

Microhabitat Requirements of the Federally Endangered *Dalea foliosa*, with Recommendations on Establishment of New Populations

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ABSTRACT

The microhabitat of the federally endangered *Dalea foliosa* was compared to that of its cedar glade congener *D. gattingeri*, as well as to adjoining habitat absent of both species but appearing suitable for *D. foliosa* (control site). Compared to *D. gattingeri* sites, *D. foliosa* sites had lower coverage of gravel, higher coverage of herbaceous vegetation, and deeper soils. Both species were present on sites with similar leaf litter and moss coverages. *Nostoc commune* was absent from *D. foliosa* populations, but present in most *D. gattingeri* populations. In terms of soil depth and coverage variables, control sites differed little from *D. foliosa* sites. Coverage of *D. foliosa* was negatively correlated with that of associated (neighboring) species. No appreciable differences in soil fertility were noted among sites. New populations of *D. foliosa* should be established in areas relatively free of competition, exposed to full or partial sunlight, with soil depths >4 cm, and near washes.

INTRODUCTION

Recovery of endangered plants often involves the (re)introduction of populations within or outside a species' historical range, or the enhancement of small populations (Maunder 1992). The success of a restoration program depends on knowledge of the species' life history and habitat requirements; consideration of genetic, demographic, and ecological processes influencing population dynamics; and the identification of suitable restoration sites. Microhabitat requirements are crucial to understand since they are a major factor controlling the distribution and abundance of a species. In particular, potential recovery sites should match, as close as possible, the habitat conditions where the source population grows (DeMauro 1994, Menges et al. 1999).

Determining habitat requirements can be a difficult task, especially when one considers the complexity and interrelationships of multiple factors that need to be measured to accurately delineate the habitat boundaries of a population. However, two items assist in designing research investigations and gathering relevant information. First, rare species often are absent from apparently suitable habitats due to poor dispersal ability or to insufficient adaptation rendering a site unsuitable for establishment, growth, and reproduction (Helenum 1998). Second, comparisons among congeners provide insight into the relative importance of various ecological factors controlling habitat utilization. This can be particularly important when the congeners are sympatric and grow in adjoining but different microhabitats (Menges et al. 1999). Taken together, both types of sites, suitable habitat not utilized and habitat of the congener, provide useful information in determining the habitat preferences and limitations of a rare species.

Dalea foliosa (Gray) Barneby (= *Petalostemon foliosum* A. Gray, Fabaceae) occurs in northeastern Illinois, central Tennessee, and northern Alabama. The species is closely

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associated with limestone cedar glades and barrens in Tennessee and Alabama. In Illinois, it is found in dolomite prairies along river terraces and historically also on dry, gravelly riverbanks and rocky hills (Baskin and Caudle 1967, Baskin and Baskin 1973, DeMauro and Bowles 1996, Molano-Flores 2004). The species has declined by over 45% from historical occurrences due to destruction or alteration of habitat, overgrazing, and habitat loss from encroachment by woody plants. Severe drought also may drastically impact populations (DeMauro and Bowles 1996). It is federally endangered (United States Fish and Wildlife Service [USFWS] 1991), endangered in Tennessee (Nordman 2001) and Illinois (Illinois Endangered Species Protection Board 1999), and critically imperiled in Alabama (Alabama Natural Heritage Program 2001).

Recovery criteria recommend that current populations be restored to high viability and new populations be established at suitable recovery sites. The major focus of recovery should be in Tennessee since (1) it is the center of distribution and abundance of the species, and (2) it contains a reservoir of genetic diversity (USFWS 1991, Wiltshire 1994, DeMauro and Bowles 1996). In Tennessee, *D. foliosa* is sympatric with *D. gattingeri* (A. Heller) Barneby [= *P. gattingeri* (A. Heller) A. Heller], which grows in shallower rocky soil often adjacent to populations of *D. foliosa* (Smith and Wofford 1980; DeMauro and Bowles 1996; J. Thompson et al., pers. obs.). *Dalea gattingeri* grows in limestone cedar glades of central Tennessee to northwestern Georgia and northern Alabama, and is disjunct to Missouri and Arkansas (Baskin and Baskin 2003).

The two species are not sister taxa and have had different evolutionary histories (Breedon 1968, Baskin and Baskin 1986). *Dalea gattingeri* has a decumbent spreading growth habit and flowers between May and July, while *D. foliosa* is erect and flowers between July and August. The 5–7 leaflets of *D. gattingeri* are narrower than the 11–31 leaflets of *D. foliosa* (Breedon 1968, Smith and Wofford 1980, Baskin and Baskin 1989). Similar to *D. foliosa*, *D. gattingeri* is a hemicryptophyte perennial without vegetative reproduction and has delayed (several years) maturity, insect-pollinated (purple) flowers, and physically dormant seeds that germinate primarily in March to April and form a persistent soil seed bank (Breedon 1968; Barneby 1977; Baskin and Baskin 1989, 1998).

DeMauro and Bowles (1996) noted several important factors that may limit the distribution of *D. foliosa*: shallow soils, low soil moisture, low pH, poor competitive ability, and possibly allelopathy. Although the species is easily propagated and has high seed production in natural and artificial settings, past transplant efforts have not been very successful. Appropriate microhabitat conditions need to be chosen carefully for seeding or transplanting, yet the environmental requirements for successful establishment are not fully understood, leading to undesired results. The present study was undertaken to characterize the microhabitat of *D. foliosa* by comparing it to that of *D. gattingeri* and to a site in which neither species grows but appears suitable for *D. foliosa*. Specifically, two questions were addressed: (1) Do the coverages of biotic and abiotic variables and soil depth and fertility differ among the three microhabitats?, and (2) Which coverage and soil parameters are correlated with coverage of *D. foliosa*? The information then was used to formulate guidelines regarding habitat selection for establishing new (or augmenting existing) populations of *D. foliosa*.

MATERIALS AND METHODS

Study locations and sampling procedure

Five locations of *Dalea foliosa* in Tennessee were included in the present study: Couchville Cedar Glade State Natural Area and Hamilton Creek Park in Davidson County, Cedars of Lebanon State Forest in Wilson County, Columbia Glade—east and Blue Springs of the Columbia Cedar Glade State Natural Area in Maury County. The distance between locations ranged from approximately 0.6 km (between Columbia—east and Blue Springs) to 80.5 km (between Columbia and Cedars of Lebanon). Data were collected primarily between June and September 2001.

Three sites (microhabitats) were examined at each location: a population of *D. foliosa*, a population of *D. gattingeri*, and an area not supporting either species but appearing suitable

for *D. foliosa* (henceforth referred to as a control site). At two locations (Couchville, Hamilton Creek), the control sites historically have never contained plants of *D. foliosa* (A. Bishop, pers. comm.). A sketch of the population sites for *D. foliosa* and *D. gattingeri* was made, with each mature (flowering) plant indicated and numbered, and ten plants of each species randomly selected at each location. A sketch of the control site was constructed that included transects with consecutively numbered points at equal distances, and ten of the points were randomly selected at each location. The chosen plants and points were spread over each site. A circular 30.5 cm diameter plot was placed at the center of each plant or point for data collection.

Coverage and soil depth

Percentage cover was visually estimated in each plot for the following categories: gravel/flagstone (including some exposed soil); leaf litter; herbaceous (and minor amounts of woody) vegetation, excluding *D. foliosa* and *D. gattingeri*; moss/lichen [mostly the moss *Pleurochaete squarrosa* (Brid.) Lindb.]; colonies of the cyanobacterium *Nostoc commune* Vaucher; and the focal species (*D. foliosa* or *D. gattingeri*). Soil depth was measured using a metal probe and meter stick at one randomly selected position in each quadrant of the plots. From the four measurements, the deepest was recorded as maximum soil depth.

Two-way analyses of variances (ANOVAs) examined the factors, location and site, and the interaction between them for each coverage variable and soil depth (SPSS 2000). The protected least significant difference test (PLSD, $P = 0.05$) was the multiple comparison procedure used to examine means among sites and locations, except for the coverages of the two focal species between sites in which a *t*-test was used. Soil depth and coverage data were log-transformed and arcsin-square root-transformed, respectively.

Pearson correlation coefficients were calculated to quantify the relationships among soil depth and coverages of *D. foliosa*, gravel, leaf litter, associated herbaceous vegetation, and moss on a per plot basis; *Nostoc* was not included since it did not occur with *D. foliosa* (SPSS 2000). Results of the correlation analysis were then used to guide the development of a path diagram, in which the relative strengths of direct and indirect interactions among these variables could be described (Arbuckle 1999, Wootton 1994). All variables were standardized, and a residual variable, representing unmeasured factors was included (regression weight = 1). A model that fits reasonably well has the following combination of characteristics: a nonsignificant chi-square, indicating no deviation between the observed and expected correlations for a particular model; small values of standardized root mean square residual (RMR) (<0.05) and root mean square error of approximation (RMSEA) (<0.08); large values (>0.90) of goodness-of-fit index (GFI), comparative fit index (CFI), and incremental fit index (IFI); and a nonsignificant test of close fit (CFit) (Jaccard and Wan 1996). Multicollinearity was not considered to be a severe problem since the largest variance inflation factor and condition index were 3.4 and 19.9, respectively (cf. Belsley et al. 1980, Myers 1990). Maximum likelihood estimators are robust against departures from normality (Jaccard and Wan 1996), but transformations (see above) were effective for removing skewness and kurtosis from each variable and for eliminating multivariate kurtosis.

Soil fertility

Two samples of soil were collected from a random place in each site. The samples were about 8 cm deep, depending on the shallowness of the soil, with the total amount collected

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Figure 1. Coverages (means \pm 1SE) of various variables associated with *Dalea foliosa* (DF) and with *D. gattingeri* (DG), and in habitat not supporting either species but appearing suitable for *D. foliosa* (control), at five locations in middle Tennessee: Blue Springs (BS), Cedars of Lebanon (CL), Columbia (CO), Couchville (CV), and Hamilton Creek (HC). Ten plants of each species and ten control points were surveyed at each location. Values with dissimilar lower-case letters above bars within each location are significantly different (protected least significant difference test, $P = 0.05$).

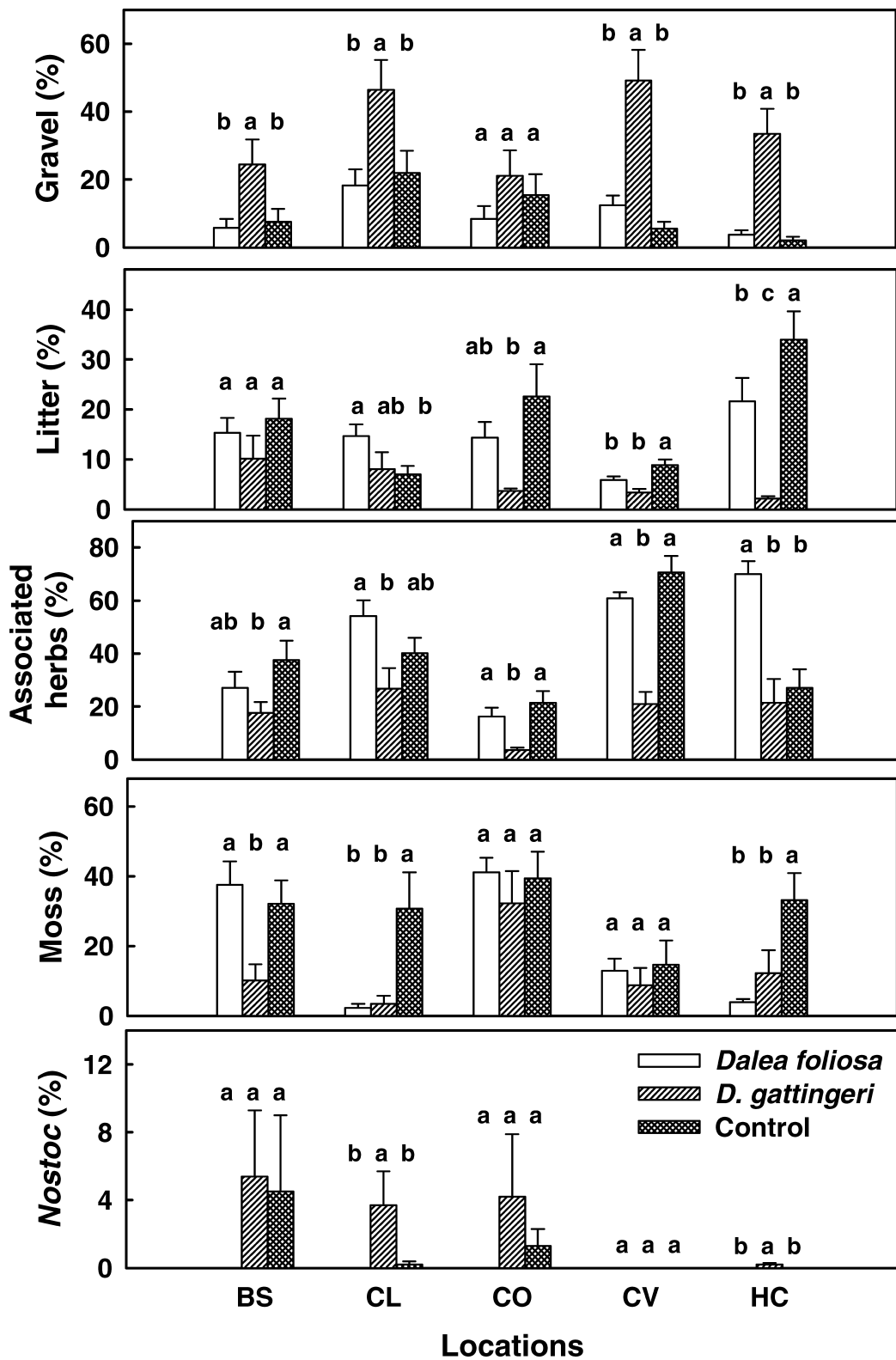


Table 1. Results of protected least significant difference tests (P = 0.05) among locations for vegetation and environmental parameters associated with plants of *Dalea foliosa* and *D. gattingeri* and at random points in habitat not supporting either species but appearing suitable for *D. foliosa* (control). Results of tests also are given for coverages of *D. foliosa* and *D. gattingeri*. Dissimilar upper-case letters within rows indicate significant differences. Ten plants of each species and ten control points were surveyed at each location. See Figures 1-3 for means \pm 1 SE

| Parameter Site | Blue Springs | Cedars of Lebanon | Columbia | Couchville | Hamilton Creek |
|---|--------------|-------------------|----------|------------|----------------|
| Gravel/flagstone coverage (%) | | | | | |
| <i>D. foliosa</i> | BC | A | AB | AB | C |
| <i>D. gattingeri</i> | A | A | AB | A | A |
| Control | BC | A | AB | BC | C |
| Leaf litter coverage (%) | | | | | |
| <i>D. foliosa</i> | A | A | BC | B | A |
| <i>D. gattingeri</i> | A | AB | A | AB | B |
| Control | BC | C | AB | C | A |
| Herbaceous species, excluding <i>D. foliosa</i> and <i>D. gattingeri</i> , coverage (%) | | | | | |
| <i>D. foliosa</i> | C | B | C | AB | A |
| <i>D. gattingeri</i> | A | A | B | A | A |
| Control | BC | B | C | A | BC |
| Moss coverage (%) | | | | | |
| <i>D. foliosa</i> | A | B | A | C | B |
| <i>D. gattingeri</i> | B | B | A | B | AB |
| Control | AB | AB | A | B | AB |
| <i>Nostoc</i> coverage (%) | | | | | |
| <i>D. foliosa</i> | A | A | A | A | A |
| <i>D. gattingeri</i> | A | A | A | A | A |
| Control | A | A | A | A | A |
| Maximum soil depth (cm) | | | | | |
| <i>D. foliosa</i> | B | A | C | B | B |
| <i>D. gattingeri</i> | B | A | AB | A | AB |
| Control | B | B | B | A | A |
| Focal species coverages (%)* | | | | | |
| <i>D. foliosa</i> | AB | B | A | B | C |
| <i>D. gattingeri</i> | AB | C | A | BC | AB |

* Species not present in control sites.

being 240 cm³. Soil samples were air-dried and analyzed for NO₃-N (nitrate electrode method); available P, K, Ca, Mg (Mehlich 1 method); organic matter (Walkley-Black procedure); and pH [1:1 (v/v) soil:water]. Analyses of soils were done by the University of Tennessee Agricultural Extension Service in Nashville. The soil testing service does not provide amounts of Ca or Mg above a certain value; as such, Ca (1,423 kg/ha) and Mg (71 kg/ha) did not vary among locations or sites and were excluded from subsequent analyses.

Soil characteristics were examined by two-way ANOVAs with location and site as factors. PLSD examined means among sites and locations. Transformations of the K, pH, and organic matter data were not needed, the reciprocal-square root transformation was performed on the NO₃-N data, and no transformation corrected the P data. Pearson correlation coefficients were calculated to quantify the relationships among locations for the mean values of NO₃-N, P, K, organic matter, and pH and mean coverage of *D. foliosa*.

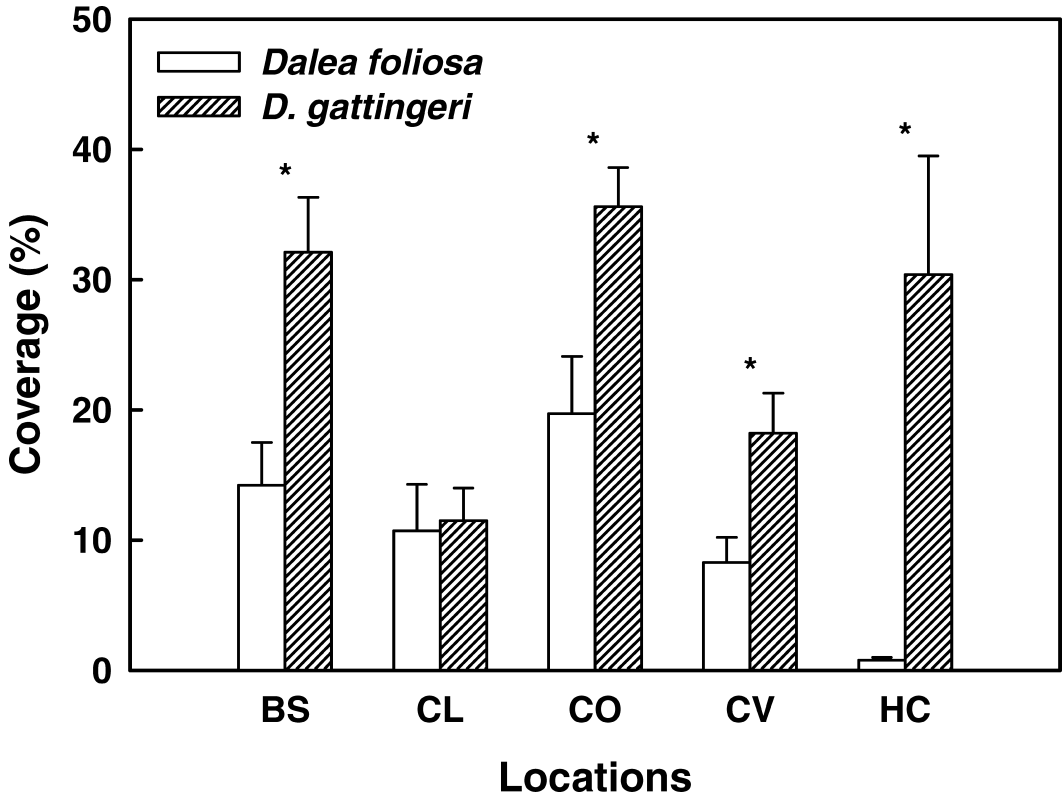


Figure 2. Coverages (means \pm SE) of *Dalea foliosa* and *D. gattereri* at five locations in middle Tennessee: Blue Springs (BS), Cedars of Lebanon (CL), Columbia (CO), Couchville (CV), and Hamilton Creek (HC). Ten plants of each species were surveyed at each location. Values with asterisks are significantly different within locations and those without asterisks are not different (*t*-test, $P \leq 0.05$).

RESULTS

Coverage and soil depth

Coverages of litter, herbaceous vegetation, and moss differed significantly among locations and sites (main effects and interaction, $P \leq 0.009$). Although the coverage of gravel was different among sites and locations (main effects, $P \leq 0.002$), the trend among sites was similar regardless of the location (interaction, $P = 0.231$). Coverage of *Nostoc* differed significantly among sites ($P = 0.004$), but not among locations (main effect and interaction, $P \geq 0.122$). *Dalea foliosa* and control sites mostly had significantly less gravel and more associated herbaceous vegetation than the *D. gattereri* site, but the former two sites had similar coverages of these variables (Figure 1, Table 1). At most locations, leaf litter in *D. foliosa* sites did not differ significantly from that in the *D. gattereri* and/or control sites. *Nostoc* was significantly highest in the *D. gattereri* sites at two locations; it did not differ among sites at the other three locations. Coverage of moss was similar in the *D. foliosa* and control sites at three locations, but it was significantly highest in control sites at the other locations. Coverages of both focal species differed significantly among locations and sites ($P < 0.001$; interaction, $P = 0.002$). With the exception of Cedars of Lebanon (*t*-test, $P = 0.863$), *D. foliosa* coverage was significantly less than *D. gattereri* coverage ($P \leq 0.015$) (Figure 2, Table 1). Soil depth varied significantly among locations and sites (main factors and interaction, $P < 0.001$). Maximum depth of soil, with the exception of Cedars of Lebanon, ranged from deepest to shallowest: *D. foliosa* = control \geq *D. gattereri* (PLSD, $P = 0.05$) (Figure 3, Table 1). At Cedars of Lebanon, soil depth in the *D. foliosa* site was significantly higher than in the *D. gattereri* or control sites.

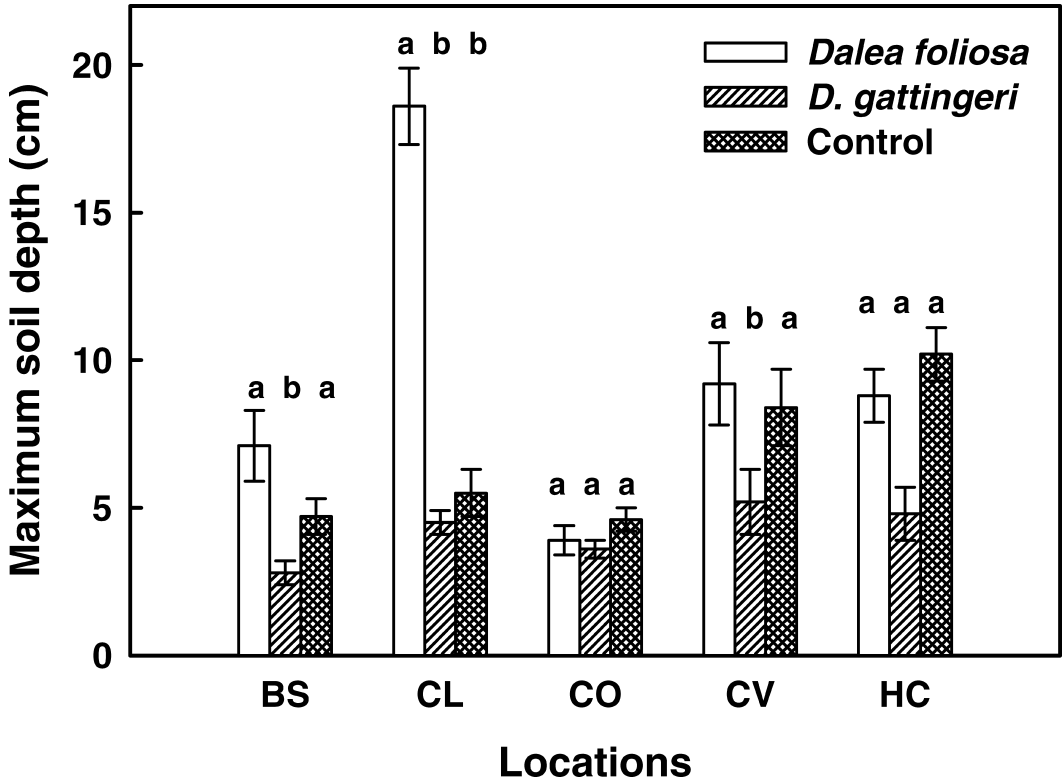


Figure 3. Maximum soil depth (means \pm 1SE) associated with *Dalea foliosa* and with *D. gattereri*, and in habitat not supporting either species but appearing suitable for *D. foliosa* (control), at five locations in middle Tennessee: Blue Springs (BS), Cedars of Lebanon (CL), Columbia (CO), Couchville (CV), and Hamilton Creek (HC). Ten plants of each species and ten control points were surveyed at each location. Values with dissimilar lower-case letters above bars within each location are significantly different (protected least significant difference test, $P = 0.05$).

The following coverage and soil variables were significantly correlated: *D. foliosa* and associated herbaceous vegetation (Pearson coefficient = -0.55 , $P = 0.01$), gravel and moss (-0.33 , 0.05), litter and associated herbs (-0.35 , 0.05), moss and associated herbs (-0.72 , 0.01), soil depth and associated herbs ($+0.51$, 0.01), and soil depth and moss (-0.66 , 0.01). A path diagram was assembled depicting four variables directly or indirectly affecting the coverage of *D. foliosa* (chi-square, $P = 0.158$; RMR = 0.004 ; RMSEA = 0.110 ; GFI, CFI, IFI, CFI ≥ 0.943). Inclusion of leaf litter produced a poorly fit model, and so this variable was omitted from the path analysis. The only variable that had a significant impact on the coverage of *D. foliosa* was the coverage of associated herbaceous vegetation, and this relationship was negative (Figure 4). In turn, soil depth had a significantly positive influence on the coverage of associated herbs. Three variables negatively affected the coverage of moss: associated herb coverage, gravel coverage, and soil depth.

Soil fertility

Soil pH was the only soil parameter that varied significantly among sites ($P = 0.009$; all others, $P \geq 0.157$; interaction, $P = 0.038$; all others, $P \geq 0.091$); the effect of location was significant for $\text{NO}_3\text{-N}$, K, pH, and organic matter ($P \leq 0.005$) but not for P ($P = 0.438$). Significant differences in pH among the sites occurred only at Blue Springs and Hamilton Creek (Table 2). None of the soil variables were correlated with coverage of *D. foliosa* ($P \geq 0.113$).

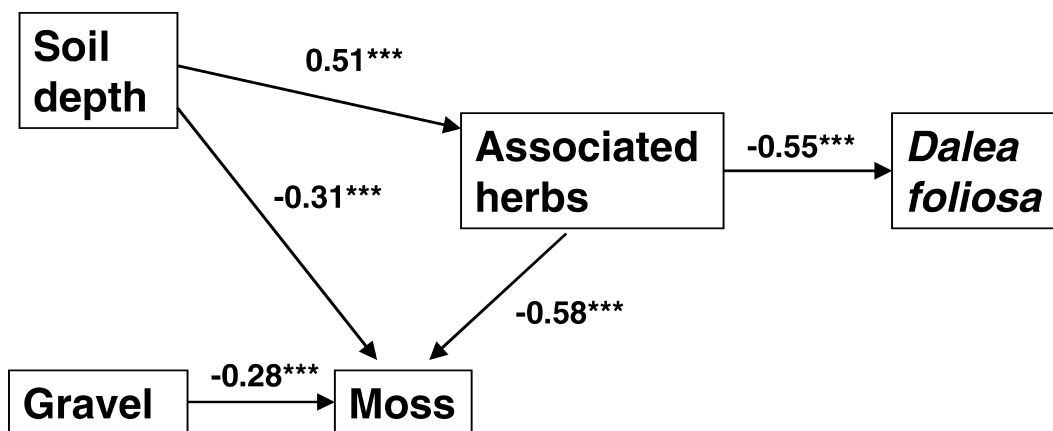


Figure 4. Representation of the direct and indirect effects of soil depth and coverages of various variables on the coverage of *Dalea foliosa*. Coefficients (***) $P \leq 0.001$ are given for each path; arrows designate the direction of effect.

DISCUSSION

As compared to *Dalea gattingeri* sites, *D. foliosa* sites usually have lower coverage of gravel, higher coverage of herbaceous vegetation, and deeper soils (Figures 1, 3, Table 1). *Nostoc* was not present in any of the *D. foliosa* populations surveyed, but it was present in nearly all *D. gattingeri* populations. On the other hand, both species grew on sites with similar coverages of leaf litter and moss. Of all the coverage and soil depth variables, four of the six mostly were similar between the *D. foliosa* and control sites. Coverages of leaf litter and moss in *D. foliosa* sites versus control sites were highly dependent on the location. Moss coverage was similar between *D. foliosa* and control sites at three sites, whereas it was significantly higher in the control sites at the other locations. On the other hand, leaf litter in the *D. foliosa* sites compared to the control sites was similar (two locations), higher (one location), or lower (two locations). Except for individual location differences, control sites appear to be suitable for *D. foliosa*.

Over all locations, the ranges in soil depth of the *D. foliosa* and control sites were 3.9–18.6 and 4.6–10.2 cm, respectively, whereas that of the *D. gattingeri* sites were 2.8–5.2 cm (Figure 3, Table 1). DeMauro and Bowles (1996) reported that the preferred habitat of *D. foliosa* has soil depths of 4–45 cm, but the species is most abundant in soil with 10–30 cm depth. *Dalea foliosa* usually grows on deeper soil near the transition zone between the open glades and glade thickets or woods; it is not found on the shallow soils where *D. gattingeri* occurs. Within the *D. foliosa* sites, however, soil depth influenced directly the coverages of associated herbs (positive) and moss (negative) and it affected indirectly the coverage of *D. foliosa* (Figure 4). As soil depth increased, the coverage of associated herbs increased which then caused a decrease in the coverage of *D. foliosa*. On the other hand, moss coverage decreased as soil depth and coverage of associated herbs increased. Quarterman (1956) reported that *Pleurochaete squarrosa* primarily grows on shallow soils and that best growth occurs in partially shaded conditions.

Poor competitive ability has been one factor indicated by DeMauro and Bowles (1996) that might limit the distribution of *D. foliosa*. The present study would support this contention since the single most important factor determining the coverage of *D. foliosa* was the coverage of associated (neighboring) native and nonnative species, and this relationship was negative (Figure 4). Disturbance plays a key role in the population dynamics of *D. foliosa* by reducing the amount of competition, particularly by removing overstory (woody) species. Extant populations have persisted along roadsides and in utility right-of-ways with periodic mowing that avoided destruction of the root crowns of *D. foliosa* plants (Smith and Wofford 1980). Fire also has been observed to enhance populations of this species (DeMauro and Bowles 1996).

Table 2. Characteristics of the soil (means \pm 1 SE) associated with plants of *Dalea foliosa* and *D. gattingeri* and in habitat not supporting either species but appearing suitable for *D. foliosa* (control). At each location, two samples of soil were randomly collected in each site. Values with dissimilar upper-case letters within columns or lower-case letters within rows are significantly different (protected least significant difference test, $P = 0.05$)

| Parameter & Location | <i>Dalea foliosa</i> | <i>Dalea gattingeri</i> | Control Site |
|------------------------|-------------------------------|--------------------------------|--------------------------------|
| Nitrate nitrogen (ppm) | | | |
| Blue Springs | 4.5 \pm 0.1 ^{Ba} | 3.7 \pm 0.2 ^{Ba} | 4.3 \pm 0.1 ^{Aa} |
| Cedars of Lebanon | 19.3 \pm 4.4 ^{Aa} | 7.2 \pm 0.2 ^{Aa} | 6.2 \pm 3.9 ^{Aa} |
| Columbia | 9.7 \pm 1.6 ^{ABa} | 10.8 \pm 1.0 ^{Aa} | 8.7 \pm 0.4 ^{Aa} |
| Couchville | 4.9 \pm 1.6 ^{Ba} | 4.3 \pm 1.2 ^{Ba} | 4.2 \pm 0.9 ^{Aa} |
| Hamilton Creek | 5.1 \pm 0.9 ^{Ba} | 10.0 \pm 1.3 ^{Aa} | 7.2 \pm 0.9 ^{Aa} |
| Phosphorus (kg/ha) | | | |
| Blue Springs | 4.0 \pm 0.0 ^{Aa} | 4.0 \pm 0.0 ^{Aa} | 4.0 \pm 0.0 ^{Aa} |
| Cedars of Lebanon | 4.0 \pm 0.0 ^{Aa} | 4.0 \pm 0.0 ^{Aa} | 4.0 \pm 0.0 ^{Aa} |
| Columbia | 8.5 \pm 4.5 ^{Aa} | 4.0 \pm 0.0 ^{Aa} | 4.0 \pm 0.0 ^{Aa} |
| Couchville | 4.0 \pm 0.0 ^{Aa} | 4.0 \pm 0.0 ^{Aa} | 4.0 \pm 0.0 ^{Aa} |
| Hamilton Creek | 4.0 \pm 0.0 ^{Aa} | 4.0 \pm 0.0 ^{Aa} | 4.0 \pm 0.0 ^{Aa} |
| Potassium (kg/ha) | | | |
| Blue Springs | 86.0 \pm 6.0 ^{Aa} | 100.0 \pm 3.5 ^{Aa} | 51.5 \pm 12.5 ^{ABa} |
| Cedars of Lebanon | 35.5 \pm 1.5 ^{Ba} | 27.5 \pm 5.5 ^{Ba} | 33.0 \pm 10.0 ^{Ba} |
| Columbia | 98.5 \pm 11.5 ^{Aa} | 49.0 \pm 15.0 ^{Ba} | 95.5 \pm 15.5 ^{Aa} |
| Couchville | 58.5 \pm 4.0 ^{Ba} | 53.5 \pm 25.5 ^{ABa} | 42.5 \pm 23.5 ^{ABa} |
| Hamilton Creek | 95.0 \pm 4.0 ^{Aa} | 75.0 \pm 3.0 ^{ABa} | 83.0 \pm 4.0 ^{ABa} |
| pH | | | |
| Blue Springs | 7.8 \pm 0.0 ^{ABb} | 8.2 \pm 0.1 ^{Aa} | 8.1 \pm 0.1 ^{Aab} |
| Cedars of Lebanon | 7.9 \pm 0.2 ^{Aa} | 8.1 \pm 0.0 ^{Aa} | 8.1 \pm 0.1 ^{Aa} |
| Columbia | 7.7 \pm 0.3 ^{ABa} | 8.0 \pm 0.1 ^{Aa} | 7.9 \pm 0.0 ^{Aa} |
| Couchville | 7.6 \pm 0.1 ^{ABa} | 7.7 \pm 0.4 ^{Aa} | 7.8 \pm 0.2 ^{Aa} |
| Hamilton Creek | 7.3 \pm 0.0 ^{Bb} | 7.8 \pm 0.0 ^{Aa} | 6.8 \pm 0.1 ^{Bc} |
| Organic matter (%) | | | |
| Blue Springs | 6.1 \pm 0.3 ^{Ba} | 6.8 \pm 1.4 ^{Aa} | 4.5 \pm 0.6 ^{Ba} |
| Cedars of Lebanon | 5.8 \pm 0.4 ^{Ba} | 3.7 \pm 1.8 ^{Aa} | 3.0 \pm 0.8 ^{Ba} |
| Columbia | 9.6 \pm 0.2 ^{Aa} | 7.4 \pm 1.6 ^{Aa} | 8.4 \pm 0.7 ^{Aa} |
| Couchville | 6.0 \pm 0.3 ^{Ba} | 4.9 \pm 0.8 ^{Aa} | 8.4 \pm 1.6 ^{Aa} |
| Hamilton Creek | 5.5 \pm 0.6 ^{Ba} | 4.3 \pm 0.3 ^{Aa} | 5.7 \pm 0.0 ^{ABa} |

Morphological characteristics exhibited by *D. gattingeri* allow it to be more drought tolerant than *D. foliosa*, and may partly explain the microhabitat suitability of the two species. The well-developed root systems of *D. gattingeri* are able to penetrate deep within pockets of rock to find soil moisture without encountering severe root competition (Breedon 1968). Moreover, its narrow involute (ca. 1 mm wide) leaflets would have a reduced heat load and transpiration. Indeed, decreased reproduction (Molano-Flores 2004) and mortality (Baskin and Baskin 1973, DeMauro and Bowles 1996) have been observed in populations of *D. foliosa* during summer droughts. During the course of the present study, severe wilting in *D. foliosa* was observed but *D. gattingeri* appeared not to be impacted by droughty conditions (J. Thompson et al., pers. obs.). *Dalea foliosa* often grows along the edges of moist, shallow pans or ephemeral streams or washes. These areas would provide sufficient soil moisture for the species, especially during late summer/early autumn when precipitation is often limited and the reproductive portion of its life cycle occurs.

Plants of *D. foliosa* should not be restricted from growing in the control sites due to a difference in soil nutrients, organic matter, and pH per se (Table 2). In some respects, there

should not be much difference between the sites with regards to soil fertility since at any one location they were adjacent to each other and the soils were all derived from the same type of bedrock. Moreover, nitrogen should be adequately available since both *Dalea* species have nitrogen-fixing nodules on their roots (Breedeen 1968, Baskin and Baskin 1989).

Choosing appropriate microhabitat conditions for seeding and/or transplanting is critical for the successful recovery and restoration of *D. foliosa* populations (DeMauro and Bowles 1996). Based on the information obtained by the present study, it is recommended that new populations be established on sites that are relatively free of competition from other herbaceous plants and with soil depths >4 cm. Moreover, sites that are in full or partial sunlight and near a stream/wash would be suggested. Mowing, hand clearing and burning should be used to keep sites clear of competing vegetation and prevent woody succession, particularly with regards to exotic species.

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