Ecology of *Botrychium campestre* on Northeastern Iowa Glades

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ABSTRACT --*Botrychium campestre* is one of the more cryptic and rare species of Upper Plains and Great Lakes grassland communities. Little information has been published about the ecological preferences for this species. Our study reports the findings of a three-year survey for it on 41 northeastern Iowa glade sites. *Botrychium campestre* was found to significantly prefer hillslope shoulders over other hillslope positions, and to significantly prefer north and south-facing slopes over east and west-facing slopes. A strong, although statistically non-significant, trend was also noted with individuals appearing to favor soils developed on carbonate substrates. A positive association was also noted between *B. campestre* and *Andropogon scoparius*. Ourresults help define the landscape and environmental parameters related to occurrence of *B. campestre* and suggest further avenues of analysis in the investigation of the factors leading to its rarity.

Key words: *Botrychium campestre,* Iowa, rare species ecology, glades.

Botrychium campestre W.H. Wagner & D.R. Farrar is a cryptic fern of dry grasslands. Initially located in the Loess Hills of western Iowa in 1982 (Howe et al. 1984), it was subsequently found in the Northern Plains (Lellinger 1985, Wagner and Wagner 1986, Coffin and Pfannmuller 1988, Wagner and Wagner 1993), the northern Great Lakes (Wagner and Wagner 1993), and northeastern Iowa (Nekola and Schlicht 1996).

Botrychium campestre is rare throughout its range. Wagner and Wagner (1993) consider it of conservation concern. The Nature Conservancy lists *B. campestre* as globally endangered (Wisconsin Heritage Program Database, unpubl.data). It is threatened in Minnesota (Coffin and Pfannmuller 1988) and Michigan (Hazlett 1991). It has been reported from three sites in Saskatchewan, two in North Dakota, and single sites in Alberta, Nebraska, New York, and Wisconsin (Wagner and Wagner 1986, Wagner and Wagner 1993, Wisconsin Heritage Program Database, unpubl. data). In Iowa it is limited to fewer than 30 populations in 18 counties (Peck et al. 1989, Nekola and Schlicht 1996).

Since *B. campestre* has been recognized for only 10 years, little is known of its ecological preferences. No information regarding the substrate or slope-position preferences for *B. campestre* has been published. Farrar (1985) and Farrar and Johnson-Groh (1986) report that in western Iowa B. campestre demonstrated no slope-aspect preferences, and noted that emergence is limited to spring when soil moisture is highest. Coffin and Pfannmuller (1988) state that in Minnesota B. campestre favors dry loess or gravel prairies where it often occurs with *Andropogon scoparius* and *Muhlenbergia cuspidata*. Neither of these papers used statistical analyses to validate these conclusions. Our paper summarizes an ecological survey for B. campestre conducted from 1993-1995 within northeastern Iowa glade sites. These data allowed analysis of the bedrock substrate preferences, slope-aspect preferences, slope position preferences, and common associates of this rare fern.

MATERIALS AND METHODS

Study Sites

Forty-one northeastern Iowa glades were selected for analysis (Table 1). Sample sites were stratified across the geographic range of this habitat and represent all major bedrock formations associated with glade occurrence. Because of the natural distribution of habitats, most inventoried sites fell within one of two main geographical clusters (Fig. 1): those on the western margin of the Iowan Erosional Surface, and those within 100 km of the Mississippi River on the Southern Iowa Drift Plain, Paleozoic Plateau, and the Iowan Erosional Surface (Prior 1991).

Sites were chosen for inventory independent of their disturbance or successional state. Eleven sites (Aurora South, Earlville, Foot, Hanes, Idlewild 1, Idlewild 2, Quasqueton, Raymond South, St. Olaf, Troy Mills Quarry, and Wadena) showed evidence of previous (or contemporaneous) high grazing pressure, while four others (Clark, Foot, Mineral Creek, and Turkey River) were in advanced stages of forest succession.

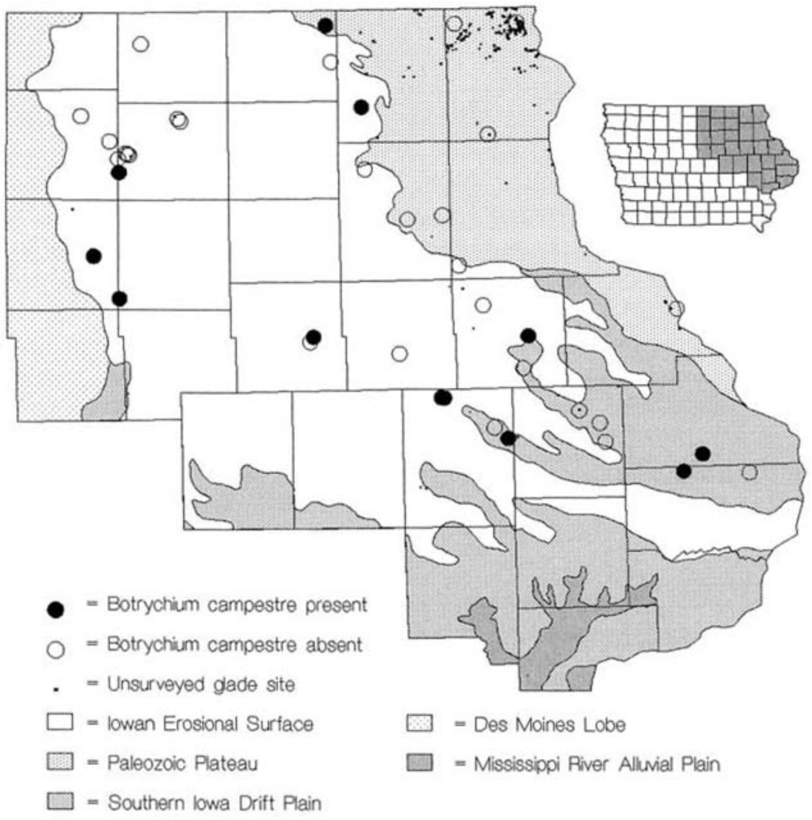

Figure 1. Map of northeastern Iowa showing county and physiographic region boundaries, with the location of glade sites inventoried for *B. campestre*. Open circles designate sites in which *B. campestre* was absent; filled circles sites in which *B. campestre* was present.

Table 1: Summary of glade sites surveyed and population sizes of *Botrychium campestre* in northeastern Iowa.

Site Name	Location	Bedrock Formation(s)	Bedrock Type	Size (ha)	Abundance of *B. campestre*
Allamakee					
Sand Cove North	NE¼ NW¼ Sec. 27, T. 100 N., R. 4 W.	Prairie du Chien-St. Croxian	Dolomite-Sandstone	12.0	0
Clark	NE¼ SW¼ NW¼ Sec. 28, T. 100 N., R. 6 W.	Prairie du Chien-St. Croxian	Dolomite-Sandstone	1.9	0
Hickory Creek	SW¼ NW¼ SE¼ Sec. 28, T. 96 N., R. 5 W.	Dunleith	Limestone	0.7	0
Black Hawk					
Raymond South	NW¼ SW¼ NW¼ Sec. 11, T. 88 N., R. 12 W.	Cedar Valley	Limestone	1.4	0
Pints	SW¼ SE¼ SE¼ Sec. 6, T. 89 N., R. 12 W.	Cedar Valley	Limestone	3.6	1
Buchanan					
Quasqueton	SW¼ NW¼ NE¼ Sec. 25, T. 88 N., R. 9 W.	Cedar Valley	Limestone	10.3	0
Aurora South	SW¼ SW¼ SW¼ Sec. 18, T. 90 N., R. 7 W.	Hopkinton	Dolomite	1.4	0
Butler					0
Austinville	NW¼ SW¼ SW¼ Sec. 19, T. 90 N., R. 18 W.	Aplington	Dolomite	18.2	7
Cerro Gordo					
Buffalo Slough	NW¼ SW¼ SW¼ Sec. 45, T. 97 N., R. 20 W.	Shell Rock	Limestone	1.4	0
Claybanks	NE¼ SW¼ NW¼ Sec. 35, T. 96 N., R. 19 W.	Lime Creek	Shale	8.1	0
Bird Hill	NW¼ NE¼ NE¼ Sec. 24, T. 95 N., R. 19 W.	Lime Creek	Shale	10.1	0
Clayton					
St. Olaf	NE¼ SE¼ SW¼ Sec. 16, T. 94 N., R. 5 W.	Dunleith	Limestone	.2	0
Strawberry Point	NE¼ NE¼ NW¼ Sec. 20, T. 91 N., R. 6 W.	Hopkinton	Dolomite	8.5	0
Clinton					
Goose Lake	SE¼ NW¼ SE¼ Sec. 21, T. 83 N., R. 5 E.	Hopkinton	Dolomite	25.0	0
Maquoketa South	SW¼ NW¼ SW¼ Sec. 5, T. 83 N. R. 3 E.	Hopkinton	Dolomite	5.3	11
Delaware					
Earlville	NW¼ NW¼ SW¼ Sec. 4, T. 88 N., R. 4 W.	Hopkinton	Dolomite	18.5	1
Dundee	NE¼ SW¼ SE¼ Sec. 31, T. 90 N., R. 5 W.	Hopkinton	Dolomite	1.9	0
Buck Creek	Sec. 9, T. 87 N., R. 4 W.	Hopkinton	Dolomite	0.1	0
Dubuque					
Roosevelt Road	W½ SE¼ SW¼ Sec. 7, T. 89 N., R. 3 E.	Dunleith	Dolomite	8.7	0

Table 1: cont.

Site Name	Location	Bedrock Formation(s)	Bedrock Type	Size (ha)	Abundance of *B. campestre*
Fayette					
Foot	SW¼ NW¼ SE¼ Sec. 16, T. 95 N., R. 10 W.	Waucoma	Limestone	2.0	0
Fayette East	NW¼ SW¼ SE¼ Sec. 28, T. 93 N., R. 8 W.	Wapsipinicon	Limestone	6.8	0
Wadena	SE¼ NE¼ NW¼ Sec. 26, T. 93 N., R. 7 W.	Blanding	Dolomite	22.9	0
Floyd					
Idlewild 1	NE¼ SE¼ SW¼ Sec. 5, T. 96 N., R. 16 W.	Lithograph City	Limestone	20.7	0
Idlewild 2	NE¼ NW¼ SW¼ Sec. 5, T. 96 N., R. 16 W.	Lithograph City	Limestone	7.1	0
Beemis Creek	NW¼ NW¼ NW¼ Sec. 6, T. 94 N., R. 18 W.	Lime Creek	Limestone	2.7	52
Rockford Brick Pit	SW¼ NE¼ NW¼ Sec. 16, T. 95 N., R. 18 W.	Lime Creek	Shale	6.5	0
Juniper Hill	NE¼ NE¼ NE¼ Sec. 17, T. 95 N., R. 18 W.	Lime Creek	Shale	10.1	0
Hanes	NW¼ SW¼ SE¼ Sec. 8, T. 95 N., R. 18 W.	Lime Creek	Shale	15.0	0
Franklin					
Hampton East	S½ NE¼ NW¼ Sec. 6, T. 91 N., R 19 W.	Hampton	Limestone	18.4	4
Howard					
Florenceville	SW¼ NW¼ NE¼ Sec. 27, T. 100 N., R. 11 W.	Cedar Valley	Dolomite	10.1	5
Turkey River	NW¼ NW¼ NE¼ Sec 2, T. 98 N., R. 11 W.	Cedar Valley	Dolomite	0.2	0
Jackson					
Hamilton	NE¼ SE¼ NE¼ Sec. 23, T. 84 N., R. 3 E.	Hopkinton	Dolomite	8.1	6
Jones					
Jerdan Creek	SW¼ NW¼ NE¼ Sec. 33, T. 86 N., R. 3 W.	Hopkinton	Dolomite	0.1	0
Mineral Creek	SE¼ SE¼ SE¼ Sec. 32, T. 85 N., R. 1 W.	Hopkinton	Dolomite	6.6	0
Canton	NW¼ NE¼ NE¼ Sec. 18, T. 85 N., R. 1 W.	Hopkinton	Dolomite	2.3	0
Linn					
Matsell	NE¼ SE¼ SE¼ Sec 26, T. 85 N., R. 5 W.	Gower	Dolomite	2.1	5
High Point	SW¼ SW¼ NW¼ Sec. 16, T. 85 N., R. 5 W.	Gower	Dolomite	0.4	0
Baty	NE¼ SW¼ SW¼ Sec. 10, T. 86 N., R. 7 W.	Cedar Valley	Limestone	3.3	22
Troy Mills Quarry	SW¼ NW¼ SE¼ Sec. 9, T. 86 N., R. 7 W.	Wapsipinicon	Limestone	4.2	3
Mitchell					
St. Ansgar	NW¼ SW¼ SW¼ Sec. 12, T. 99 N., R. 18 W.	Lithograph City	Limestone	13.7	0
Winneshiek					
Ludwig	NE¼ SW¼ NW¼ Sec. 25, T. 97 N., R. 10 W.	Ft. Atkinson	Limestone	3.1	3

Search Methods and Habitat Parameters

The presence or absence of *B. campestre* was recorded from all bedrock-substrates, slope-aspects, and slope-positions within each site. Species occurrence was assessed within and among sites through linear transects approximately 10 cm wide, which were created by parting the grass and other foliage at ground level. Transects ran from the bottom to top of each slope and were placed on all slope-aspects found on a site. Surveys ranged from 60-90 min. per site.

Bedrock substrate was divided into three categories: carbonates (limestone and/or dolomite), sandstone, and shale. We surveyed 43 different bedrock exposures. Slope-aspects were divided into eight categories: north (aspect from 337.5o-22.5o), northeast (22.5o-67.5o), east (67.5o-112.5o), southeast (112.5o-157.5o), south (157.5o-202.5o), southwest (202.5o-247.5o), west (247.5o-292.5o), and northwest (292.5o-337.5o). We surveyed 133 different slope-aspect positions. Slope-positions were divided into four categories based on the generalized hillslope positions of Ruhe (1975): summits, shoulders, backslopes, and footslopes. Toeslopes were not sampled as they were not present on any of the sites surveyed. We surveyed 119 slope positions. The size and location of sites (in state plane coordinates) were determined through digitization of USDA county soil or USGS 7.5 min. topographic maps.

Statistical Analyses

Contingency table analyses were used to assess whether substrates, slope-aspects, and slope-positions significantly differed between sites that harbored B. campestre and sites that did not. The effect of slope-aspect and slope-position on species distribution within sites of occurrence was also analyzed using contingency tables. The effect of substrate on species distribution within sites was not tested as 95% of inventoried sites possessed only single bedrock types.

In all but one of these tables, predicted values were sparse (<5) in more than one-fifth of cells. This situation could not be addressed by simply increasing sample size due to the rarity of northeastern Iowa glade sites, which harbor *B. campestre*. As such, the Pearson chi-square test was not used to analyze these tables. Because there is no single optimal statistical test in these situations (Zar 1984), each table was analyzed with both the Log-Likelihood Ratio and Fisher's Exact tests. Tables were considered to exhibit non-significant differences when both of these tests generated p-values greater then 0.05, while significant differences were indicated when both tests generated p-values less than 0.05.

RESULTS

Before results from these analyses are reported, an important caveat must be made. *Botrychium campestre* seems to be the epitome of a 'ghost species' (Preston 1962) as its limited population size (fewer than 10 individuals were observed on 9 of 12 stations), small stature (usually less than 4 cm), and tendency to occur only in dense thatch can make it impossible to observe even with intensive sampling. Any information gathered about it will undoubtedly be incomplete. We undoubtedly overlooked this species simply by placing transects a few decimeters distant from individuals. Also, its environmental tolerances are likely wider than observed; we do not doubt that scattered individuals may occur in situations where we observed none. However, we suggest that the 120 individuals encountered during sampling adequately assess the typical preferences of *B. campestre* in glades.

Bedrock Preference

No significant differences were observed between the bedrock substrates found on sites of occurrence and non-occurrence (Log-Likelihood Ratio *P*=0.0785, Fisher's Exact *P*=0.35; Table 2). However, *B. campestre* seemed to exhibit a very clear limitation to carbonate substrates: no populations were observed on either sandstone or shale exposures. While this trend is pronounced, the limited number of sandstone and shale glades in the region precluded statistically significant results.

Table 2. Occurrence of *B. Campestre* in relation to underlying bedrock type.

	Bedrock Type		
Presence of B. campestre	Carbonate	Sandstone	Shale
Yes	12	0	0
No	24	2	5

Log-Likelihood Ratio: 5.089, *P*=0.0785; Fisher's Exact *P*=0.3500

Slope-aspect Preference

No significant differences were observed in the eight slope-aspect categories among sites of occurrence and non-occurrence (Log-Likelihood Ratio *P*=0.7913, Fisher's Exact *P*=0.7929; Table 3). However, within sites of occurrence, the frequency of slope-aspects harboring individuals of *B. campestre* were found to be significantly different from the frequency of slope-aspects not harboring individuals (Log-Likelihood Ratio *P*=0.0031, Fisher's Exact *P*=0.0067; Table 4). While none of the east and west-facing slopes were occupied by this species, 50% of the north-facing, 60% of the south-facing, and 83% of the northwest-facing slopes were occupied (Fig. 2).

Table 3. Frequency of slope-aspect classes between sites of B. campestre occurrence vs. sites of non-occurrence.

Presence of B. Campestre on site	Slope-Aspect							
	N	NE	E	SE	S	SW	W	NW
Yes	6	6	5	6	5	6	8	6
No	11	12	6	6	14	16	9	11

Log-Likelihood Ratio: 3.899, *P*=0.7913; Fisher's Exact *P*=0.7929

Table 4. Effect of slope-aspect on B. campestre distribution within sites of where the species occurs.

Presence of B. Campestre on site	Slope-Aspect							
	N	NE	E	SE	S	SW	W	NW
Yes	3	1	0	1	3	3	0	5
No	3	5	5	5	2	3	8	1

Log-Likelihood Ratio: 21.520, *P*=0.0031; Fisher's Exact *P*=0.0067

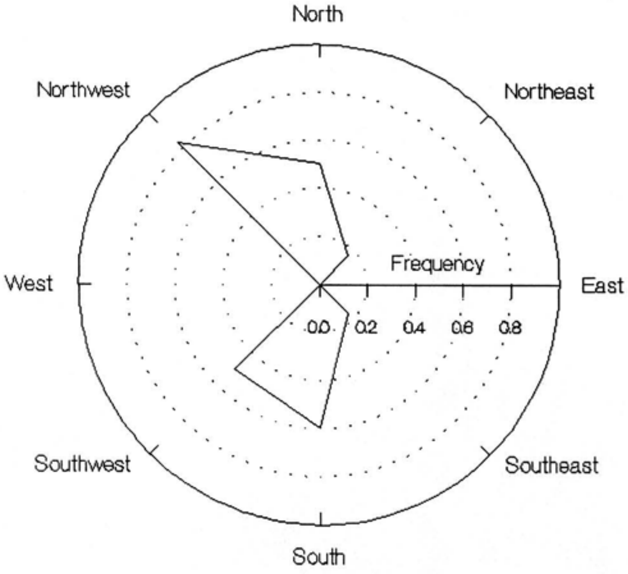

Figure 2. Polar coordinate graph showing the relative frequency of B. campestre on differing slope aspects within sites of B. campestre occurrence.

Slope-position Preference

No significant differences were observed in the four slope-position categories among sites of occurrence and non-occurrence (Log-Likelihood Ratio P=0.8677, Fisher's Exact P=0.8759; Table 5). However, within sites of occurrence, the frequency of slope-positions harboring individuals of B. campestre were found to be significantly different from the frequency of slope-positions not harboring individuals (Log-Likelihood Ratio P=0.0002, Fisher's Exact P=0.0005; Table 6). None of the hillslope summits were occupied by this species, while 83% of shoulders, 42% of backslopes, and 25% of footslopes harbored B. campestre individuals. After removing summits from the contingency table analysis, Log-Likelihood Ratio and Fisher's Exact tests still demonstrated significant differences (P=0.0435 and 0.0283, respectively). Following removal of hillslope shoulders from analysis, the Log-Likelihood Ratio and Fisher's Exact tests were found to be highly non-significant (P=0.4386 and 0.6424, respectively). These analyses demonstrate that on sites of occurrence hillslope shoulders appear to be favored by *B. campestre* over all other hillslope positions.

Table 5. Frequency of slope-position classes between sites of *B. campestre* occurrence vs. sites of non-occurrence.

Presence of B. campestre on site	Slope-Position			
	Summit	Shoulder	Backslope	Footslope
Yes	9	12	12	8
No	15	23	28	12

Log-Likelihood Ratio: 0.7234, *P*=0.8677; Fisher's Exact *P*=0.8759

Table 6. Effect of slope-position on *B. campestre* distribution within sites of where the species occurs.

Presence of B. campestre on site	Slope-Position			
	Summit	Shoulder	Backslope	Footslope
Yes	0	10	5	2
No	9	2	7	6

Log-Likelihood Ratio: 19.526, *P*=0.0002; Fisher's Exact *P*=0.0005

Common Associates

A few additional qualitative observations regarding associated species were made during the course of survey work. All 120 individuals were found emerging from bare soil no more than 15 cm from Andropogon scoparius clumps. Some individuals were found within small *A. scoparius* clumps (<2 cm tall). In habitats where other graminoids (*Poa pratensis*, *Poa compressa, Carex microhyncha, Carex richardsonii*, etc.) or mosses filled the spaces between *A. scoparius clumps, B. campestre* did not occur. *Carex richardsonii* was found within a meter of *B. campestre* individuals at all but one site.

DISCUSSION

Our analyses help document the preferred environment for *B. campestre* in northeastern Iowa glades. This species favors hillslope shoulders while avoiding hillslope summits, appears to prefer northern and southern-facing slopes over eastern and western, and is potentially limited to carbonate substrates in areas immediately adjacent to *Andropogon scoparius* clumps.

Although no statistical difference exists in the frequency of hillslope positions found among sites of occurrence and non-occurrence, hillslope position was found to significantly affect the distribution of *B. campestre* within sites. Over 80% of hillslope shoulders within sites of occurrence were found to harbor this species, while hillslope summits were completely unoccupied. A potential mechanism underlying this marked preference could be related to slightly higher levels of water seepage or runoff on hillslopes. Such a difference is suggested by the slightly more mesic nature of the flora of hillslope shoulders as compared to summits. These observations corroborate the conclusions of Farrar (1985) that *B. campestre* might be less xerophytic than associated species as it emerges only in spring when yearly soil moisture levels are highest and evapotranspiration rates are lowest.

Although no statistical difference exists in the frequency of slope aspects found among sites of occurrence and non-occurrence, slope aspect was found to significantly affect the distribution of *B. campestre* within sites. On sites of occurrence, individuals avoided east and west-facing slopes and occurred in at least 50% of north, northwest, south, and southwest facing slopes. This finding counters Farrar (1985), who suggested that no slope aspect preferences exist within this species. It is possible, however, that these results may be due to a confounding correlation between slope-aspect and other environmental conditions on the sites inventoried. For instance, the absence of *B. campestre* on east-facing slopes at Matsell Bridge may be due to all other slope aspects developing in eolian sands rather than carbonate bedrock on this site. Further analysis will be necessary to allow differentiation of slope aspect affects from those of other environmental variables.

The qualitative positive association noted between *Botrychium campestre* and *Andropogon scoparius* was unexpected. A potential explanation may exist in the well developed relationships most members of the genus *Botrychium* have with mycorrhizal fungi (Lellinger 1985, Wagner and Wagner 1993). If *B. campestre* can only become established in the presence of a mycorrhizal host, which is itself restricted to *A. scoparius*, the affinity of these two taxa could be explained. Further investigation into the association among *B. campestre*, A. scoparius, and associated mycorrhizal fungi will be needed to decipher the exact nature of this relationship.

Even though the small sample size of sandstone and shale glade sites precluded the substrate analysis from being statistically significant, based upon our observations the limitation of individuals to carbonate exposures was a very important feature defining the preferred niche of *B. campestre*. This perception is based in large part on the effect substrate seemed to play on the local distribution of *B. campestre* where environmental factors, rather than dispersal limitation, should be more important in explaining distributional pattern. Thus, although no shale glades harbored this species, the largest single population occurred less than 10 km away on a carbonate glade site (Beemis Creek). At the Troy Mills Quarry and Matsell Bridge sites all individuals were restricted to limestone outcrops, but were absent from seemingly identical vegetation on sandy substrates a few meters away.

The apparent restriction of *B. campestre* to carbonate outcrops in the vicinity of *A. scoparius* is puzzling. Great Lakes populations of *B. campestre* are restricted to sand areas (Hazlett 1991), and may be associated with *Calamovilfa longifolium* var. *magna* (Wisconsin Heritage Program Database), the dominant grass of Lake Michigan dune communities.

CONCLUSIONS

Our study documented some of the important attributes that define the niche of *B. campestre* in northeastern Iowa glades, and also suggested additional questions that, when addressed, will further refine the conservation strategies directed to this species. First, the apparent differences in ecological niche between the northeastern Iowa and Great Lakes populations should be more carefully investigated. Given the complete aversion of the northeastern Iowa populations to conditions apparently required by the Great Lakes populations, that two closely-related taxa may be present instead of just one. Second, the exact nature of the association between *B. campestre* and *A. scoparius* needs to be studied to determine why these two autotrophs so consistently co-occur. Third, the mechanisms that limit this species to bare-soil areas should be addressed. Fourth, the exact nature of the slope-aspect relationship should be studied to determine if and why this species avoids east and west-facing slopes. Lastly, to help land managers better care for populations within sites, the role of herbivory on mortality and dispersal, and the effect of fire on population vigor and reproductive rate should be investigated.

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