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Studies on the Endangered *Echinacea tennesseensis* (Asteraceae): Plant Community and Demographic Analysis

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ABSTRACT

Echinacea tennesseensis (Beadle) Small is a federally endangered vascular plant species endemic to the limestone cedar glades of the Central Basin of Tennessee. The vegetation associated with each of the five known populations of *E. tennesseensis* was sampled in 1987, and its population demographics were analyzed based on observations of 492 marked individuals over two years. Although vegetative cover and species' frequency varied among sites, *Echinacea tennesseensis* is an important component of the vegetation at all five sites, and a dominant at three sites. The vegetation of four sites is relatively similar, but the fifth site differs in species composition and reflects a history of human disturbance. In both growing seasons mortality was highest among the smallest plants. A critical stage of growth (>30 cm total leaf length) at which survivability increases was identified. Plants that have not reached this stage have only a 50% chance of surviving an extreme summer drought such as that of 1988. Nearly half of the plants that produced flowers in 1987 did not produce flowers in the exceedingly dry summer of 1988; however, of these, 68% flowered in 1989. In addition, mortality was higher in year 1 (1987–88) than in year 2 (1988–89). These differences between years are attributable to the higher rainfall recorded during the 1989 growing season, and they demonstrate that flowering is sporadic and most likely dependent on growing season rainfall.

INTRODUCTION

Echinacea tennesseensis (Beadle) Small is a federally endangered endemic of the cedar glades (i.e., horizontal outcrops of Lebanon limestone and associated shallow soils) of Middle Tennessee (Baskin and Baskin 1986, USDI/FWS 1979). The glades are discontinuous and small (0.25–5 hectares) and they account for approximately 5% of the area of the Central Basin, which occupies most of Middle Tennessee (Quarterman 1950). Only five extant populations of *E. tennesseensis* were known in 1987: two in Wilson County (Vesta and Vine sites), one in Rutherford County (Allvan site), and two in Davidson County (Couchville and Mt. View sites). Lack of adequate dispersal mechanisms and limited specialized habitat are thought to contribute to the rareness of the species (Hemmerly 1976).

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Echinacea tennesseensis is an herbaceous perennial that does not flower in the first growing season after germination, even under optimal greenhouse conditions (Clebsch, pers. obs.). In the non-flowering stage, the habit of *E. tennesseensis* is a basal rosette of linear leaves from a taproot. At anthesis, one to ten (up to 20) stems are clustered on a well-developed taproot with basally disposed leaves and generally one flowering head per stem.

Historically the taxonomic status of *E. tennesseensis* has been disputed. Whereas Cronquist (1980) considers *E. tennesseensis* an eastern outlier of *E. pallida* var. *angustifolia,* McGregor (1968) recognizes *E. tennesseensis* as a distinct species. In a recent review based on numerous comparative studies on the genetics (Baskauf 1993), morphology, anatomy, chromosome number, geographical distribution, and root chemistry, Baskin et al. (1993) conclude *E. tennesseensis* warrants specific recognition.

There are three primary objectives of this study: 1) To describe and compare the vegetation associated with each of the five populations; 2) To analyze demographic data regarding the stage class distribution and population dynamics of the species; and 3) To estimate the total number of individuals in each population. This study involves some of the initial phases of research outlined in the Tennessee Coneflower Recovery Plan (Somers et al. 1982).

The overall goals are to obtain baseline data on the population structure of *E. tennesseensis* and on the structure of the community in which the species occurs. These data will provide insights useful in the management of this rare species. In addition, assessing the fate of marked individuals will establish a feasible method of monitoring population growth or decline in the future.

METHODS

Vegetation Analysis

The vegetation associated with each of the five populations was sampled in late summer of 1987 using 0.5 m^2 plots (70.7 cm × 70.7 cm) positioned along transects at 4 m intervals across each site. Parallel transects were placed 4 m apart. The number of plots per site (30–96) were stratified based on the area occupied by *Echinacea tennesseensis.* The Couchville population was unique in its relatively large area and its degree of patchiness, and required modification of the sampling strategy. Two areas (approximately 50 m × 50 m) with the highest densities of *E. tennesseensis* were selected for sampling; areas with low densities and/or small patches were not sampled.

In each plot, percent cover of each vascular plant species and total percent cover were estimated. In the few plots with overlapping layers of vegetation, only the cover of the uppermost layer was estimated so that the sum of the individual species percentages equaled the total cover. Total percent cover and percent cover of each species were averaged for each site. Differences in total percent cover among sites were determined using the Kruskal-Wallace Test and Duncan's Multiple Range Test (Sokal and Rohlf 1969). Nomenclature follows Baskin et al. (1968), Fernald (1950), Small (1933) and Gleason (1952).

The total number of *E. tennesseensis* plants per population was estimated using the average density (plants/m^2) and the total area occupied by *E. tennes-*

Table 1. **Total areal size of *Echinacea tennesseensis* populations, density of *E. tennesseensis* and estimated number of *E. tennesseensis* plants by site**

Site	Total Area (m^2)	Average Density ($plants/m^2$)	Estimated Total # Plants
Allvan	470	6.2	3,700
Couchville	13,860	6.2	89,300
Mt. View	830	12.9	12,000
Vesta	1,420	13.1	20,900
Vine	800	20.7	20,200
Total	17,370	—	146,000

seensis (Table 1); plants scattered outside the sampled areas were counted individually.

Demographics

In summer 1987, 492 individuals of *Echinacea tennesseensis* were systematically selected and measured. In each 0.5 m^2 plot, the nearest five individuals to the plot center were marked using color-coded roofing nails. For non-flowering individuals, length of each leaf was measured, and for flowering individuals the number of flowering heads was counted. Total leaf length is assumed to indicate relative photosynthetic capacity in non-flowering plants, and number of flowering heads provides an estimate of reproductive capacity in flowering plants. Plants lose their leaves during anthesis, and thus total leaf length is not a good indicator of photosynthetic or reproductive capacity for plants in flower.

Each plant was assigned one of seven stage classes based on total leaf length (0–30 cm, 31–70 cm, or >70 cm which will be referred to as the "1st, 2nd, and 3rd" stage classes, respectively) for non-flowering plants, and number of flowering heads (1, 2–3, 4–8, or >8 which will be referred to as "4th, 5th, 6th, and 7th" stage classes, respectively) for flowering plants. The sample data were used to construct stage class distributions for each population and were also combined to construct a stage class distribution for the species.

The tagged plants were measured again in late summer of 1988 and 1989. Mortality of marked individuals and plants with missing markers were recorded; seedling recruitment was not recorded. In 1988, 456 of the original 492 plants were relocated and measured; in 1989, only 203 of the original 492 plants were relocated. The high percentage of markers lost in 1989 was due presumably to heavy rains that washed markers (and often small plants) from the thin soil; tags were frequently observed downslope from their original position. Plants with missing markers were excluded from the analysis, thus mortality is underestimated.

One-year transition matrices based on the Lefkovich model (Lefkovich 1965) were calculated from the combined data of all five sites for year 1 (1987–88) and year 2 (1988–89). These one-year transition matrices were then tested for temporal constancy (Anderson and Goodman 1957), which exists when the

Table 2. Percent cover and frequency of important species (≥2% cover at any site) by site

	Allvan		Couchville		Mt. View		Vesta		Vine	
No. of Plots:	30		48		55		96		33	
Mean Richness:	8.2 ± 2.1		6.4 ± 1.6		5.3 ± 1.8		5.4 ± 1.8		4.9 ± 1.2	
Taxon	% Cover	Freq.	% Cover	Freq.	% Cover	Freq.	% Cover	Freq.	% Cover	Freq.
Aster pilosus var. *priceae*	8	0.60	—	—	—	—	—	—	—	—
Echinacea tennesseensis	3	0.57	2	0.77	10	0.63	8	0.48	12	0.73
Grindelia lanceolata	11	0.90	2	0.73	—	—	—	—	—	—
Houstonia nigricans	—	—	12	0.88	—	—	2	0.19	11	0.82
Hypericum sphaerocarpum	2	0.27	—	—	3	0.53	—	—	—	—
Isanthus brachiatus	2	0.43	—	—	—	—	—	—	—	—
Petalostemon gattingeri	5	0.50	—	—	6	0.47	4	0.55	2	0.27
Ruellia humilis	2	0.53	—	—	4	0.67	2	0.44	—	—
Andropogon scoparius	4	0.27	14	0.60	—	—	6	0.42	3	0.33
Silphium trifoliatum	8	0.43	—	—	—	—	—	—	—	—
Sporobolus vaginiflorus	6	0.47	3	0.75	16	0.87	11	0.68	7	0.73
Others (48 spp.)	7	—	6	—	6	—	9	—	7	—
Total cover*	58	—	39	—	45	—	42	—	42	—

* Allvan site determined to have significantly higher ($P \le 0.05$, Kruskall-Wallace and Duncan's Multiple Range Test) total cover than other sites.

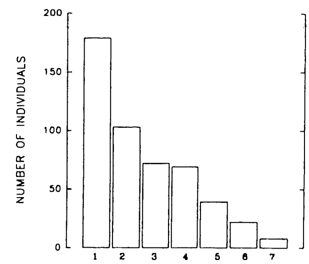

Figure 1. Number of individuals in each stage class (1987 census) using combined data of all sites (1 = total leaf length of 1–30 cm, 2 = total leaf length 31–70 cm, 3 = total leaf length of >70 cm, 4 = one flowering head, 5 = 2–3 flowering heads, 6 = 4–8 flowering heads, 7 = >8 flowering heads.

probability of moving from one stage class to another stage class is the same each year.

RESULTS AND DISCUSSION

Vegetation Analysis

Total vegetative cover associated with *Echinacea tennesseensis* was low at all sites (<60%), and the species composition varied among sites (Table 2). Of the 59 vascular plant taxa sampled, 11 species had ≥2% cover at one or more sites, and are used in the following analyses to describe and compare the vegetation of the five sites. Frequency of occurrence of these species is consistently high (Table 2), indicating they are not localized within the sampling area. Complete species lists are provided in Drew (1991).

Four of the five sites (Couchville, Mt. View, Vesta, and Vine) were similar in species composition. The dominant species (in terms of percent cover and frequency) of these sites (*Houstonia nigricans, Petalostemon gattingeri, Andropogon scoparius,* and *Sporobolus vaginiflorus*) are typical of relatively undisturbed cedar glades in Middle Tennessee (Somers et al. 1986, Baskin et al. 1968, Baskin and Baskin 1975). This conclusion is consistent with field observations on approximately 300 glades in Middle Tennessee (Drew, pers. obs.).

The vegetation of the Allvan site differed from the other four sites, probably as a result of human disturbance. The dominant species of the Allvan site (*Grindelia lanceolata, Silphium trifoliatum,* and *Aster pilosus* var. *priceae*) were absent from the other sites, or were present in low frequency and percent cover. Conversely, the dominant species of the other four sites were present only in low frequencies and low percent cover at the Allvan site (Table 2).

Heavy equipment operation and dumping have been documented for the Allvan site (Somers et al. 1982). *Grindelia lanceolata,* the species with the highest percent cover and highest frequency at the Allvan site, is considered by Baskin et al. (1968) to be "common and abundant; principally in disturbed areas." In addition, mean richness per plot and total percent cover is higher at Allvan than the other sites (Table 2).

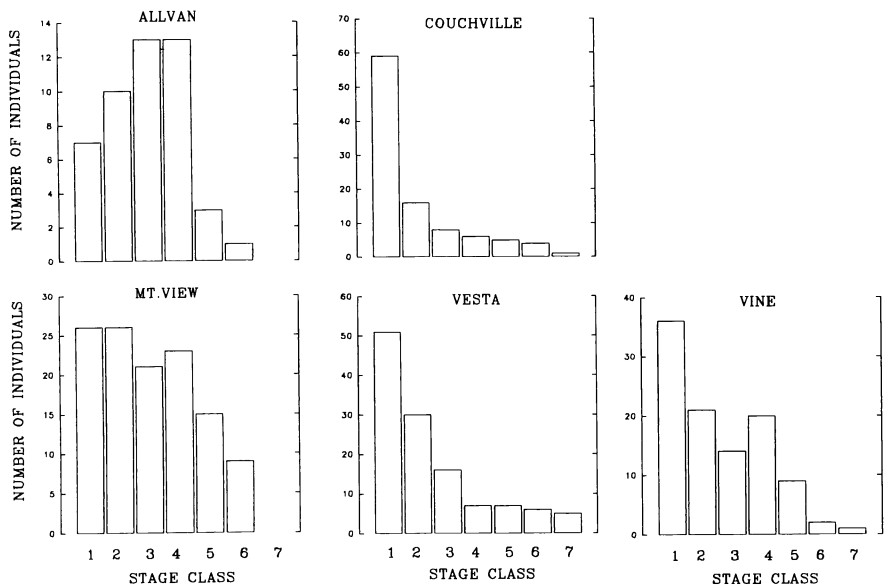

Figure 2. Number of individuals in each stage class by site in 1987 (1 = total leaf length of 1–30 cm; 2 = total leaf length of 31–70 cm, 3 = total leaf length of >70 cm, 4 = one flowering head, 5 = 2–3 flowering heads, 6 = 4–8 flowering heads, 7 = >8 flowering heads).

At all sites, *Echinacea tennesseensis* had ≥2% cover and a frequency of ≥0.48. It is a co-dominant at the Mt. View, Vesta, and Vine sites. Although mean density of *E. tennesseensis* is highest at the Vine site, the estimated total number of plants and the area occupied by *E. tennesseensis* are highest at the Couchville site. Estimated total number of plants and area occupied by *E. tennesseensis* are lowest at the Allvan site (Table 1).

Demographics

The stage class distribution of the initial (1987) sample population using combined data (Figure 1) displays classical type III survivorship. The number of small plants (i.e., individuals in stage classes with decreased total leaf length) far exceeds the number of large plants (i.e., individuals in stage classes with increased total leaf length and number of flowering heads). This pattern of survivorship is common in long lived, *K*-selected plant species (Barbour et al. 1987).

Stage class distributions from individual sites (with the exception of the Allvan site) demonstrate the same general trend of survivorship (Figure 2). The stage class distribution at Allvan suggests high mortality among small plants at this site, possibly due to increased competition with ruderal species.

Transition probability matrices often are used to predict future population structure if the assumptions of the model are met. Because transition probabilities

Table 3. Transition probabilities for year 1 (1987–88). Number of individuals in each transition is shown in parentheses

Stage[1] Class	1	2	3	4	5	6	7
1	0.161 (27)	0.094 (9)	0.076 (5)	0.046 (3)	—	—	—
2	0.185 (31)	0.167 (16)	0.045 (3)	0.062 (4)	0.059 (2)	—	—
3	0.161 (27)	0.323 (31)	0.409 (27)	0.462 (30)	0.324 (11)	0.095 (2)	—
4	0.006 (1)	0.073 (7)	0.182 (12)	0.092 (6)	—	0.095 (2)	—
5	—	0.031 (3)	0.121 (8)	0.015 (1)	0.235 (8)	0.286 (6)	—
6	—	—	—	0.015 (1)	0.118 (4)	0.286 (6)	1.0 (6)
7	—	—	—	—	—	—	—
Dead	0.488 (82)	0.313 (30)	0.167 (11)	0.308 (20)	0.265 (9)	0.238 (5)	—
Total	168	96	66	65	34	21	6

[1] Where 1 = leaf length 0–30 cm, 2 = leaf length 31–70 cm, 3 = leaf length >70 cm, 4 = one flowering head, 5 = 2–3 flowering heads, 6 = 4–8 flowering heads, 7 = >8 flowering heads.

determined by this study (Tables 3–4) are not constant through time ($\chi^2 = 444.2$, df = 56, $p < 0.001$ for the pair of matrices of year 1 and 2), and recruitment data are lacking, it is not possible to predict future population structure. However, these transition matrices do suggest trends in the population dynamics and allow comparisons of mortality rates among stage classes and/or between years.

Mortality was much higher in year 1 than in year 2. High mortality in year 1 was most likely due to the extreme drought during the 1988 growing season (12.23 inches of precipitation between March 1 and August 31, 1988 recorded in Nashville, Tennessee by the National Oceanic and Atmospheric Administration). Higher total rainfall for the growing season of 1989 (27.32 inches between March 1 and August 31, 1989) and a concomitant decrease in recorded mortality support this relationship. However, the large proportion of plants omitted from the analysis in 1989 confound these findings.

Mortality decreased with increased leaf length (plant size), and among flowering plants it decreased with higher numbers of flowering heads (Tables 3 and 4). Similar results have been documented in numerous studies of perennial and biennial plants (Gross and Werner 1983, Bierzychudek 1982, Gross 1981, Werner 1975).

The mortality data identify a critical stage of growth (>30 cm cumulative leaf length) at which drought tolerance increases. In this study, plants with a total leaf length ≤30 cm had a high probability of dying during the exceedingly dry growing season. Hemmerly (1976) observed much lower mortality (approximately 15–20%) in first year *Echinacea tennesseensis* seedlings of this stage

Table 4. **Transition probabilities for year 2 (1988–89). Number of individuals in each transition is shown in parentheses**

Stage[1] Class	1	2	3	4	5	6	7
1	0.160	0.028	—	—	0.050	—	—
	(4)	(1)			(1)		
2	0.360	0.222	0.045	0.100	—	—	—
	(9)	(8)	(4)	(2)			
3	0.240	0.444	0.416	0.050	0.200	—	—
	(6)	(16)	(37)	(1)	(4)		
4	—	0.278	0.180	0.300	—	—	—
		(10)	(16)	(6)			
5	—	—	0.191	0.350	0.350	—	—
			(17)	(7)	(7)		
6	—	—	0.146	0.200	0.400	0.308	—
			(13)	(4)	(8)	(4)	
7	—	—	0.011	—	—	0.615	—
			(1)			(8)	
Dead	0.240	0.028	0.011	—	—	0.077	—
	(6)	(1)	(1)			(1)	
Total	25	36	89	20	20	13	0

[1] Where 1 = leaf length 0–30 cm, 2 = leaf length 31–70 cm, 3 = leaf length >70 cm, 4 = one flowering head, 5 = 2–3 flowering heads, 6 = 4–8 flowering heads, 7 = >8 flowering heads.

class, but these observations were made during the growing season of 1971 in which near average rainfall was recorded for Nashville, Tennessee (23.56 inches between March 1 and August 31).

Forty-one percent of the plants that flowered in 1987 failed to flower in 1988. Of the plants that failed to flower in 1988, 68% flowered in 1989. The 4th stage class had the greatest deviation from constancy ($\chi^2 = 219.5$, df = 7, $p < 0.001$). Many of the plants in this stage class died in year 1 (30.8%) or did not flower (57.0%), whereas the "4th" stage class plants in year 2 had 0% mortality, and 85% of them flowered (Tables 3 and 4). Thus, individuals display plasticity in demographic behavior that seems dependent on the amount of rainfall of a particular growing season.

This study provides basic knowledge of the community structure and of short-term fluctuations in *E. tennesseensis* populations. Additional research on *E. tennesseensis* should focus on the causes of high mortality among small non-flowering plants. Specifically the role of competition, the physiology of drought stress, and the effect of natural erosion caused by surface wash of heavy rains should be addressed. Habitat management options including the effects of fire, soil disturbance, and mowing regimes should be examined.

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