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The effects of management treatments on Tennessee coneflower, *Echinacea tennesseensis* (Beadle) Small; Wilson County, Tennessee

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Edward M. Maclin

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Dedication

This thesis is dedicated to my parents,

Glenn M. Maclin

and

Judy H. Maclin

Acknowledgments

Volumes could be written to thank all those upon whom I have relied during the recent months. Specifically, though, I would like to thank my major professor, Dr. Ed Clebsch, for his unyielding patience and support, along with my other committee members, Dr. Cliff Amundsen and Dr. Sally Horn; their poignant advice and catalyzing questions were invaluable. Thanks also to Andrea Shea and the Tennessee Department of Environment and Conservation for providing the grant that funded these experiments, as well as Dr. Bill Sanders for providing the incomplete block design and statistical assistance. I would especially like to thank my wife, Amy, for her unending mental, spiritual, and fiscal support over the course of my studies. Thanks to my entire family across the state of Tennessee. Thanks to my many friends, both inside the Botany Department and out, for being my link to sanity, and to all those who stayed for the ride even though they thought it would never end. And last, but not least, thanks to the Tennessee coneflower, whose stubborn recalcitrance in the face of my manipulations forced me into a wider view of myself and the natural world.

Abstract

The Tennessee coneflower, *Echinacea tennesseensis* (Beadle) Small, is an endangered, endemic composite of the cedar glades and barrens of middle Tennessee. As part of the recovery plan for the species as laid out by the U.S. Fish and Wildlife Service, experiments were conducted to determine the effects of various management treatments on the species. Treatments included mowing, burning, discing, and all combinations of these treatments, as well as herbicidal removal of grasses and a trample treatment designed to test the impact of standing on plants during research. Results indicate that *E. tennesseensis* is not significantly impacted by mowing, discing, burning, or combinations of these habitat disturbances. Herbicidal removal of grasses produced a negative effect on density of *E. tennesseensis* adults. Trampling produced a negative effect on density of *E. tennesseensis* juveniles, but a positive effect on density of *E. tennesseensis* seedlings and on the mean number of flower heads per adult. Several other members of the cedar glade community were also impacted by the treatments, including *Croton* spp. and *Schizachyrium scoparium*. Effects on *E. tennesseensis* were limited due to the timing of the treatments and to the root system of the plant, which is often protected within cracks in the surface limestone. Significant effects of treatments on *E. tennesseensis* and other species were likely due to microsite changes in light penetration and moisture retention. Recovery of the species will depend upon continued habitat protection and development of new populations.

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1. Introduction

The management of endangered species for conservation is a multifaceted endeavor, the salient features of which are a deep understanding of the species' role in the natural environment and a realization of all possible human impacts on the population, for good or for ill. The management of endangered plant species draws heavily from the fields of plant ecology and systematics, but also entails a break from the normal "scientific detachment" into the provinces of politics and public relations.

The management of the Tennessee coneflower, *Echinacea tennesseensis* (Beadle) Small, is particularly important not only because of its endangered status, but also due to the fourfold value of the species—as a source of immunostimulatory chemicals, a source of natural insecticidal agents, a landscaping herb, and an aesthetically enjoyable constituent of its natural habitat. The case of the Tennessee coneflower is also particularly interesting since the continuation of the species may depend not only on the minimization of negative human impacts, but also upon the maintenance of conditions that were more prevalent at the end of the Pleistocene Epoch, including sparse tree cover, frequent climatic extremes, and highly calcareous soils (Miller 1988; Delcourt, H.R. et al. 1986).

The genus *Echinacea* has a rich ethnobotanical history, and Native Americans of the Great Plains gave it many names. The Pawnee called it *ksapitahako*, after a child's game in which the plants were used, or *saparidu kahts*, meaning "mushroom medicine," apparently in reference to the shape of the flower head. The Omaha-Ponka named it *Mikahi* (comb plant) or *ikigahai* (comb).

It appears that *Echinacea* species were among the most widely used of medicinal plants, being called upon as a treatment for cancer, colds, colic, cramps, toothache, and snakebite, among many other ailments (Foster 1985).

The recent resurgence of herbal remedies in popular culture has pointed the way toward an increase in the utilization of the *Echinacea*s. Recent studies have indicated that *Echinacea* species contain ingredients that improve the function of the immune system, with hundreds of papers on the pharmacology, chemistry, and clinical applications of the genus available in the literature (Foster 1990). *Echinacea purpurea* is widely used in Germany as an immunostimulant. Recent tests have also shown that the genus is a producer of a natural insecticide, echinacein (Caster and Myers 1987), and attempts are being made to genetically manipulate the genus to increase production of beneficial chemicals (Myers 1990).

Unfortunately, the increased public awareness of the genus' uses may be its downfall. Although *E. purpurea* is grown commercially, the supply has been unable to meet the demand for herbal products, and all *Echinacea* species have experienced a dramatic decline in the wild as commercial collection has increased. The Tennessee coneflower, due to its small numbers, is particularly vulnerable to this trend, as well as to the increase in off-road vehicle activity within the species' range.

To this point, efforts to conserve the species have focused mainly upon limiting the public's access to glade habitats where *Echinacea tennesseensis* occurs through the placement of large boulders as blockades to off-road traffic, as well as signs proclaiming the presence of "fragile glade plants." While traffic has certainly decreased in general, it should be noted that some disturbances do still occur, including removal of marker flags placed as part of this study. As a result, education of the public as to the value of undisturbed glade areas and the importance of conservation in general is becoming a focal point for further work.

This study focused on the effects of cultivation, mowing, burning, and removal of grassy competitors as possible beneficial techniques for managing the remaining populations of *E. tennesseensis* in its native habitat at the Vesta Glade Natural Area in Cedars of Lebanon State Forest, where a protected, naturally occurring population of *E. tennesseensis* was available for study.

2. Background

Tennessee coneflower, *Echinacea tennesseensis* (Beadle) Small, is an endemic species of the cedar glades and barrens of middle Tennessee. Cedar glades (also limestone or dolomite glades) are natural, treeless areas characterized by limestone or dolomite bedrock at or near the surface (Baskin and Baskin 1986). Glades are areas in which more than 50 percent of the grass cover is composed of annual grass species. A barren, on the other hand, is an area in which more than 50 percent of the grass cover is composed of perennial grass species (Drew 1991). Cedar glades are located primarily within the Ozark Plateaus of Missouri and Arkansas and the Interior Low Plateaus of Tennessee, and are so named due to the prevalence of Red Cedar, *Juniperus virginiana* L., in and around such sites.

In the southeast, the flora of the cedar glades consists of over 400 taxa of vascular plants, including 29 endemic taxa, several of which are endangered or nearly endangered (Baskin and Baskin 1986). Of the native flora in the cedar glades, 50 percent is at least somewhat characteristic of prairies and glades outside the region, and 35 of the non-endemic taxa have distribution centers to the west or northwest (Bridges and Orzell 1986). Baskin and Baskin (1986) propose that several cedar glade endemics whose center of distribution is in the western United States migrated into the southeast from the Ozarks or the southwest. The cedar glades have apparently acted as a refugium since the end of the Pleistocene, when the Tennessee climate was more suited to prairie species (Delcourt, H.R. et al. 1986). The role of fire in maintaining *E. tennesseensis* populations since the end of the Pleistocene has been questioned in the past

(Delcourt, P.A. et al. 1986) and is at this writing undergoing further observation (Roach and Sutter 1990).

Echinacea tennesseensis (Beadle) Small is most closely related to *E. angustifolia* DC. var. *angustifolia,* a species native to the dry barrens and prairies stretching from Texas to Canada (Baskin and Baskin 1986). *E. tennesseensis* is somewhat larger than *E. angustifolia*, with more leafy, softly pubescent stems and smaller pollen grains. It is particularly characterized by upturned ray flowers, rather than the drooping ones common to other *Echinacea*s (Foster 1985). *E. tennesseensis* was first described as *Brauneria tennesseensis* by Beadle in 1898 and moved to *Echinacea tennesseensis* in 1933 by Small. There have been differing views on the taxonomic status of *E. tennesseensis,* based mainly on A. Cronquist's joining of the species with *E. angustifolia* DC. var. *angustifolia* into *E. pallida* (Nutt.) Nutt. var. *angustifolia* (DC.) Cronq. versus the continued separation of the two species favored by R.L. McGregor (Baskin et al. 1993). Baskin and associates (1993) go on to conclude that *E. tennesseensis* and *E. angustifolia* should be recognized as distinct species based on a combination of morphology, anatomy, chromosome number, geographical distribution (McGregor 1968), root chemistry (Bauer et al. 1990), and genetics (Baskauf 1993).

The Tennessee coneflower was first reported by Dr. A. Gattinger in 1878 at LaVergne, Tennessee, but was not found in 1968 and was believed to be extinct (Hemmerly 1986). At the time of Mark Drew's demographic studies in 1990, five populations were known to exist in the wild (Drew 1991), but since that time an additional five populations have been discovered, all within a 15-mile radius east of Nashville, Tennessee. The area in which all known *E. tennesseensis* populations have been found and the location of the Vesta Glade Natural Area are shown in Figure 1. It is probable that, before the increase in development of the Nashville area during this century, stands of the species were more widespread than at present.

On June 6, 1979, the Tennessee coneflower, *Echinacea tennesseensis* (Beadle) Small was officially listed as a federally endangered species by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 1989). It is ranked by The Nature Conservancy as a G1 species (Roach and Sutter 1990), giving it a high priority for protection. As is required by federal law, a recovery plan for the species has been developed (U.S. F&WS 1989), under the auspices of which the present research is being conducted.

Among the requirements of the recovery plan are the introduction of Tennessee coneflower into new areas and the development of cultivated specimens for seed. To this end, study of the species' life cycle has been undertaken by Baskin and Baskin (1982) and Hemmerly (1976, 1986). Baskin and Baskin, in addition to studying distribution patterns of glade species (1986), have conducted experiments on the effects of vernalization and photoperiod on flowering in the Tennessee coneflower, demonstrating that the species does not require vernalization for flowering. The studies of Hemmerly (1976, 1986) have shown that *E. tennesseensis* has low competitive ability and a lack of seed dispersal mechanisms, which may be responsible for the plant's endemism. Populations apparently enjoy the ability to maintain themselves via allelopathic effects on some competing species and thrive under cold, wet winters which ensure good germination.

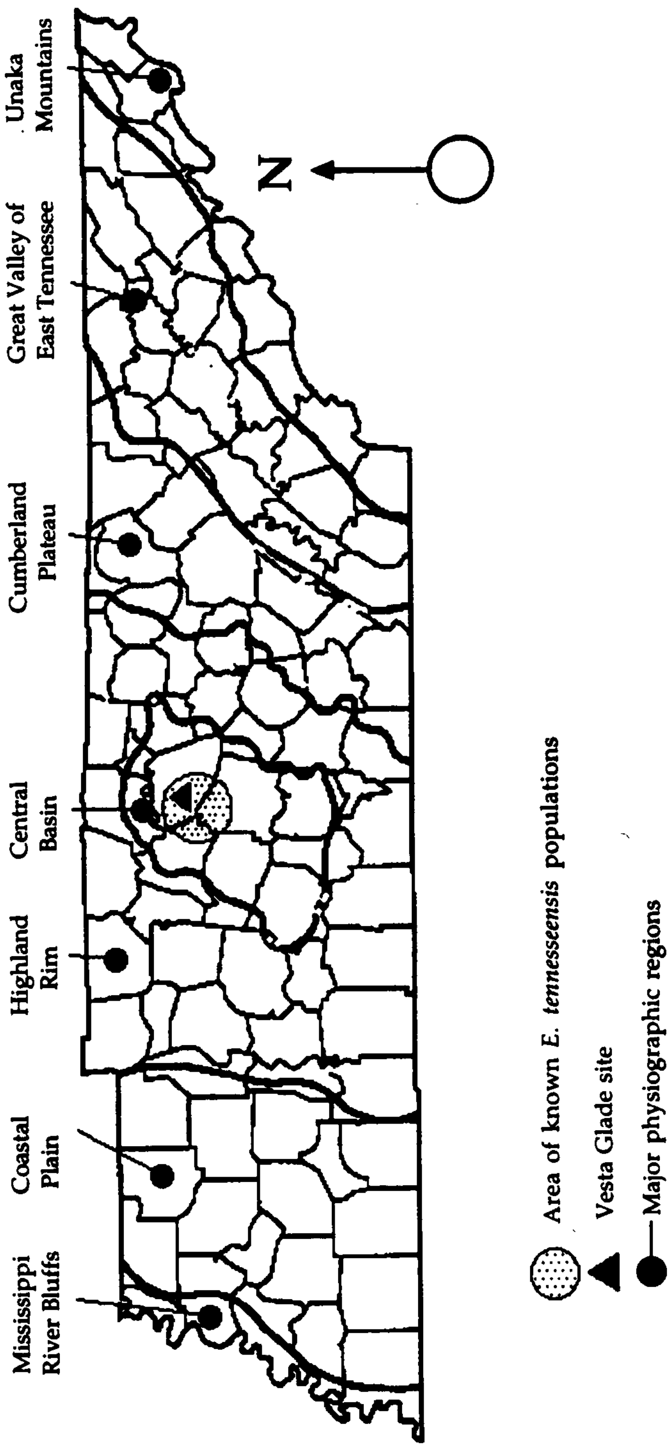

Figure 1: Area of known *E. tennesseensis* populations and location of the Vesta Glade Natural Area.

Mark Drew's (1991) exhaustive work contains the results of demographic studies, including a listing of major taxa and communities at five sites (Allvan, Couchville, Mt. View, Vesta, and Vine); mean soil depth by community; ratio of juvenile to adult plants; and data reflecting percent cover of *Echinacea*, other species, and litter. His study determined that the population appeared to be in no immediate danger of extinction at four of the five sites, the Allvan site being the exception (Drew 1991). Several methods developed by Drew (1991) were applicable to this study, including a qualitative life stage ranking system based on the number of flowering heads produced by one plant, in which plants are categorized as either seedlings (first-year growth), juveniles (more than one year of growth, but with no flowering heads), or adult (with flowering heads).

3. Site Description

The Vesta Glade Natural Area is located in Wilson County, Tennessee, just east of the small community of Vesta in an area marked by karst topography and dotted with small farms and horse ranches. The property itself is overseen by the Tennessee Division of Forestry, whose equipment and effort were used in installing the first set of experimental treatments. The Tennessee coneflower population at the Vesta Glade site is distributed through three main clusters, the largest of which was unavailable for use during layout of the first set of treatment blocks due to the still ongoing work of Drew (1991) in the area. Figure 2 shows the layout of experimental plots across the site, as well as the topography of the area and distribution of Tennessee coneflower. Statistically there is no significant variation among these three clusters, based on the density of *E. tennesseensis* seedlings, juveniles, or adults. The site, as with many cedar glades, is characterized by high levels of heterogeneity across several spatial scales. During two years of study at the site, 91 species of plants were observed within the experimental plots, including several species that are considered to be rare or endangered by either the state or federal government (Table 1). Some of the most common of these species are listed by mean percent cover and mean frequency in Table 2.

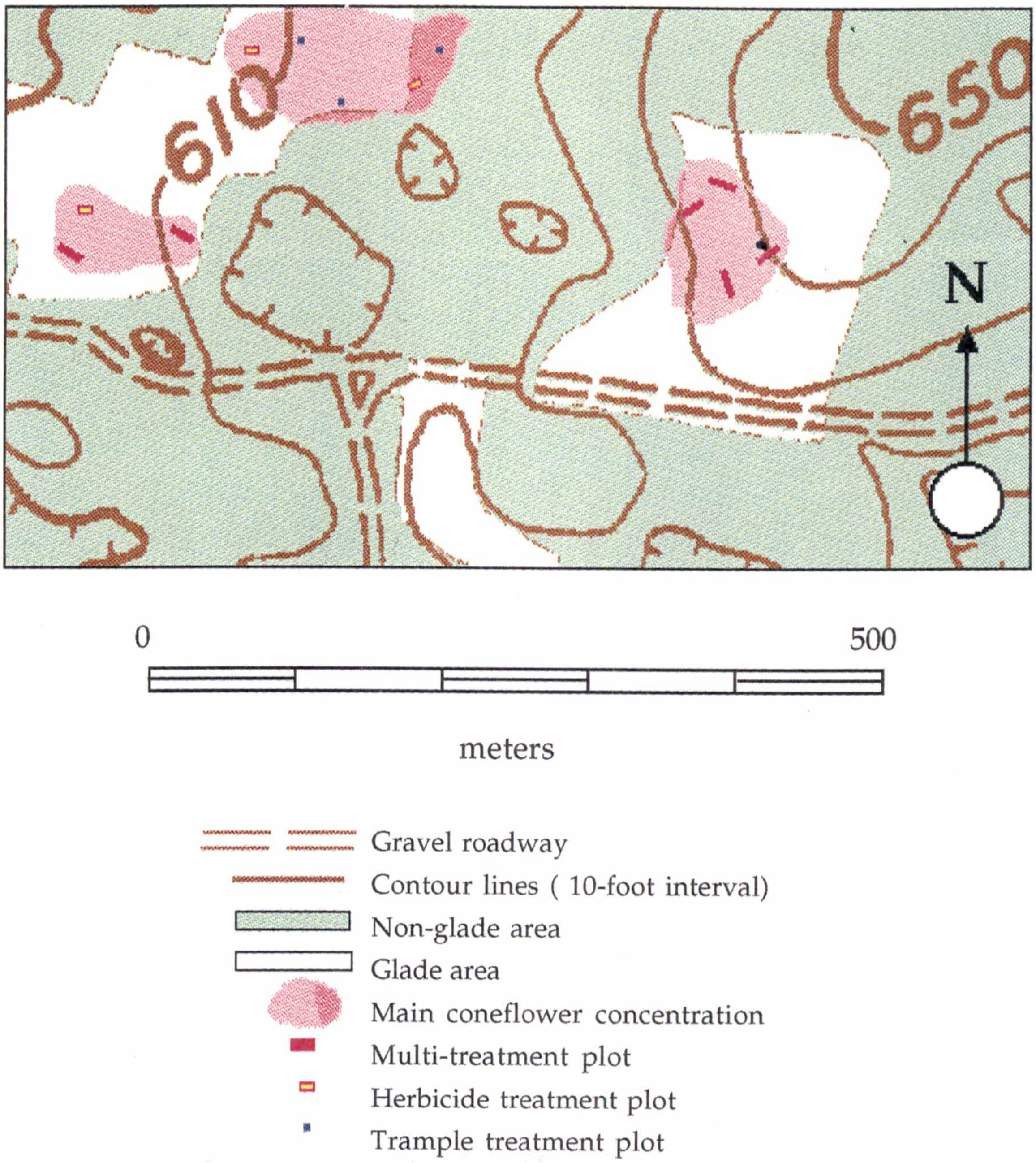

Figure 2: *E. tennesseensis*, experimental plots, and topography at the Vesta Glade Natural Area

Table 1. Species associated with *E. tennesseensis* at the Vesta glade site. Special notations are as follows:
Introduced - *; endemic - END; Listed by Tennessee as endangered, threatened, or of special concern - E, T, S respectively; listed by the federal government as endangered or as a candidate for the endangered list - LE, C2 respectively.

Species Name	Species Name	Species Name
Allium vineale L.*	*Fraxinus americana* L.	*Physalis virginiana* Mill.
Ambrosia artemesiifolia L.	*Galactia volubilis* (L.) Britton	*Polygala verticillata* L.
Arenaria patula Michx.	*Galium* sp.	*Prunella vulgaris* L.*
Asclepias verticillata L.	*Gleditsia triacanthos* L.	*Prunus* sp.
Asclepias viridiflora Raf.	*Grindelia lanceolata* Nutt.	*Pycnanthemum* sp.
Asclepias viridis Walt.	*Hedeoma hispidum* Pursh	*Quercus muhlenbergii* Engelm.
Aster sp.	*Hedyotis* sp.	*Rhus aromatica* Aiton
Bignonia capreolata L.	*Helianthus divaricatus* L.	*Rhus copallina* L.
Bouteloua curtipendula (Michx.) Torr.	*Helianthus hirsutus* Raf.	*Rosa carolina* L.
Carex sp.	*Heliotropium* sp.	*Ruellia humilis* Nutt.
Celtis laevigata Willd.	*Hypericum frondosum* Michx.	*Salvia lyrata* L.
Cercis canadensis L.	*Hypericum sphaerocarpum* Michx.	*Schizachyrium scoparium* (Michx.) Nash
Chamaecrista fasciculata Michx.	*Hypoxis hirsuta* (L.) Coville	*Scutellaria sp.*
Chamaecrista nictitans L.	*Ipomoea pandurata* (L.) G.Mey.	*Senecio aureus* L.
Cirsium sp.	*Juniperus virginiana* L.	*Silphium terebinthinaceum* Jacq. var. *pinnatifidum* (Elliot) A.Gray -T
Clematis viorna L.	*Lactuca* sp.	*Sisyrinchium* sp.
Clitorea mariana L.	*Lespedeza cuneata* (Dum.Cours.)G.Don*	*Smilax bona-nox* L.
Croton spp.	*Linum* sp.	*Solidago* sp.
Dalea gattingeri (A.Heller) Barneby	*Lithospermum canescens* (Michx.) Lehm.	*Sorgastrum nutans* (L.) Nash
Danthonia spicata (L.) P.Beauv. ex Roem. & Schult	*Lobelia appendiculata* A.DC. var. *gattingeri* (A.Gray) McVaugh-C2	*Sporobolus vaginiflorus* (Torr. ex. A.Gray) A.W.Wood
Daucus carrota L.*	*Manfreda virginica* (L.) Rose	*Stylosanthes biflora* (L.) Britton, Sterns, & Poggenb.
Delphinium sp.	*Matelea carolinensis* (Jacq.) Woodson	*Symphoricarpus orbiculatus* Moensch
Dioscorea sp.	*Onosmodium molle* Michx. -S	*Trichostema brachiatum* L.
Echinacea tennesseensis (Beadle) Small - LE,E,END	*Opuntia humifusa* (Raf.) Raf.	*Triosteum sp.*
Erigeron strigosus Muhl. ex Willd.	*Oxalis* sp.	*Ulmus alata* Michx.
Euphorbia chamaesyche L.*	*Panicum* sp.	*Ulmus rubra* Muhl.
Euphorbia corollata L.	*Parthenocissus quinquefolia* (L.) Planch.	*Verbesina virginica* L.
Euphorbia dentata Michx.	*Passiflora lutea* L.	*Verbena simplex* Lehm.
Festuca pratensis Huds.*	*Pediomelum subacaule* (Torr. & A.Gray) Rydb.	*Verbena* sp.
Forestiera ligustrina (Michx) Poir.	*Phlox bifida Beck* ssp. *stellaria* (A.Gray) Wherry -C2,T	*Viburnum rufidulum* Raf.

Table 2. Common species of Vesta Glade listed by mean percent cover and frequency (F). Data averaged from that collected in treatment plots.

MEAN % COVER	(F)	SPECIES NAME
7.96	92.9	*Echinacea tennesseensis*
2.88	76.7	*Grindelia lanceolata*
1.95	70.4	*Sporobolus vaginiflorus*
0.52	62.1	*Ruellia humilis*
0.28	61.3	*Croton* spp.
5.02	59.8	*Schizachyrium scoparium*
0.75	45.4	*Hedyotis* sp.
0.49	41.7	*Manfreda virginica*
0.67	37.5	*Phlox bifida* ssp. *stellaria*
1.26	34.6	*Helianthus divaricatus*
0.74	32.9	*Hypericum sphaerocarpum*
1.87	29.6	*Helianthus hirsutus*
7.96	23.3	*Cercis canadensis*
0.14	11.3	*Onosmodium molle*
1.69	6.3	*Prunus* sp.
0.28	4.2	*Silphium terebinthinaceum* var. *pinnatifidum*
0.02	3.3	*Lobelia appendiculata* var. *gattingeri*

4. Methods

The main objectives of this study were to analyze, interpret, and report on the results of habitat management treatments at Vesta Glade Natural Area near Nashville, Tennessee. The treatments included: control (1); disc (2); burn (3); mow (4); mow and disc (5); burn and disc (6); mow and burn (7); and mow, burn, and disc (8). (In the analysis of the data, treatments will be referred to by the numbers used above.) Herbicidal elimination of competing grasses on selected sample plots was also tested, along with the effects of foot traffic on the welfare of *E. tennesseensis* and its associated community at the Vesta Glade site.

In July 1991, six sample plots divided into four sections measuring 4 m by 4 m each (a total of 24 sections) were marked and sampled for baseline vegetation data by Dr. Ed Clebsch and Mark Drew of the University of Tennessee Department of Botany. In December 1991, these sections became home to a set of experimental management treatments, precisely installed by employees of the state of Tennessee. The management treatments were of eight types and each was set in triplicate.

The management techniques being tested included discing (a cultivation method utilizing two series of large, sharp metal discs set in parallel and pulled tangentially across the ground in a direction slightly deviated from perpendicular to their combined edge front), mowing (sometimes referred to as bushhogging, in reference to the common name of a large, tractor-drawn mower), burning, and all possible combinations of two or more of the above. An unviolated control serves as the eighth treatment type.

During May and July 1992, and again in May and July 1993, the experimental plots were resampled, utilizing a 1 m^2 sampling quadrat formed from four equal lengths of common PVC pipe. The sampling quadrat was laid out in two locations within each 4 m by 4 m experimental unit, 1 meter toward the square's center from each of two predetermined opposite corners, in the same orientation as the larger block. Data regarding changes in *E. tennesseensis* population cover and age structure over the two-year period of the experiment were gathered, with the life stage structure of the population determined qualitatively by the method advanced by Drew (1991) in which adults are defined as flowering individuals, juveniles are defined as non-flowering individuals more than one year old, and seedlings are defined as being any individuals in their first year of growth (as determined by the presence of cotyledons or, when absent, the presence of only two small leaves less than 3 cm in length). Simultaneously, percent cover of other glade species and exotics, along with substrate types, was estimated, allowing for exploration of the treatment's impacts on other individual species, as well as community level processes.

During June 1992, separate plots were established at the Vesta Glade site for the purpose of determining the effect of the removal of competing grasses from among the coneflower population, both by hand and chemically, using Poast® Postemergence Grass Herbicide (Sethoxydim 18.0%). These experimental competition removal plots were sampled in the spring of 1993 and, following spraying with herbicide, the summer of 1993.

Also during the spring of 1993, three plots, each 1 m^2 in size, were established for the purposes of quantifying the "bigfoot effect": the amount of measurable disturbance in experimental results caused by trampling. After initial counts and coverages were obtained in the same manner as above, heavy trampling was applied for a period of no less than two minutes per plot and was not repeated. These plots were resampled in early August of 1993.

5. Analysis of Data

The first series of treatments at the Vesta Glade site was laid out according to an incomplete block design for the purpose of maximizing use of the very limited space available. The design consisted of six plots or blocks, each containing four experimental units. Three replications of each of the eight treatments were spread through this design. The incomplete block design calls for a complicated intrablock analysis to compensate for variation between blocks (John 1980). Fortunately, the analysis was simplified by the inclusion of an initial ANOVA, which indicated that the interblock effect was not significant. Because of this, that parameter was not included in the analysis.

The selective herbicide treatments presented a simpler case from the start, constituting a complete block design with only two treatment levels replicated three times in three separate blocks. The zero treatment level of the herbicide treatment also acted as control for the trample treatment plots, made possible by the lack of significant variation between the blocks of the two treatments.

The data collected throughout the study were entered into a series of Lotus 1-2-3 spreadsheets and analyzed using the ANOVA procedure within SAS. The actual analysis was performed in two steps, the first being a generalized two-way ANOVA testing for differences among all treatments, and the next being a more specific series of two-way ANOVA designed to look more closely at trends indicated by the first set. In the first analysis step, an ANOVA with two factors crossed was carried out with the two factors being 1) the treatment type and 2) the date on which the variables were measured. In the case of the first treatment series, significant variation among treatment areas was not enough to determine the true effect of the actual treatments since, even before imposition of the treatments, there was significant variation between treatment locations for many of the variables that would be tested. Significant interaction between the treatment and date factors shows what may be the result of specific treatments, and in cases where this interaction was not significant at the 0.25 level, no further analysis was undertaken. The second step of the analysis consisted of a comparison of the control to each of the other treatments for those variables that showed significant interaction in the previous step.

5.1. Analysis of the first treatment series

Analysis of the effects of the first group of treatments (disc; burn; mow; disc and burn; burn and mow; disc and mow; and disc, burn, and mow) showed no significant effect of any treatment on the density of *E. tennesseensis* seedlings, juveniles, or adults based on treatment X date interaction in the analysis of variance, with values for the probability of a greater F of 0.78 for seedlings, 0.98 for juveniles, and 0.86 for adults.

In the ANOVA for determination of treatment effects on the number of flower heads per adult, the data collected in May were disregarded in an attempt to minimize variation due to date. In this case, also, no significant effect over the course of the study was seen, with a probability of a greater F of 0.93.

Analysis was also carried out to determine treatment effects on percent cover of other species, especially rare species and potentially competing grasses and woody stems, as well as on the overall vegetative cover of the site and the composition of the substrate layer. Results of the data analysis are further summarized below in Table 3. Significant results indicate a rejection of the null hypothesis (H_0: There is no significant variation between the first eight treatments due to treatment X date interaction), in favor of the alternative (H_a: There is significant variation between the first eight treatments due to treatment X date interaction). Of all variables considered, the only ones that were affected significantly were percent cover of *Croton* spp. (both *Croton capitatus* and *Croton monathogynus*) and the percent of total substrate made up of both litter and bare soil.

Although these three variables were significantly affected by the treatments over the full three-summer course of the study, further analysis shows that, considering only the initial pre-treatment data (July 1991) and the final data collected (July 1993), no long-term effect can be found (Table 4). In the first year following treatment imposition, there was a significant increase in both soil as percent of total substrate and percent cover of *Croton* spp., as well as a significant decrease in percent of total substrate listed as litter resulting from treatments 2 (disc), 3 (burn), 6 (mow, burn), and 8 (disc, burn, mow). In addition, treatment 5 (disc, burn) showed a significant increase in the percent cover of *Croton* spp., and treatment 7 (disc, mow) showed an increase in the percent of total substrate listed as bare soil (Table 5). See Appendix A for a graphic representation of mean coverage for substrate categories (Figure A-1) and species other than *E. tennesseensis* over the course of the study.

The lack of significant effects of these treatments on *E. tennesseensis*, as well as the spatial and temporal variation in the population, is illustrated in Figure 3.

Table 3. Probability of greater F values from ANOVA of the first eight treatments for various variables. Values below 0.25 (indicated by asterisks) are significant at the 0.25 level.	
VARIABLE CONSIDERED	PR > F
Density of *E. tennesseensis* seedlings	0.78
Density of *E. tennesseensis* juveniles	0.98
Density of *E. tennesseensis* adults	0.86
Mean # of *E. tennesseensis* flower heads/adult	0.93
%Cover of *E. tennesseensis*	0.99
%Cover of *Onosmodium molle*	0.89
%Cover of *Lobelia appendiculata*	0.83
%Cover of *Phlox bifida* ssp. *stellaria*	0.99
%Cover of *Silphium terebinthinaceum* var. *pinnatifidum*	1.00
%Cover of *Schizachyrium scoparium*	0.70
%Cover of *Croton* spp.	0.009*
%Cover of *Grindelia lanceolata*	0.98
%Cover of *Ruellia humilis*	0.96
%Cover of *Sporobolus vaginiflorus*	0.91
Total %cover of all grasses	0.86
Total %cover of all woody plants	1.00
Total %cover of all species present	0.79
Total # of species per m^2	0.75
Litter : % of total substrate	0.09*
Flagstone : % of total substrate	0.39
Soil : % of total substrate	0.0008*
Gravel : % of total substrate	0.91
Moss : % of total substrate	0.54
Lichen : % of total substrate	0.98

Table 4. Probability of greater F values from ANOVA of the first eight treatments for various variables with only the pre-treatment(July 1991) and first summer post-treatment (July 1992) data considered. Values below 0.25 (indicated by asterisks) are significant at the 0.25 level.	
VARIABLE CONSIDERED	PR > F
%Cover of *Croton* spp.	0.65
Litter : % of total substrate	0.67
Soil : % of total substrate	0.59

Table 5. Probability of greater F values from ANOVA comparison of control with each of the remaining seven treatment types over the first year (July 1991 and July 1992);. Values below 0.25 (indicated by asterisks) are significant at the 0.25 level.							
VARIABLE CONSIDERED	PR > F BY TREATMENT#						
	D	B	M	MD	BD	MB	MBD
%Cover of *Croton* spp.	0.16*	0.09*	0.83	0.14*	0.03*	0.25	0.02*
Litter : % of total substrate	0.08*	0.04*	0.98	0.31	0.16*	0.52	0.02*
Soil : % of total substrate	0.01*	0.04*	0.99	0.31	0.13*	0.11*	0.003*

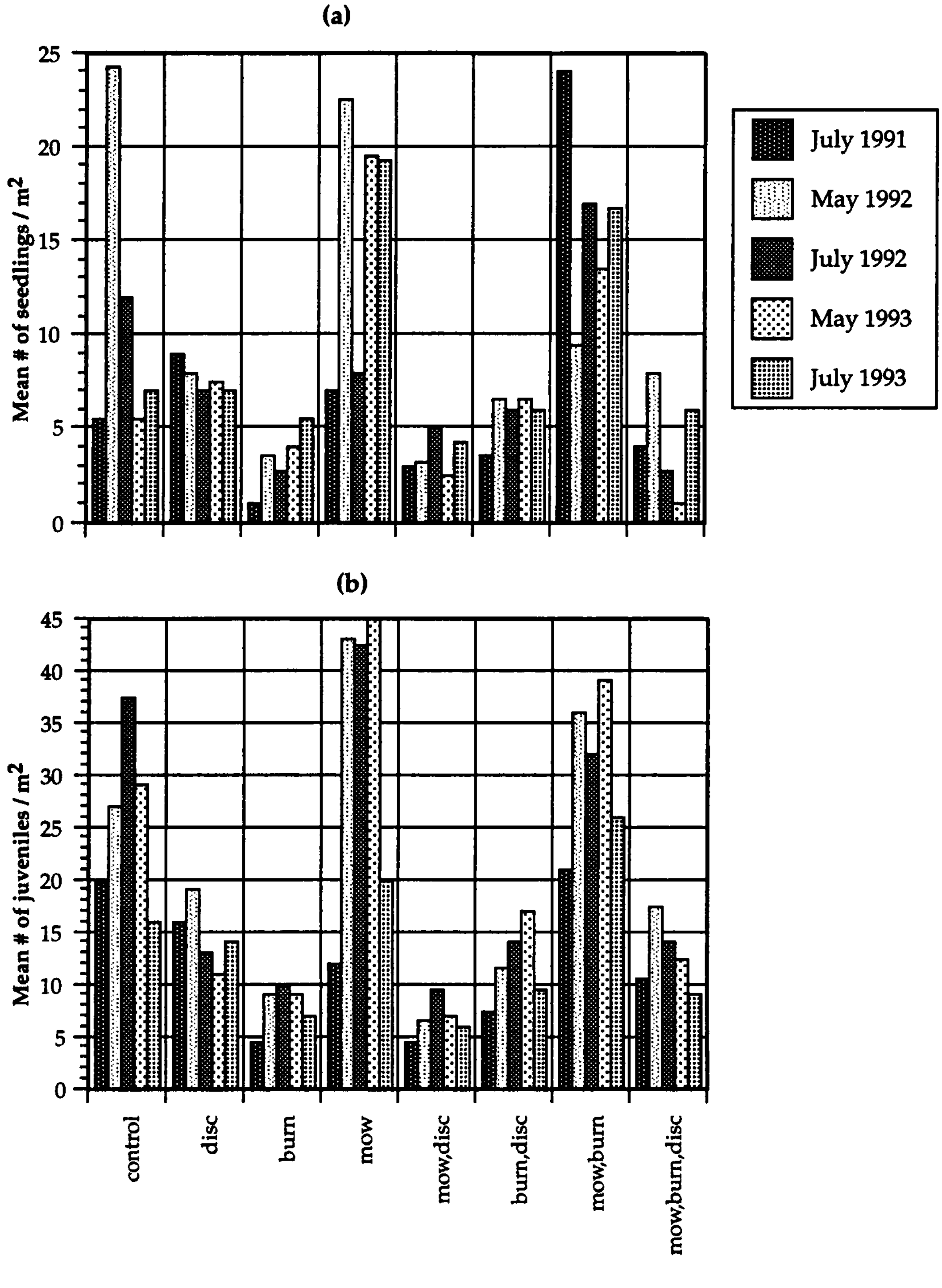

Figure 3: Variation in the *E. tennesseensis* population among treatments and over time: seedling density (a) and juvenile density (b). None of the treatments showed a significant effect at the 0.25 level (continued on next page).

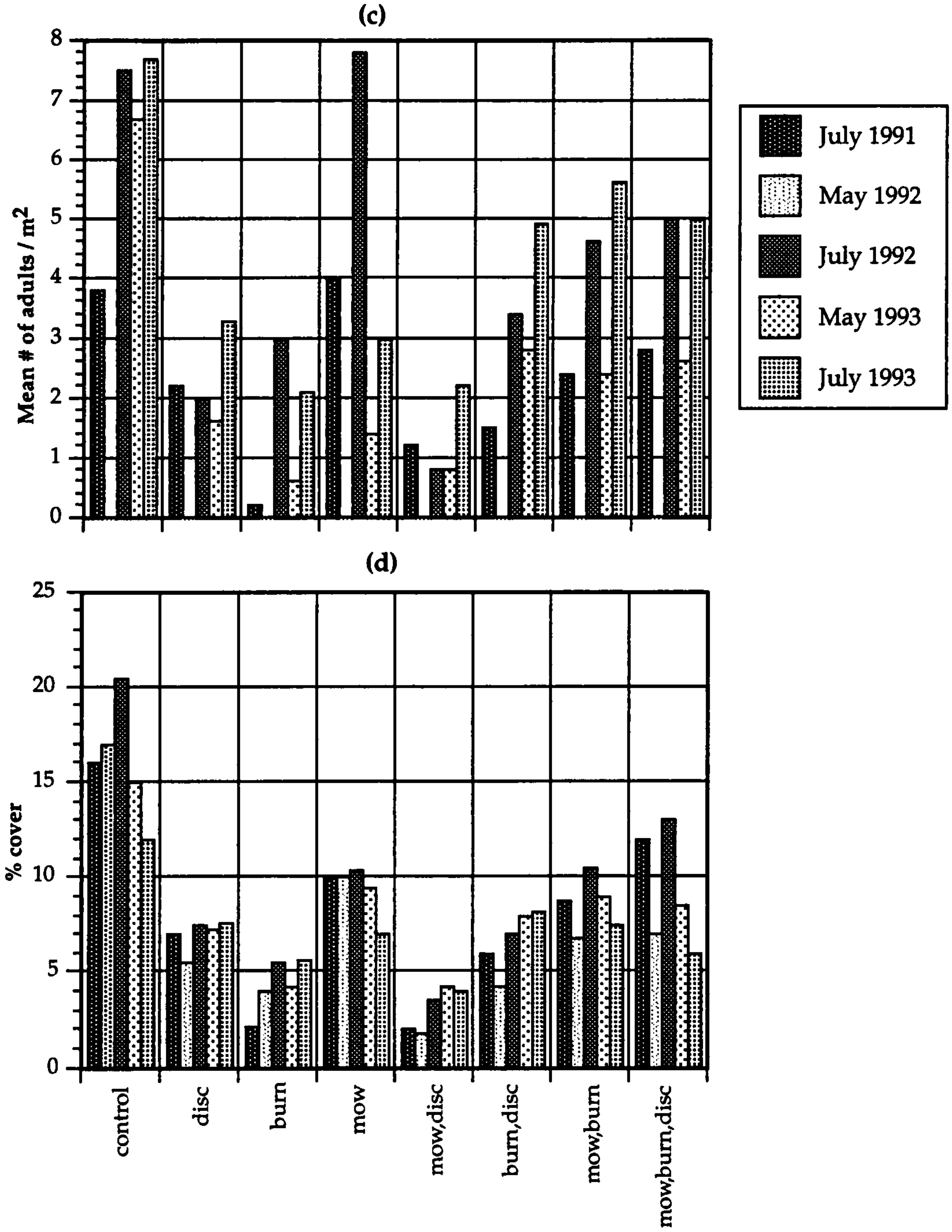

Figure 3: (continued)

Variation in the *E. tennesseensis* adult density (c) and percent cover (d) among treatments and over time. None of the treatments showed a significant effect at the 0.25 level.

5.2. Analysis of the herbicide treatment

The data from the selective herbicide treatment plots were also analyzed by a two-way ANOVA in order to separate from the analysis variation present during the initial May 1993 sample date. As Table 6 shows, the herbicidally treated plots showed treatment X date interactions significant at the 0.25 level for the density of *E. tennesseensis* adults (see Figure 4); the percent cover of *Dalea gattingeri*, *Croton* spp., *Schizachyrium scoparium*, and *Sporobolus vaginiflorus*; and the percent of total substrate made up of mosses. The negative effects of herbicides upon *Sporobolus* and *Schizachyrium* were not unexpected, since the herbicide used (Poast® Postemergence Grass Herbicide) is designed to kill grasses, but the negative effects of treatment on the density of *E. tennesseensis* adults are important, and the effects on *Croton* and *Dalea* are interesting ecologically. Qualitative observation of the herbicidally treated plots indicated an increase in the greenness and vigor of *Croton*, in particular, as well as an apparent increase in the dryness of the soil in areas denuded of grassy vegetation. Since only one year of data is available for this and the trample treatment, it is impossible to say if these effects will persist or if they are only transitory.

5.3. Analysis of the trample treatment

The trample treatment plots were analyzed using the same method and the same control plots as the herbicide treatments. Table 7 shows the probability

Table 6. Probability of greater F values from ANOVA testing for significant variation between the herbicide treatment and control areas. Values below 0.25 (indicated by asterisks) are significant at the 0.25 level.

Variable Considered	Pr > F
Density of *E. tennesseensis* seedlings	0.70
Density of *E. tennesseensis* juveniles	0.83
Density of *E. tennesseensis* adults	0.19*
Mean # of *E. tennesseensis* flower heads/adult	0.80
%Cover of *E. tennesseensis*	0.76
%Cover of *Dalea gattingeri*	0.04*
%Cover of *Hedyotis* sp.	0.46
%Cover of *Schizachyrium scoparium*	0.25*
%Cover of *Croton* spp.	0.007*
%Cover of *Grindelia lanceolata*	0.88
%Cover of *Ruellia humilis*	0.80
%Cover of *Sporobolus vaginiflorus*	0.11*
Total %cover of all grasses	0.76
Total %cover of all woody plants	0.91
Total %cover of all species present	0.91
Total # of species per m^2	1.00
Litter : % of total substrate	0.89
Flagstone : % of total substrate	0.93
Soil : % of total substrate	0.42
Gravel : % of total substrate	0.75
Moss : % of total substrate	0.07*
Lichen : % of total substrate	0.32

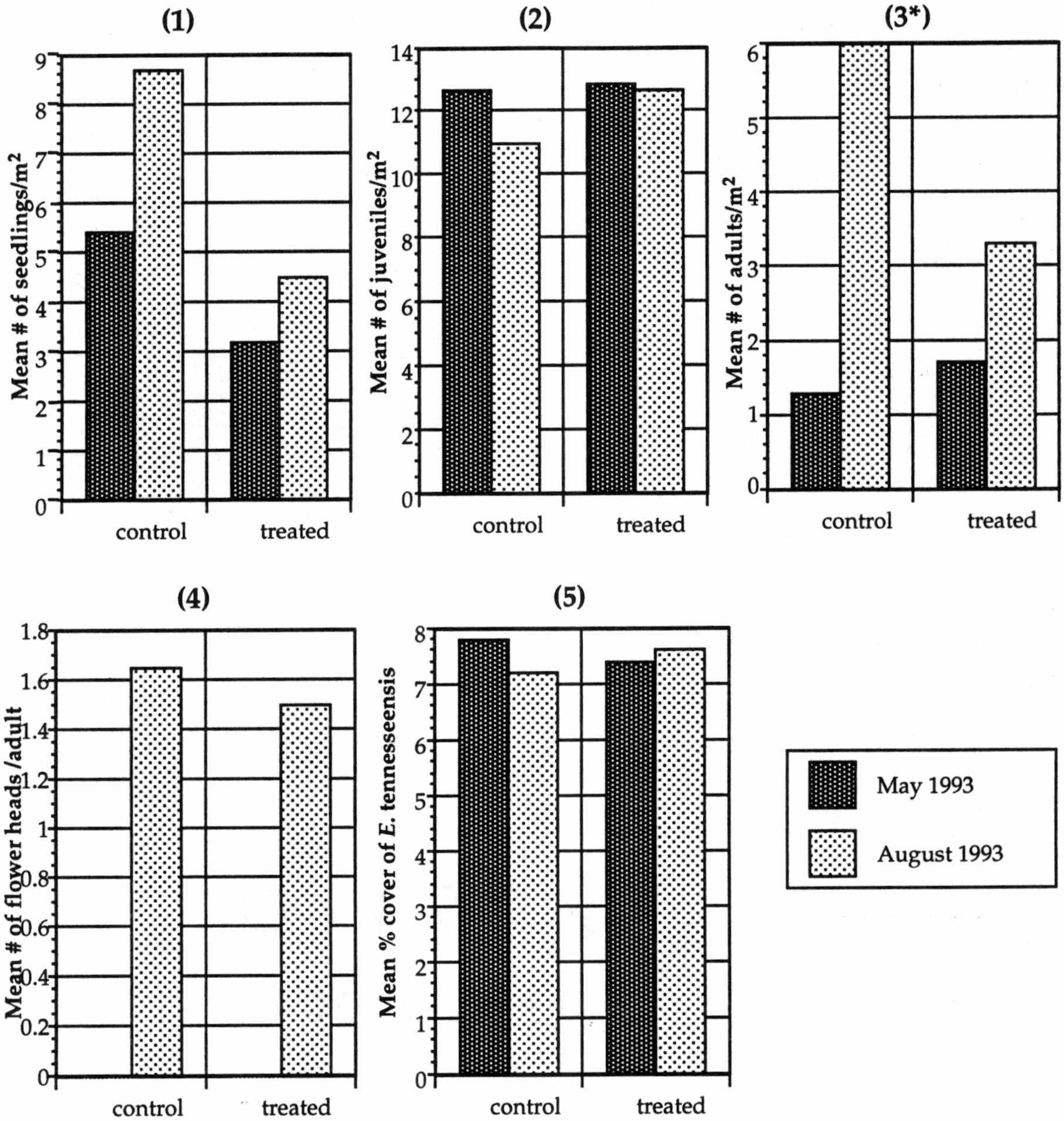

Figure 4: Effects of selective herbicide treatment on *E. tennesseensis* : seedlings (1), juveniles (2), adults (3), flower heads per adult (4), and total percent cover (5). Points significant at the 0.25 level are indicated by asterisks (*).

Table 7. Probability of greater F values from ANOVA testing for significant variation between the trample treatment and control areas. Values below 0.25 (indicated by asterisks) are significant at the 0.25 level.	
VARIABLE CONSIDERED	PR > F
Density of *E. tennesseensis* seedlings	0.03*
Density of *E. tennesseensis* juveniles	0.05*
Density of *E. tennesseensis* adults	0.85
Mean # of *E. tennesseensis* flower heads/adult	0.13*
%Cover of *E. tennesseensis*	0.28
%Cover of *Dalea gattingeri*	0.80
%Cover of *Hedyotis* sp.	0.07*
%Cover of *Schizachyrium scoparium*	0.17*
%Cover of *Croton* spp.	0.21*
%Cover of *Grindelia lanceolata*	0.89
%Cover of *Ruellia humilis*	0.76
%Cover of *Sporobolus vaginiflorus*	0.54
Total %cover of all grasses	0.37
Total %cover of all woody plants	0.70
Total %cover of all species present	0.50
Total # of species per m^2	0.16*
Litter : % of total substrate	0.10*
Flagstone : % of total substrate	0.40
Soil : % of total substrate	0.29
Gravel : % of total substrate	0.42
Moss : % of total substrate	0.21*
Lichen : % of total substrate	0.51

of a greater F for comparison of treated to control areas. The effect of trampling on Tennessee coneflower is shown to be significant for seedling and juvenile density, as well as number of flower heads per adult. In addition, effects were seen on percent cover of *Hedyotis* sp., *Schizachyrium scoparium*, and *Croton* spp., as well as on the mean species richness of the plots and the percent of substrate in the litter and moss categories.

As the graphs in Figure 5 show, the number of seedlings present in the trample treatment plots increased significantly above what was seen in the control plots, while significance in the case of juveniles is related more to the initial high number of coneflower juveniles in the trample plots. Considering only the trample treatment plots, there was a significant decrease in the density of juveniles from May to July of 1993, with a $Pr > F$ value of 0.15 with no corresponding increase in the number of adults to explain the change. In fact, the mean number of adults in the trample plot decreased, though not significantly, with a $Pr > F$ of 0.32 .

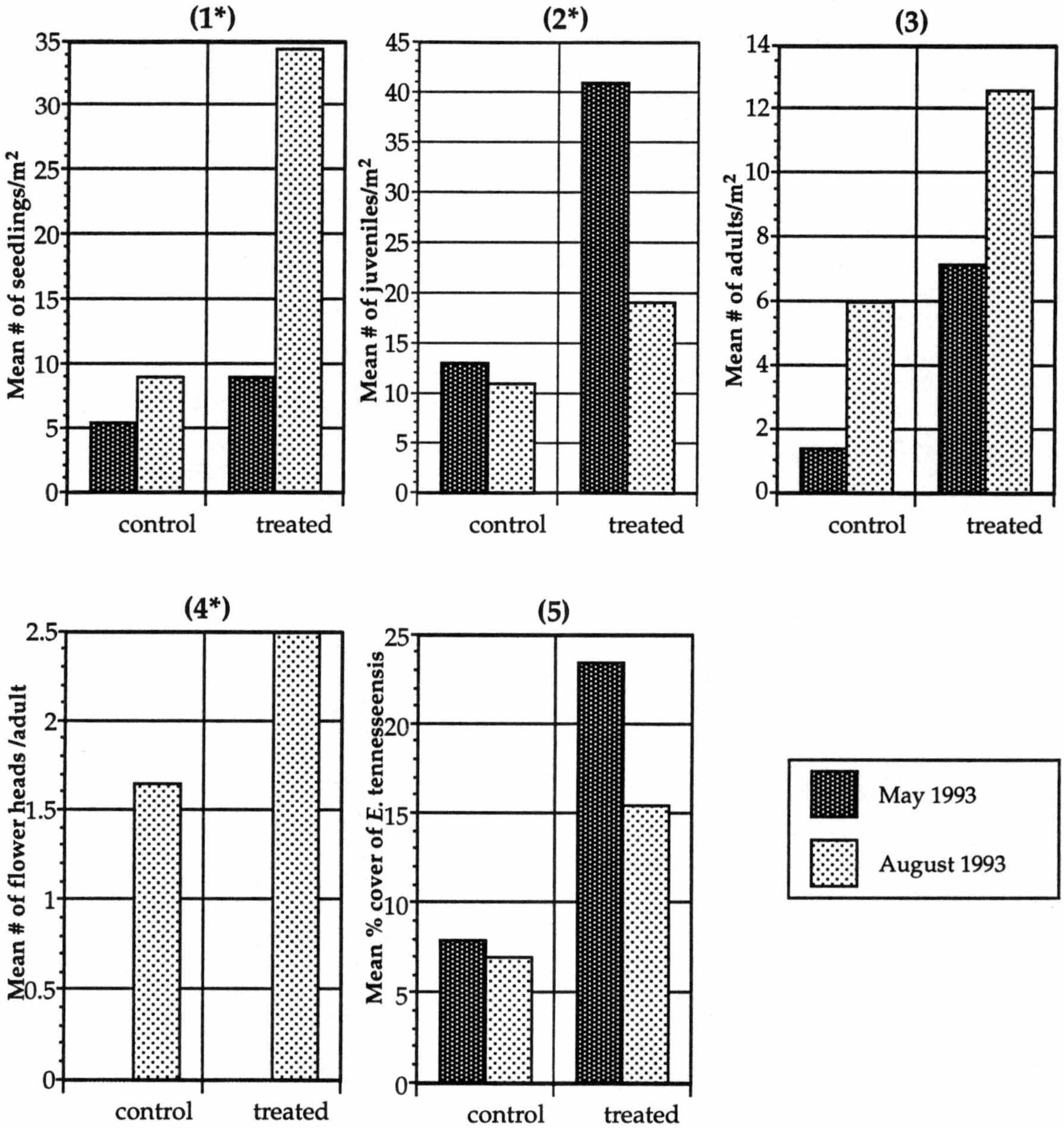

Figure 5: Effects of the trample treatment on *E. tennesseensis* : seedlings (1), juveniles (2), adults (3), flower heads per adult (4), and total percent cover (5). Points significant at the 0.25 level are indicated by asterisks (*).

6. Discussion

Despite the low level of statistical rigor in these experiments due to high levels of heterogeneity throughout the study site for many of the variables measured, several significant effects of the treatments have been found. In the first series of treatments, although no significant long-term effects were seen, short-term effects were evident for treatments 2 (disc), 3 (burn), 6 (burn and disc), and 8 (mow, burn, and disc) on percent cover of *Croton* spp., as well as percent of substrate designated as litter and as bare soil. In addition, treatment 5 (mow and disc) showed a significant short-term effect on cover of *Croton* spp., and treatment 7 (mow and burn) showed an effect on the amount of bare soil present in the total substrate. Microsite changes and substrate alteration, particularly alteration of the cryptogamic layer, may be particularly important in determining species composition changes in the long term (Bainbridge 1990). Although these effects were only short-term for the period of this study, they may have played a more crucial role had climatic conditions during 1992 and 1993 been less favorable.

In the herbicidally treated plots, negative impacts were seen on *Schizachyrium scoparium* and *Sporobolus vaginiflorus,* as well as on the number of adult individuals of *E. tennesseensis* per square meter. However, the treatment also showed a positive effect on *Dalea gattingeri* and *Croton* spp., due possibly to decreased competition for the glade's limited resources or to a nutrient flush from the dead grasses in the plot. The decline in density of *E. tennesseensis* adults (individuals in flower during the time of observation) in the treated plots is likely a result of stress due to increased evaporation of moisture from the soil, as evidenced by qualitative observation of soil conditions in the plots during the summer.

The unexpected positive treatment effect on the density of seedlings of *E. tennesseensis* seen in the case of the trample treatment may actually be related to another significant variable, the number of flower heads per adult. It is reasonable to suspect that, all other things being equal, increased seed production in the previous year could have led to increased seedling density. Since no data are available for these plots from previous years, however, the possibility remains, as suggested by the data, that trampling of Tennessee coneflower may actually benefit the species by increasing the number of seedlings. Trampling also produced a negative effect on species richness, percent cover of *Hedyotis* sp., and moss as percent of total substrate and a positive effect on both litter present and percent cover of *Schizachyrium scoparium* when compared with control plots (Figure A-4). The increased cover of litter and *Schizachyrium* likely altered the microclimate beneath the trampled grasses, providing slightly more shade and moisture retention.

In many ways even more interesting than the effects of the experimental treatments is the lack of effects of the treatments on Tennessee coneflower. None of the treatments imposed showed a significant effect on percent cover of *E. tennesseensis*, and most showed no significant effect on the species whatsoever. One possible explanation for the lack of treatment effects on *E. tennesseensis* lies in the tap root, which may be situated within vertical cracks in the rocky substrate, protecting it from substrate disturbances such as discing. The lack of effects of mowing and fire is likely due to the time of year in which the treatments were carried out: December, when the plant has died back to below ground level. The immediate aftereffects of the burning treatment in the experiment appeared qualitatively to be quite similar to effects of a natural late season fire at another glade site where Tennessee coneflower was present. In both cases, the aboveground portion of the plants was largely consumed by fire, but in the natural fire area it was noted that the seedheads themselves were undamaged except for the spiny chaff, which was burned away. Dunwiddie and Caljouw (1990) point out that the effects of fire may vary according to location and treatment regime, so that had the burns been applied during another time of year results may have been different.

Although the first set of treatments produced no statistically significant effect on percent cover of woody plants, qualitative assessment of woody growth indicates an increase in the number of woody stems in some plots. Continued monitoring of the experimental plots over the next few years may clarify what effect, if any, these treatments produced in the long term on woody species in general and *Juniperus virginiana* and *Cercis canadensis* in specific. If invasion of the coneflower's glade and barren habitat by woody species is indeed increased by substrate disturbances, continuation of disturbance may be necessary to keep these species in check once it has occurred.

The significant effects of several treatments on substrate composition and effects of the treatments that were seen only in the first year may be moderated by climatic variation, such that what was only a transitory effect during this study may be more highly pronounced when coupled with high levels of stress due to extreme climatic conditions. As shown in Figure 6, precipitation in middle Tennessee during the summer of 1991 (pretreatment) and the winter and summer of 1992 were above average, while 1993 had below average rainfall

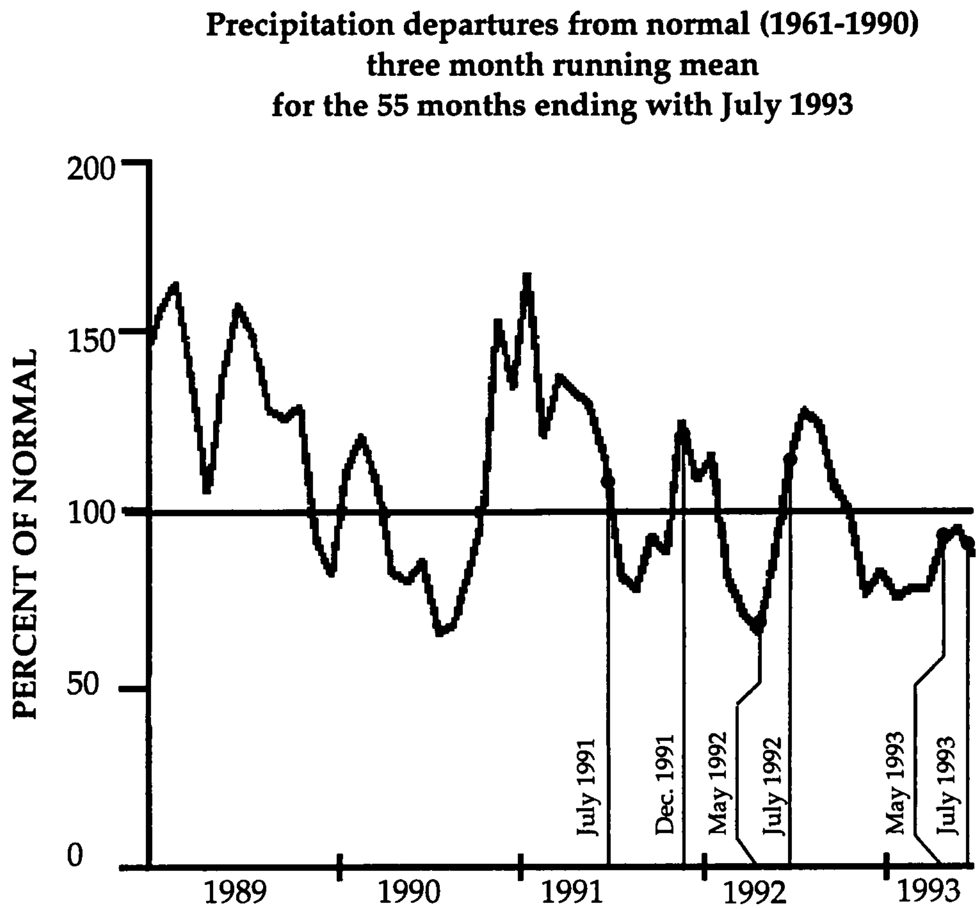

Figure 6: Precipitation departures from normal (1961-1990) three month running mean for the 55 months ending with July 1993. Vertical lines indicate pre and post treatment sample dates (May and July) and date of imposition of the first eight treatments (December 1991). Adapted from N.O.A.A. records. (N.O.A.A. 1993)

through July. In addition, the average monthly temperature at the Lebanon 3W weather station (located at 36°13' N; 86°20' W) was 0.7°F above normal during May 1993 (NOAA 1993a) and 4.6°F above normal during July 1993 (NOAA 1993b). The existence of relatively mild climatic conditions immediately following imposition of the first eight treatments may help to account for the apparent lack of treatment effects on *E. tennesseensis*, just as the dry, hot conditions during 1993 may have contributed to the negative effects of trampling on juveniles and chemical treatment on adults.

Though few impacts of the treatments were seen within the test plots, management treatments such as the ones tested could be useful in expanding marginal habitat areas by removing woody plants. Fire may be effective in limiting many woody species, particularly *Juniperus virginiana*, in marginal barrens areas (Anderson and Schwegman 1971), especially when applied during the growing season (Dunwiddie and Caljouw 1990) or in combination with hand removal of woody growth (Stritch 1990). However, it has been noted (Harnett 1991; Dunwiddie and Caljouw 1990) that fire can have beneficial effects for perennial grasses including *Schizachyrium scoparium*, possibly by removing litter buildup. In this regard, fire in grassy areas may harm many forbs by increasing growth of grass species which limit light penetration and increase water stress (Hartnett 1991).

Increasing the number of widely distributed populations of *E. tennesseensis* is important in dealing with the local habitat destruction facing the species (Dixon and Cook 1989). Marginal wooded and shrubby areas of glade habitats may be maintained in an open state through periodic disturbances such as mowing, burning, and grazing as suggested for maintenance of open heathlands

(Harrison 1976). Care must be taken in glades and barrens to avoid invasion of exotic species, especially in disturbed areas. Such invasion is made more likely by the fact that glades are in many ways isolated ecologically and are surrounded by dissimilar ecosystems (Cairns 1990).

7. Conclusions

This study focused on the responses of *Echinacea tennesseensis* to mowing, burning, discing, and combinations of these treatments as well as trampling and herbicidal removal of grasses. The effects of these treatments on other species at the Vesta Glade Natural area and substrate composition were also considered. Despite the Tennessee coneflower's endangered status, results indicate that the species is relatively hardy in the areas where it occurs naturally. Most treatment effects appeared to be short lived, including effects on species other than *E. tennesseensis* and substrate types at the site.

The mowing, burning, and discing treatments and their combinations produced no statistically significant effect on *E. tennesseensis*, though transitory increases were seen in both soil as percent of total exposed substrate and percent cover of *Croton* spp., coupled with a transitory decrease in litter cover as percent of total substrate. These effects were present only in the first year following treatment and were the result of the harshest treatments: burning, discing, and combinations containing one or both of these (Table 5). The lack of effect of these treatments on *E. tennesseensis* may be due in part to the plant's root system, which is often well protected within small cracks in the surface limestone of the glades. The timing of the treatments may also have contributed to the absence of significant effects on Tennessee coneflower, since the treatments were applied in December, when the plants had already died back to below ground level.

The negative effect of herbicidal removal of grasses on *E. tennesseensis* is likely due to microsite changes resulting in more light penetration and rapid evaporation from the soil, just as the negative effects of trampling on juveniles and the positive effects of trampling on seedlings and flower heads per adult may be the result of a combination of microsite changes due to increased cover of *Schizachyrium scoparium*.

Further study could help to clarify in what way treatment effects were mitigated by abnormal climatic conditions during 1992 and 1993, as well as which treatments are best suited for opening marginal habitat areas for *E. tennesseensis* growth.

Overall, the Tennessee coneflower appears to be resistant to most of the management practices tested. Although effects on *Echinacea tennesseensis* were minimal, effects on substrate composition and other species present may prove important ecologically. Perhaps more importantly, the stability of *E. tennesseensis* through disturbances indicates that prospects for the species' recovery are good, aside from the habitat destruction in the glades and barrens of middle Tennessee, and that management with the goal of maintaining marginal areas in an open state for the coneflower is viable, since techniques such as burning and mowing pose little or no threat to *E. tennesseensis* when used to remove woody species. Efforts in the future should focus on establishing new populations of Tennessee coneflower and protecting what remains of the fragile glade and barren habitat in middle Tennessee.

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Appendix

Appendix

This appendix contains graphic outlines of the data collected and analyzed on species other than *E. tennesseensis,* as well as substrate composition over the course of the study at the Vesta Glade Natural Area. Each graph follows the changes in one variable under all treatment conditions over several sample dates: July 1991 (pre-treatment data), May 1992, July 1992, May 1993, and August 1993 for the first series of treatments, and May (pre-treatment) and August 1993 for the herbicide and trample treatments. In the first series, each of the eight treatment types is designated by a number, as follows:

1. control
2. disc
3. burn
4. mow
5. mow and disc
6. burn and disc
7. mow and burn
8. mow, burn, and disc

For the herbicide and trample treatments, treatment values are designated by the number 2 and control values by the number one 1.

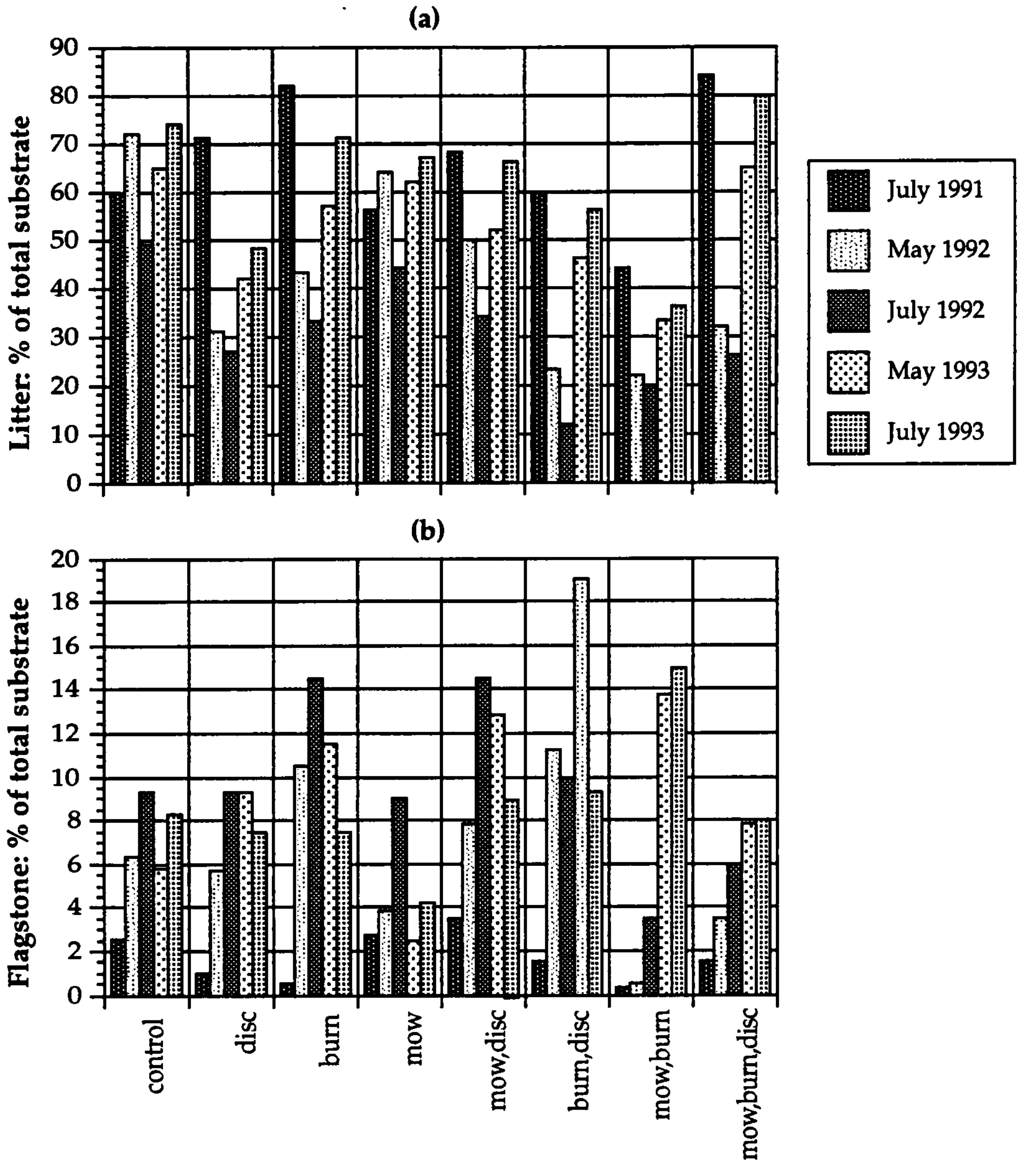

Figure A-1: Effects of the first management treatment series on substrate by category: (a) Litter, (b) Flagstone. Treatments 2 (disc), 3 (burn), 6 (burn, disc), and 8 (mow, burn, disc) showed a significant effect on litter in the first year with Pr > F values of 0.08, 0.04, 0.16, and 0.002 respectively, but overall no effect was discernable after two years recovery. None of the treatments significantly affected flagstone as percent of total substrate (tested at the 0.25 level).

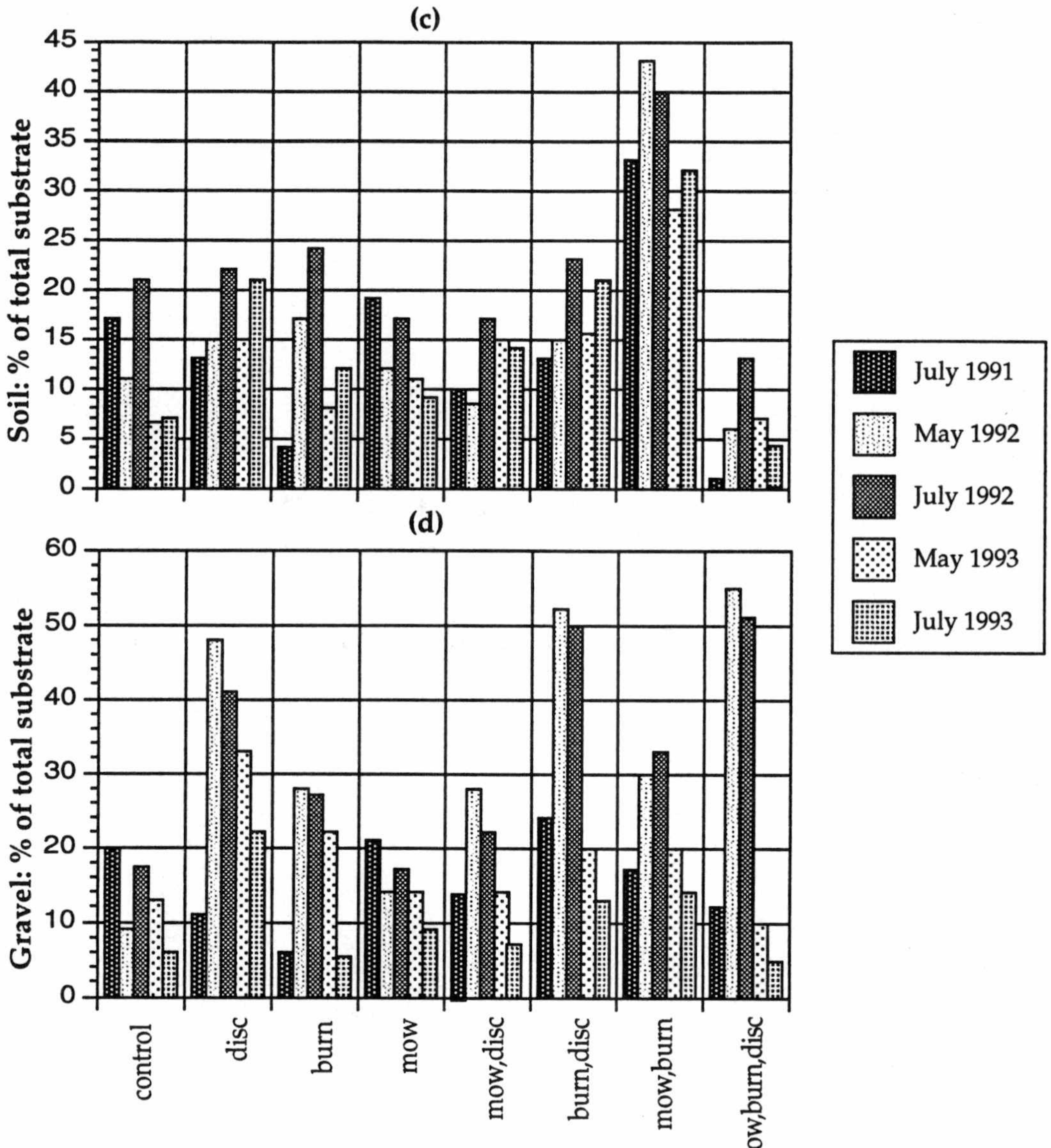

Figure A-1: (continued)

(c) Soil, (d) Gravel. Treatments 2 (disc) , 3 (burn), 6 (burn, disc), 7 (mow, burn), and 8 (mow, burn, disc) showed a significant effect in the first year on the percentage of total substrate designated as bare soil with Pr > F values of 0.01, 0.04, 0.13, and 0.003 respectively. After two years, no significant effect was seen. None of the treatments showed a significant effect on gravel in the plots when tested at the 0.25 level.

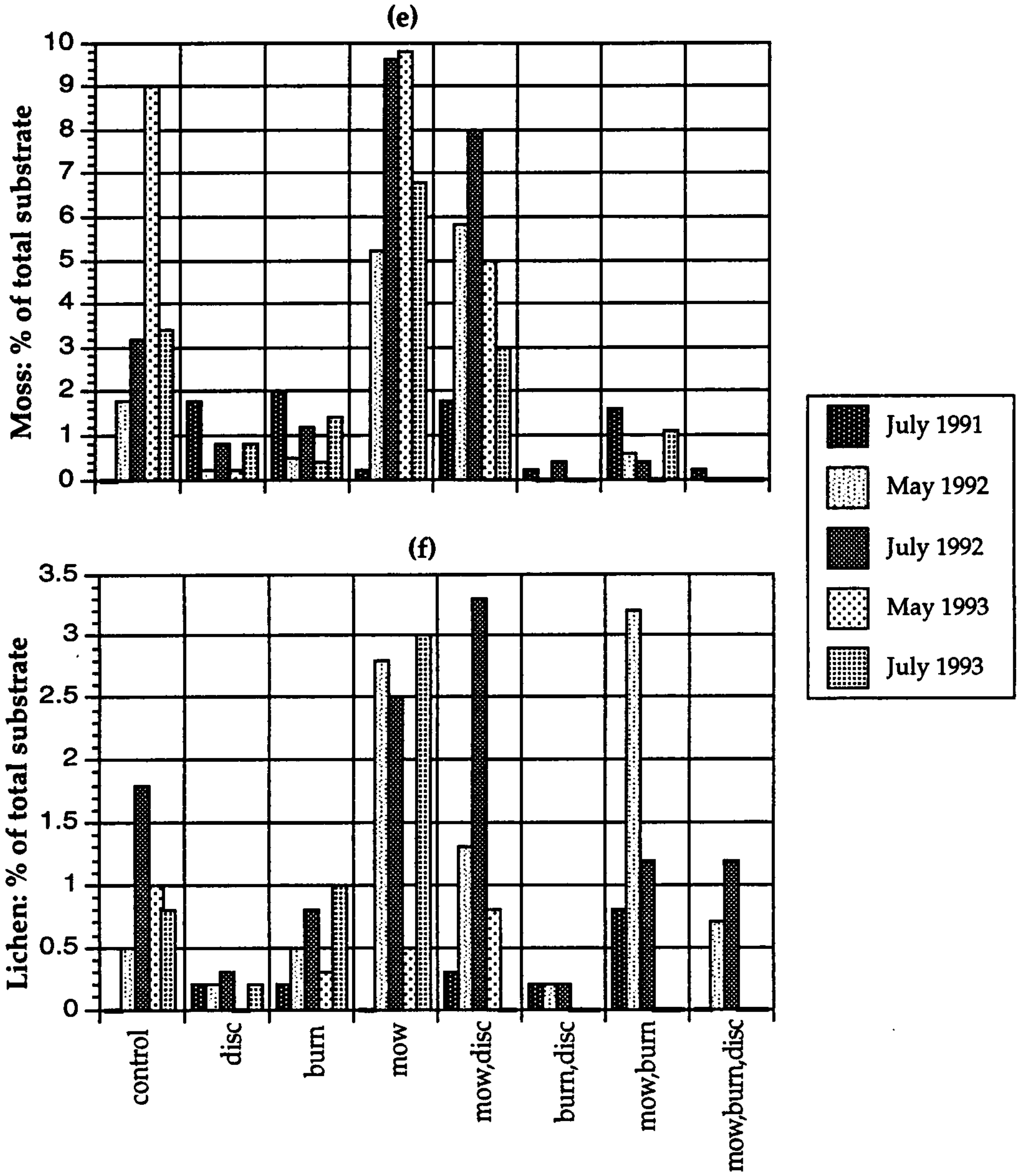

Figure A-1:(continued)

(e) Moss, (f) Lichen. No effect of the treatments was seen on either moss or lichen cover as percent of total substrate at the 0.25 level.

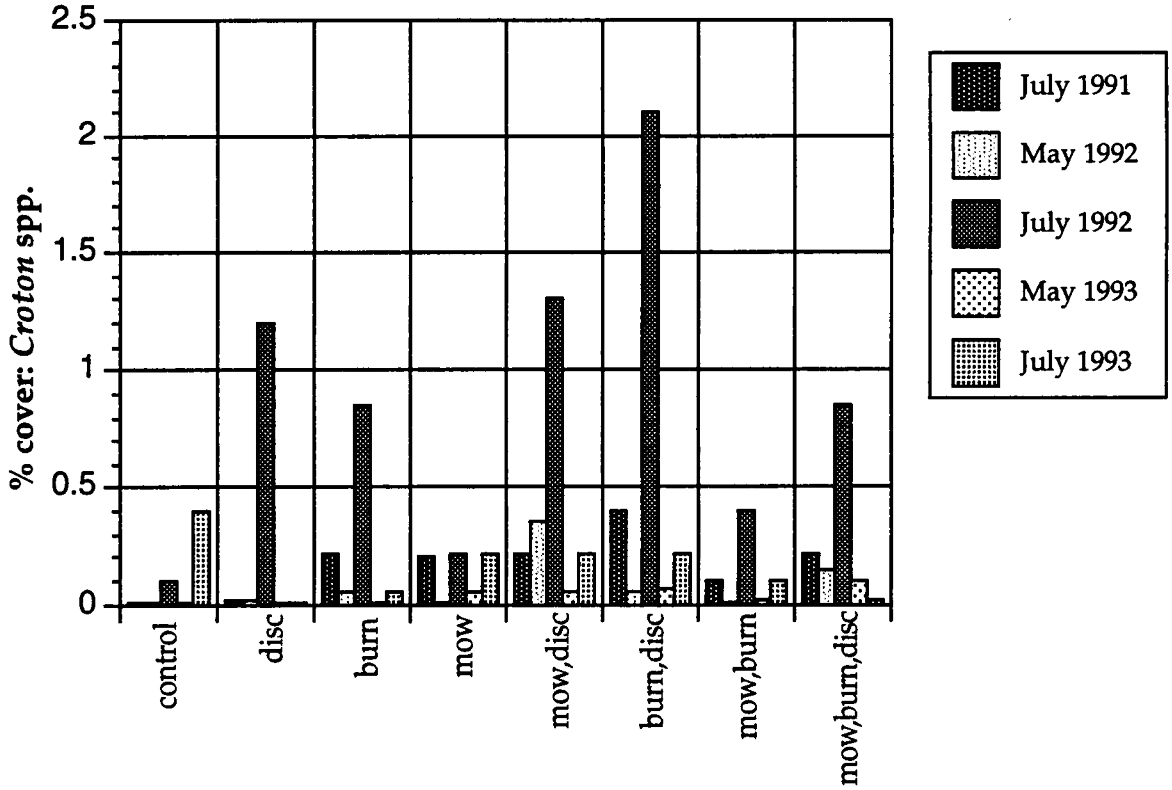

Figure A-2: Effects of the first management treatment series on *Croton* spp. Treatments 2 (disc), 3 (burn), 5 (mow, disc), 6 (burn, disc), and 8 (mow, burn, disc) showed a significant effect on *Croton* spp. in the first year following imposition with Pr > F values of 0.16, 0.09, 0.14, 0.03, and 0.02 respectively.

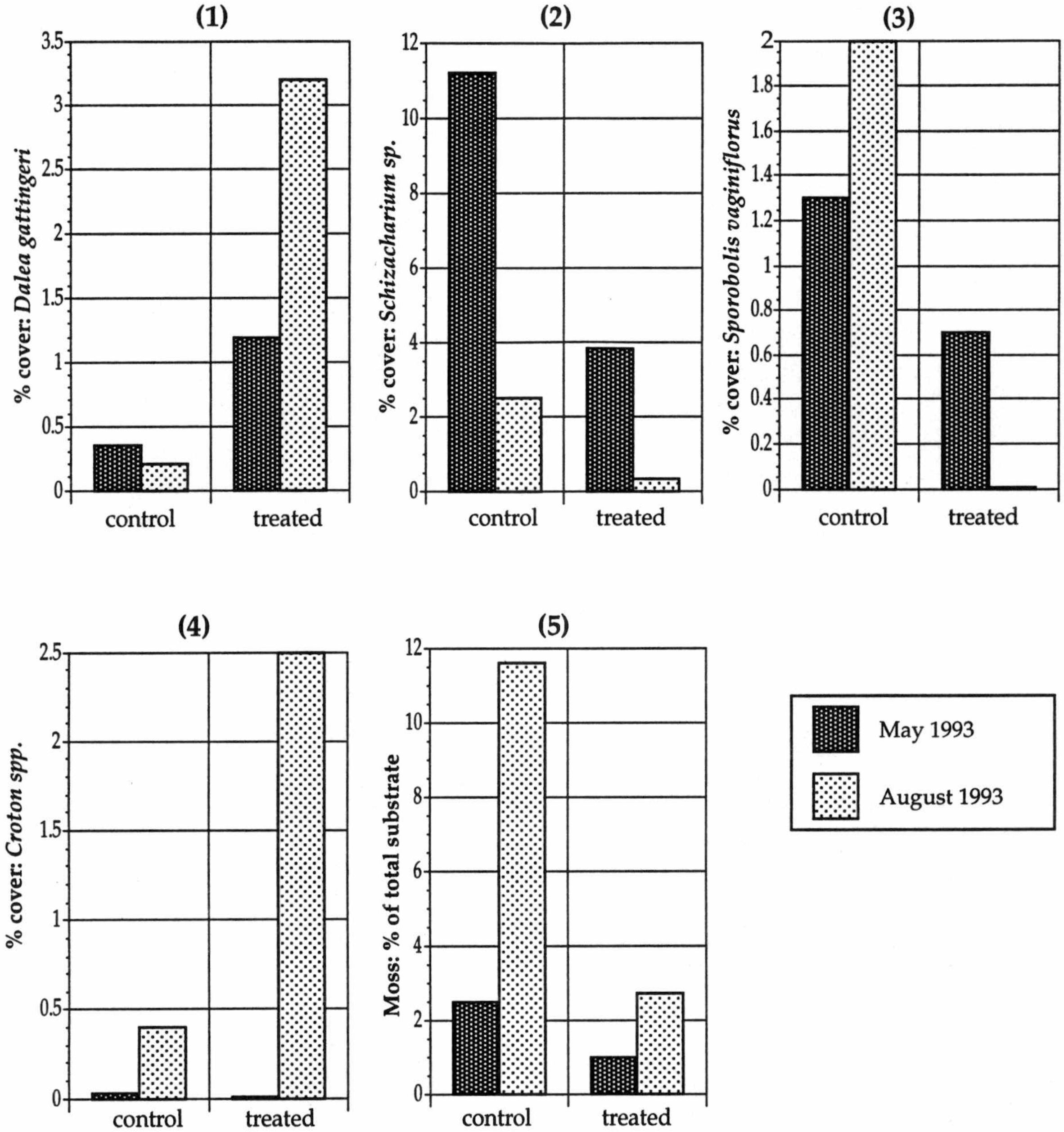

Figure A-3: Effects of the herbicide treatment on percent cover of other species: *Dalea gattengeri* (1), *Schizacharium* sp. (2), *Sporobolis vaginiflorus* (3), *Croton* spp. (4), and mosses relative to total substrate (5). Pr > F values for significance of herbicide treatment over time are 0.04, 0.25, 0.11, 0.007, and 0.07 respectively.

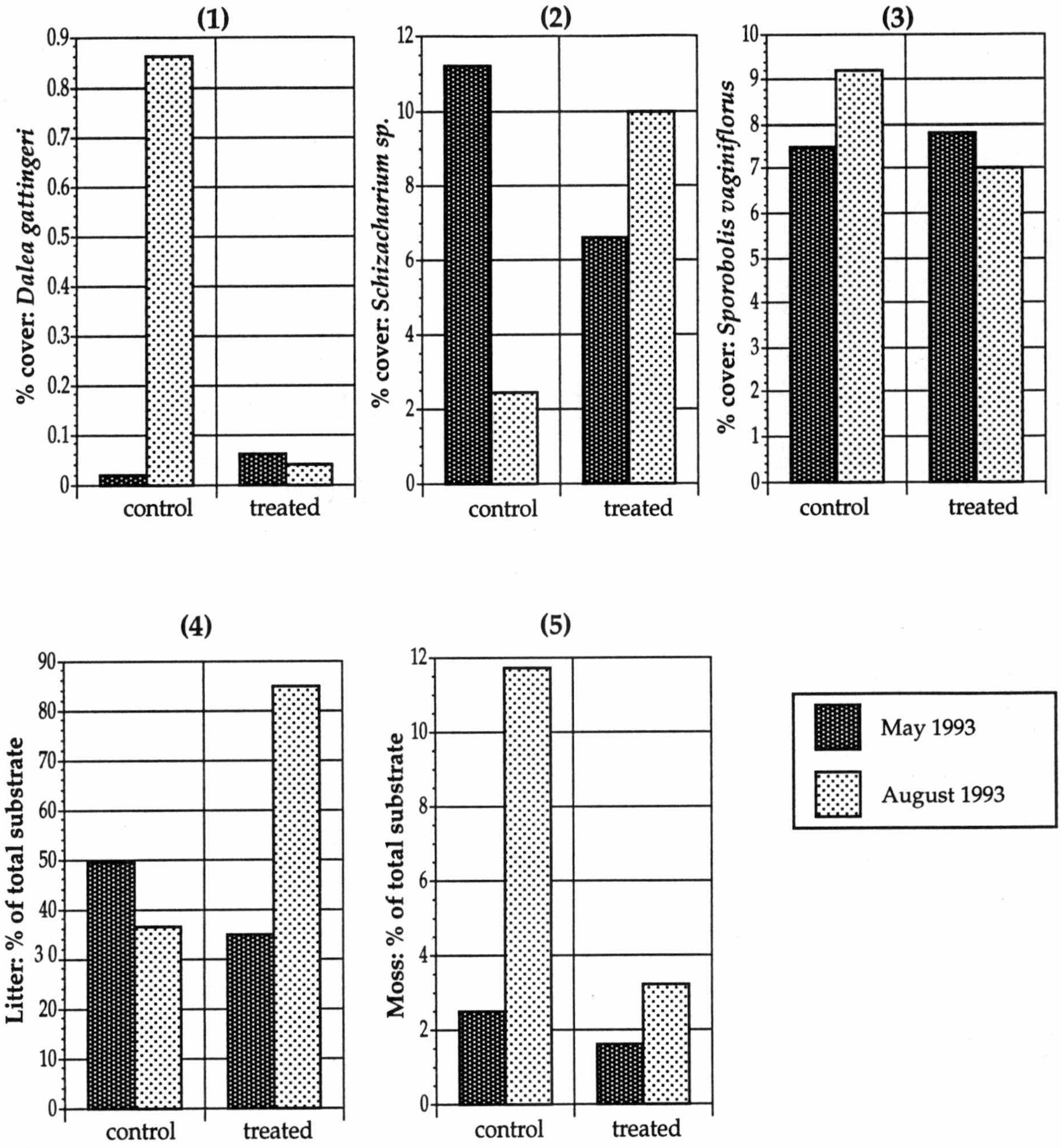

Figure A-4: Effects of the trample treatment on percent cover of other species: *Hedyotis* sp. (1), *Schizacharium* sp. (2), *Croton* spp. (3), species richness per 1m^2 plot (4), litter relative to total substrate (5), and mosses relative to total substrate (6). Pr > F values for significance of trample treatment over time are 0.07, 0.17, 0.21, 0.16, 0.10, and 0.21 respectively.

Vita

Edward (Ted) Maclin was born on July 13, 1968 in Marietta, Georgia, which he promptly left for stays in Tennessee, Alabama, and Texas. In 1976 he moved to Stanton, Tennessee where his parents began helping in the operation of his grandparents' dairy farm. Following an uneventful stint at Covington high school, Ted moved to Knoxville in 1986 to begin work on what was to become a B.S. in biology, concentrating in ecology. After numerous sidetracks into varying subject areas from art to anthropology, he finally earned his degree in May of 1991. His spirit not yet broken, he began work on a Master's degree in botany in 1992. In November of 1992, he was married to his long time companion Amy Britnell. After two years of research, he completed his degree in the summer of 1994.