (*Quercus stellata*). In a nearby area of interrupted tree canopy 75 m to the W, termed barrens, a 4 × 3 network of grid points also 25 m apart was established. Two barrens grid points were not used because they were located in an obvious transition zone with an adjacent old field.

Data were gathered from 32 grid points in the flatwoods and 10 grid points in the barrens on 17–18 June 1986. Species and diameter at breast height (dbh) were recorded for all stems over 1 cm within circular plots 5.64-m radius (100 m^2) centered on each grid point. Cover estimates for the herb layer were made for each species of vascular plant (stems <1 cm dbh), mosses and lichens within 10-m^2 circular plots (1.79-m radius) centered on grid points. Cover was estimated in equal angular (arcsine square root) classes (1–7%, 8–25%, 26–50%, 51–75%, 76–93%, 94–100%). Species nomenclature follows Gleason and Cronquist (1963) except for *Eleocharis verrucosa* = *E. tenuis* (Willd.) Schultes var. *verrucosa* (Svenson) Svenson. Hickory trees at the site showed much intergradation in leaf characteristics between *Carya ovata* and *C. laciniosa.* Because species assignment was problematic, all hickories were called *Carya* spp. Increment cores were taken at breast height from one or more tree stems (canopy post oak if available) near each grid point, sanded and rings counted with a binocular microscope for age and growth analyses. For multiple stemmed trees (more common in the barrens), age of the oldest stem was used in analyses.

Environmental data were also collected near grid points. Litter samples were taken with a 12.85-cm diam cylinder from two locations adjacent to each grid point and oven-dried at 60 C to a constant weight. Samples of surface soil (top 20 cm) were dried to a constant weight at 80 C, and percent soil moisture calculated. Soil texture was determined gravimetrically (Bouyoucos, 1962; Day, 1965). Soil water potential was measured using portable tensiometers ("Jet Fill" tensiometers, model 2725, Soil Moisture Equipment Corp., Santa Barbara, California). Two readings per grid point were averaged. Because checks of grid points sampled early compared to later revealed no trend in soil water potential during the 2 days of sampling, corrections were not necessary. These soil moisture measurements provide a comparison of the water-holding capacity of the soils sampled.

The entire grid area was systematically sampled for fire history, following the protocol of Arno and Sneck (1977). Every tree in the area was examined for fire scars and a long-time (75-yr) local resident was interviewed to learn about the history of the area, including its fire history.

Variation in tree species composition (using relativized basal area) and herb species composition (using the angular-transformed cover classes) was summarized by detrended correspondence analysis (Hill and Gauch, 1980; Gauch, 1982). Correlation analysis and overlays were used to relate individual environmental and fire history measures to ordination axis scores to interpret major ordination axes in terms of environmental and historical factors. Tree species composition (axis scores from tree species ordination) and dominance (basal area and density) were also considered as environmental factors for herbs. In reporting ordinations of herb layer species composition, species mentioned as correlated with ordination axes had cover values highly and significantly ($P < 0.01$) correlated with the ordination axis or were terminal on that axis. To compare flatwoods with barrens, discriminant analyses contrasted species composition and environment, and t-tests compared environmental measurements.

RESULTS

Tree species composition and community structure.—The flatwoods and barrens communities at Chrisney Flats are similar in tree species composition, based on density, basal area and frequency (Table 1). The flatwoods are more diverse, containing 18 of 19 tree species

TABLE 1.—Tree species composition in Chrisney Flats: flatwoods vs. barrens

Species	Flatwoods			Barrens		
	Density (trees/ha)	Basal area (m^2/ha)	IV* (%)	Density (trees/ha)	Basal area (m^2/ha)	IV* (%)
Quercus stellata	409	17.3	42	510	15.9	64
Carya spp.	300	0.8	14	60	0.1	7
Quercus imbricaria	150	0.2	8	10	0	2
Q. falcata var. *pagodaefolia*	134	0.7	9	70	1.0	10
Ulmus alata	106	0	5	40	0.2	3
Quercus rubra	750	0.7	5	20	1.3	5
Q. alba	34	0.7	4	—	—	—
Ulmus americana	31	0.3	3	10	0	2
Quercus marilandica	16	0	1	—	—	—
Fraxinus americana	130	0	1	40	0	4
Nyssa sylvatica	13	0	1	—	—	—
Quercus velutina	13	0.5	2	—	—	—
Diospyros virginiana	9	0	1	—	—	—
Fraxinus sp.	9	0	1	—	—	—
Prunus serotina	6	0	1	—	—	—
Quercus palustris	6	1.0	2	—	—	—
Juniperus virginiana	3	0	0	—	—	—
Liquidambar styraciflua	3	0	0	—	—	—
Quercus coccinea	—	—	—	10	—	2
All species	1384	22.5	100	820	17.7	100

* Importance value = mean of relative density, relative basal area and relative frequency

occurring at Chrisney Flats while the barrens had only nine (Table 1). Only *Quercus coccinea* was unique to the barrens. Both communities are dominated by post oak. *Carya* spp., *Quercus imbricaria* and *Quercus falcata* var. *pagodaefolia* follow in importance in the flatwoods. *Quercus falcata* var. *pagodaefolia, Carya* spp. and *Quercus rubra* follow post oak in importance in the barrens. Species that are unique to either community have low importance values (Table 1).

The flatwoods and the barrens differ structurally, however. The flatwoods had lower average tree basal area (0.016 vs. 0.022 m^2/tree) and greater tree density. Multistemmed trees were significantly more common in the barrens (13 of 82 trees, 15.9%) than in the flatwoods (6 of 443, 1.4%; $\chi^2 = 48.2$, 1 df, $P < 0.001$). Many of these multistemmed trees have three or more stems, united at or just above ground level.

Detrended correspondence analysis shows that the first axis of variation in tree species composition for both flatwoods and barrens communities combined stretches from quadrats heavily dominated by *Quercus palustris* to quadrats having mixed upland oaks (especially *Quercus velutina* and *Quercus alba*) (Fig. 1). The second axis explained less variation but again placed *Quercus palustris* in an extreme position, this time in contrast to the understory trees *Prunus serotina* and *Fraxinus* spp. Tree species composition is only weakly related to measured environmental variables with axis 1 scores correlated with sandy soil ($P < 0.1$) and the lower part of axis 2 related to microelevation ($P < 0.1$).

Growth analysis.—Canopy post oak stems range widely in diameter (16.9–49.7 cm) and age (55–157 yr). Flatwoods and barrens are statistically different in the size-age relationship, with barrens having a lower slope ($t = 4.45$, $P < 0.001$), suggesting slower overall growth.

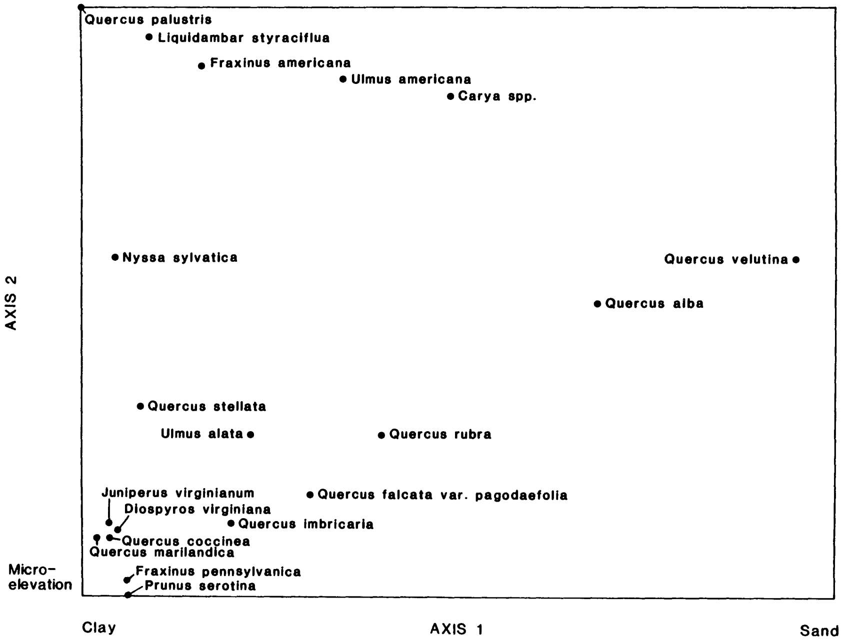

Fig. 1. Tree species ordination at Chrisney Flats. Also shown are environmental trends correlated ($P < 0.1$) or associated in overlays (flatwoods vs. barrens) with these axes

However, individual post oak tree stem diameters in the barrens are smaller than in flatwoods (Fig. 2). For both community types combined correlations with environmental parameters show that basal area growth is greater in more easterly grid points ($r = 0.60$, $P < 0.001$) and on siltier ($r = 0.35$, $P < 0.05$), lower-clay ($r = -0.30$, $P < 0.01$) soils.

Herb layer species composition and community structure.—The herb layer communities at Chrisney Flats are not particularly diverse. About seven species (range 3–11) were found in the herb layer of each plot, with no significant differences in species richness between flatwoods and barrens ($t = 0.82$, $P > 0.1$). Likewise, equitability, diversity, and the maximum cover class found at any grid point are similar between the two cover types ($t < 1.6$, $P > 0.1$ in all cases).

Danthonia spicata and the moss *Polytrichum ohioense* are the most common species in the herb layer of each community type, occurring in half or more of sampled quadrats (Table 2). Flatwoods plots sampled had distinctively high frequency and cover of *Rhus radicans. Panicum depauperatum* was found only in the flatwoods. Barrens plots were characterized by high frequency and cover of *Carex laxiflora,* the moss *Leucobryum glaucum* and the lichen *Cladonia strepsilis.* Forty percent of barrens plots contained the rare rushfoil *Crotonopsis elliptica,* which was not found in the flatwoods. This plant is recognized as endangered in Indiana.

Axis 1 for ordination of herb species composition (Fig. 3) separates such barrens specialists as *Cladonia strepsilis, Crotonopsis elliptica,* and *Leucobrym glaucum* from several flatwoods species, notably sedges, *Fraxinus pennsylvanica* and *Panicum depauperatum.* This suggests that the first axis represents a barrens-to-flatwoods gradient in part, with barrens quadrats

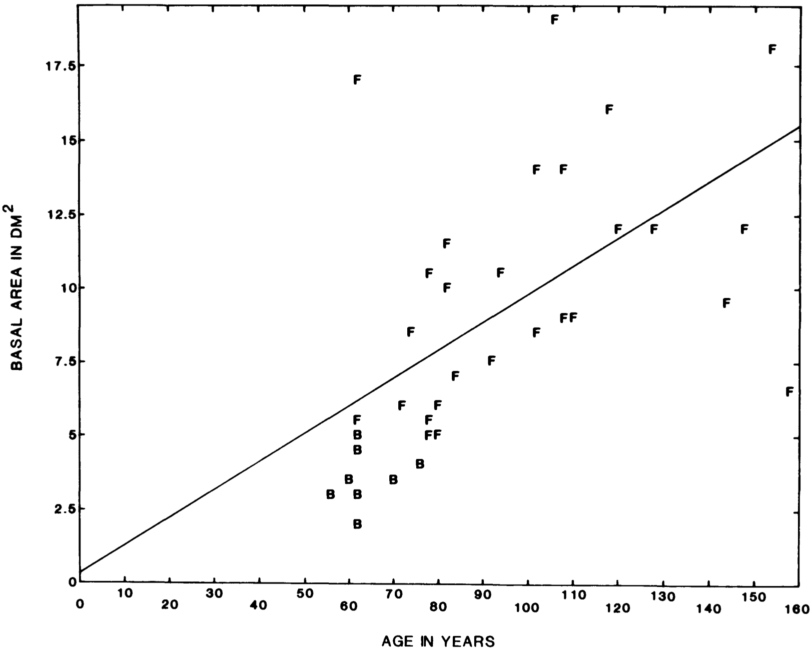

Fig. 2.—Relationship of basal area to age; for cored flatwoods (F) and barrens (B) trees. Plotted line is linear regression

restricted to the left side. Axis 1 scores relate to microelevation (P < 0.001) and correlate weakly with soil moisture (greater toward the flatwoods end of the gradient [P < 0.1]) and with scores from axis one of the tree ordination (P < 0.1). Thus, major variation in herb species composition may reflect the degree of tree canopy openness (barrens contrasted to flatwoods) and soil moisture.

The second axis is a gradient of tree basal area and soil texture (Fig. 3) and separates a mixed group of clonal plants and species found mainly in gaps: *Euphorbia corollata, Podophyllum peltatum, Ulmus alata, Danthonia spicata* and *Rubus* sp. from species observed growing near tree trunks, including two strongly climbing vines: *Parthenocissus quinquefolia* and *Vitis* sp. The lower end of axis 2 correlates with silty soils [as opposed to clay (both P < 0.05)] and tree basal area (average and total; P < 0.05).

Additional ordinations on separate flatwoods and barrens datasets confirm many of these trends and reveal others. Flatwoods ordinations suggest a strong effect of elevation on axis 1 (P < 0.001), with the highest microelevations having the driest tensiometer readings. Species associated with lower microelevations include an unidentified *Carex, Fraxinus pennsylvaticum, Amelanchier* sp. and *Rosa* sp. Species associated with higher microelevations in flatwoods were *Danthonia spicata* and *Rhus radicans.* Soil moisture is a correlate of axis 2 (P > 0.01) with *Cinna arundinacea, Nyssa sylvatica* and *Eleocharis verrucosa* on the wet end, as contrasted to seven upland herbs including *Vitis* sp., *Apios americana* and *Panicum boscii.*

The main axis of an ordination of barrens data is significantly correlated with soil-water potential (P < 0.01) and to the number and composition (axis score from tree species

TABLE 2.—Common herb-layer species in flatwoods and barrens. All species with either 15% overall frequency or greater, or 40% or greater frequency in one cover type, are listed. A total of 71 species was sampled

	Flatwoods (n = 32)		Barrens (n = 10)	
Species	% freq.	Avg. cover class	% freq.	Avg. cover class
Danthonia spicata	78.1	1.3	80.0	1.9
Polytrichum ohiohense	53.1	0.8	40.0	0.9
Rhus radicans	46.9	0.9	10.0	0.1
Quercus sp.	34.3	0.7	30.0	0.4
Potentilla simplex	28.1	0.5	30.0	0.5
Carex laxiflora	25.0	0.3	50.0	0.5
Parthenosissis quinquefolia	25.0	0.5	20.0	0.2
Eleocharis verrucosa	21.9	0.3	30.0	0.7
Panicum depauperatum	18.8	0.2	—	—
Leucobrym glaucum	15.6	0.2	40.0	0.5
Luzula campestris var. *echinata*	15.6	0.3	10.0	0.1
Cladonia strepsilis	6.3	0.1	60.0	1.2
Crotonopsis elliptica	—	—	40.0	0.4

ordination) of tree species ($P < 0.05$). Species associated with drier areas and greater tree species diversity include *Ulnus alata, Rosa* sp., post oak seedlings, *Luzula campestris* var. *echinata, Amelancier* sp., *Fraxinus* sp., and *Parthenocissus quinquefolia* in the herb-layer. Wetter areas feature *Juncus tenuis* and *Eleocharis verrucosa.* The second axis shows positive correlations with litter weight ($P < 0.01$) and average and total basal area ($P < 0.01$). Species associated with trees and their litter include *Nyssa sylvatica* and *Vitis* sp.

Flatwoods and barrens vegetation, environment and fire history.—No tree species had significantly different distribution between flatwoods and barrens, as revealed by discriminant analyses. In contrast, seven herb-layer species differed significantly between flatwoods and barrens (Table 3). Six of these were more abundant in barrens than in flatwoods, notably the rare rushfoil *Crotonopsis elliptica.*

The barrens had significantly drier soils than flatwoods ($P > 0.01$), but other environmental measures did not differ significantly at $P < 0.05$ (Table 4). In discriminant analysis for flatwoods and barrens, soil water potential is the only important environmental variable.

Thirty-seven fire-scarred trees were detected, with no significant difference in frequency between the flatwoods and barrens (Table 4). Additional information on historical fires and other land use practices was obtained from an interview with a preserve neighbor, Harold Proviance. He recalled two fires, one about 1920 or 1925 and the other in 1950. The fires burned with flames from one to (rarely) six feet high through leaf litter. Large portions of land burned in complete and extensive fires, driven by winds from the NE and E during one fire. Historic human-caused disturbances at Chrisney Flats included selective logging, but probably not grazing or cultivation.

DISCUSSION

The flatwoods of Chrisney Flats are an unusual community type. The great dominance by post oak and the presence of many other oak species are features in common with post oak flatwoods in northern Texas and Oklahoma (Dyksterhuis, 1948; Scifres, 1982; Kroh

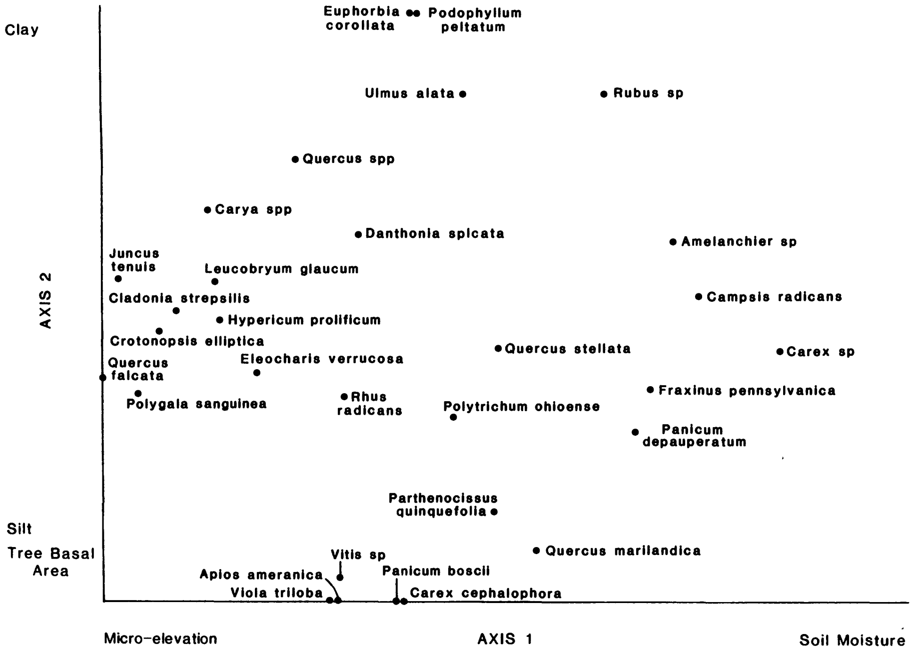

Fig. 3.—Herb species ordination at Chrisney Flats. Also shown are environmental and cover type trends correlated (P < 0.1) or associated in overlays (flatwoods vs. barrens) with these axes. All Eigenvalues are above 0.38 as determined by detrended correspondence analysis

and Nisbet, 1983). Most flatwoods in the northern Midwest are distinguished by lack of post oak dominance (*e.g.*, McCoy, 1938; Potzger and Liming, 1953; Stearns 1956; Jackson and Barnes, 1974). Characteristic herb species at Chrisney Flats differ from the prairie grasses and forbs described for flatwoods dominated by oak species in Missouri (Nelson, 1985), Illinois (White, 1978) and elsewhere in Indiana (Jackson, 1980).

While post oak flatwoods of neighboring states have been described, little information exists on post oak barrens. Our survey shows that at Chrisney Flats barrens are similar to flatwoods in tree composition, but that barrens trees are more often multistemmed. Diversity of herb species is similarly low in both cover types. Discriminant analyses show that several herb species are apparently barrens specialists, notably the rare *Crotonopsis elliptica*.

At Chrisney Flats, summer soil moisture is an important environmental factor determining the distribution of species between flatwoods and drier barrens. This is consistent with the results of previous studies of other oak-dominated flatwoods, which have shown that summer soil moisture or soil texture affects species composition differences between flatwoods and adjacent communities (Marks and Harcombe, 1981; Dooley and Collins, 1984; Hull and Woods, 1984). However, the differences found in this study are subtle, and a year-round study of soil moisture conditions might more clearly explain differences between flatwoods and barrens. It should be noted that bedrock at the site (Raccoon Creek Group of Pennsylvanian age shale, sandstone, limestone, clay and coal) is deep and unlikely to influence surface dynamics (Gray *et al.*, 1970). Although a fragipan is characteristic of the McGary silt loam soil type associated with the site, we sampled only the surface layer and did not observe a clear clay layer during our soil sampling.

TABLE 3.—Herb-layer taxa showing different distributions between woods and barrens, as shown by discriminant analyses

Species entered in discriminant analysis	Wilks Lambda*	Order of entry**	% frequency in	
			Flatwoods	Barrens
Crotonopsis elliptica	0.663 xxx	1	0.0	40.0
Cladonia strepsilis	0.761 xxx	14	6.3	60.0
Polygala sanguinea	0.840 xx	11	0.0	20.0
Rhus radicans	0.897 x	—	46.9	10.0
Hypericum prolificum	0.922 x	2	0.0	10.0
Juncus tenuis	0.922 x	3	0.0	10.0
Lechea tenuifolia	0.922 x	—	0.0	10.0
Rosa spp.	0.965	4	6.2	30.0
Nyssa sylvatica	0.981	5	3.1	10.0

* For individual species
** In stepwise analysis
x = $P < 0.05$
xx = $P < 0.01$
xxx = $P < 0.001$

Little is known of the stability of post oak flatwoods and barrens. The range of post oak ages suggest that this species is replacing itself at Chrisney Flats. The slow growth of trees [typical for post oak (Fowells, 1965)] and the minor importance of mesic species also suggests that these post-oak-dominated ecosystems are relatively stable. Some Chrisney Flats trees are over 150 years old. Historical records on the existence of barrens on the site are equivocal. Aldrich and Homoya (1984) document the existence of "barrens" and "flats" in adjacent portions of Spencer County in the early 1800s. Surveyors' records do not specifically mention barrens in the sections containing Chrisney Flats Preserve; however, Deam (1940) describes the indicator *Crotonopsis elliptica* from this location in 1929, in "a post and pin oak flat . . .

TABLE 4.—Environmental and fire history differences between barrens and flatwoods

Environmental measure	Mean value for grid point in		Significance of difference (t-test)
	Flatwoods	Barrens	
Soil water potential (cbar)†	26.0	37.6	0.011*
% sand	46.8	45.2	0.055
% clay	19.2	21.5	0.086
% soil moisture	19.6	17.7	0.088
Relative microelevation (m)	123.8	124.2	0.095
Litter weight (g)	11.3	9.7	0.422
% silt	34.0	33.3	0.554
No. observed fire scars/25 m × 25 m square centered on each grid point	0.906	0.800	0.772
Fire scars/tree††	0.0109	0.0166	—

† Significant in stepwise discriminant analysis contrasting flatwoods and barrens
†† Includes scarred and unscarred trees; not entered in discriminant analysis
* $P < 0.05$

abundant in a 40 acre fallow field and scattered in an adjoining open woods, but . . . not in the thick woods." We did not look for *C. elliptica* in adjoining old-fields, but otherwise its distribution remains as Deam described.

What factors contribute to the apparent overall stability of Chrisney Flats and other flatwoods? Fire seems important in southern pine flatwoods and in southern post oak savannas, where cessation of fire and overgrazing have resulted in invasion of shrubs and nonnative grasses (Dyksterhuis, 1948; Scifres, 1982). Evidence of fire is clear in both barrens and flatwoods, but there is little to suggest that fires control the development of barrens within the flatwoods matrix at Chrisney Flats. There is no clear evidence that fires were more widespread or frequent in barrens than in flatwoods. Instead, data suggest subtle soil differences could be responsible for the existence of barrens within the flatwoods matrix.

However, disturbance may have played a significant historical role in distinguishing some barrens from flatwoods. Multiple-stemmed trees united near the base (more common in Chrisney Flats barrens than in flatwoods) imply past cutting or burning, as post oaks sprout prolifically in response to these disturbances (Fowells, 1965; Rouse, 1986). The barrens is adjacent to previously cultivated areas, and local residents suggest that cutting probably occurred there. Thus, the barrens at Chrisney Flats may exist largely because of past human disturbance.

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