1997

An Ecological Study of Shale Barren Rock Cress (Arabis serotina Steele) at Little Fork Shale Barren, Pendleton County, West Virginia

Robert J. Jarrett

Recommended Citation

Jarrett, Robert J., "An Ecological Study of Shale Barren Rock Cress (Arabis serotina Steele) at Little Fork Shale Barren, Pendleton County, West Virginia" (1997). *Theses, Dissertations and Capstones*. 1680.
https://mds.marshall.edu/etd/1680

An Ecological Study of Shale Barren Rock Cress (*Arabis serotina* Steele) at Little Fork Shale Barren, Pendleton County, West Virginia

by

Robert J. Jarrett
Department of Biological Sciences
Marshall University
Huntington, West Virginia 25755

Date Approved: 5 May 1997

Frank S. Gilliam
Frank S. Gilliam, Co-Chairman

Leonard J. Deutsch
Leonard J. Deutsch, Dean

Jeffrey D. May
Jeffrey D. May, Co-Chairman

Paul J. Harmon
Paul J. Harmon

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the Department of Biological Sciences in the Graduate School of Marshall University

Abstract

Shale Barren Rock Cress (*Arabis serotina* Steele) was listed as a federally endangered species by the U.S. Fish and Wildlife Service in August 1989. As part of a cooperative agreement between the West Virginia Natural Heritage Program and the U.S. Navy, research was conducted in 1994 and 1995 at Little Fork Shale Barren (LFSB) to provide baseline information on the population dynamics of *A. serotina* and to study the vegetation and physical parameters associated with this shale barren community. Soil samples and plant community data were collected from 40 1-m^2 circular plots for herbaceous vegetation and six 0.02-ha circular plots for overstory vegetation. Overstory vegetation was sampled on LFSB and on a mixed hardwood forest located on the north-northwest slope behind LFSB.

Carex pensylvanica dominated the herbaceous layer of the shale barren, whereas *Quercus prinus* dominated the overstory on both the shale barren and the adjacent forested slope. The dominance of *Q. prinus* on both slopes is attributable to the low annual precipitation (84 cm yr^{-1}) on the leeward side of the Allegheny Mountains. Stem density of overstory vegetation on the forest slope was approximately double that found on the barren. Basal area was also much greater on the forest slope than on the barren. Seven herbaceous species sampled are considered to be endemic or near-endemic to the mid-Appalachian shale barrens, including *A. serotina*, *Paronychia montana*, *Calystegia spithamaea ssp. purshiana*, *Antennaria virginica*, *Scutellaria ovata*, *Allium oxyphilum*, and *Phlox subulata*. Comparison of soils between LFSB and the forest slope showed significant differences in NO_3-N and pH of the water extraction (both higher on LFSB) at

$p \leq 0.05$. LFSB also had significantly higher NH_4-N and pH of the KCl extraction at $p \leq 0.10$.

Canonical correspondence analysis (CCA) showed no significant correlation between *A. serotina* and any of the measured soil variables. CCA did appear to indicate some response of total species composition to a soil NO_3-N gradient. Gradients of soil factors appear to vary in a patchy fashion, perhaps dependent on historical and concurrent rates of litter accumulation rather than direct relation to an elevational gradient.

The *A. serotina* population on LFSB was shown to be extremely variable with respect to both spatial and temporal changes in population structure. The population declined from 880 individuals in 1992 to only 96 individuals in 1995. These population changes appear to result from the sensitivity of this species to high temperatures coupled with low precipitation early in the growing season, but herbivory, fungal infection, stochastic processes, and human disturbance may also be involved. In July 1995, 71% of rosettes and 91% of bolting plants showed evidence of some type of herbivory. Also, mortality was shown to be substantial within a single growing season for both rosettes and bolting plants. Because mortality appeared to be highest from July through August, recommendations are made to expand the August 15 to September 5 sampling period recommended by the *A. serotina* Recovery Task Force and the Shale Barren Protection Strategy Group.

Acknowledgments

This study would not have been possible without the support and assistance of the United States Navy and the West Virginia Nongame Wildlife and Natural Heritage Program. Because of their active interest in the conservation of rare and endangered species, I have had the opportunity to contribute to and hopefully expand our knowledge of the population dynamics of *Arabis serotina* and the shale barren community at Little Fork Shale Barren. For that support, I am thankful and appreciative of all individuals responsible for making this study a reality. I would also like to thank Steven W. Niethamer of Naval Security Group Activity (NSGA), Sugar Grove, West Virginia, for his efforts on this project and making my time at NSGA enjoyable.

To Dr. Frank S. Gilliam, I express my sincere thanks and gratitude for choosing me to be a part of this project and lending valuable advice on its design and presentation. His thoughtful and professional approach to research has truly been an inspiration. Apart from his efforts on this project, his course in Plant Ecology was also one of the most enjoyable, challenging, and well taught courses I have ever encountered during my college career. The road has been a difficult one, but I have learned more from him than I could possibly describe in these few pages.

To Dr. Jeffrey D. May, I have both admiration and respect for his professional thoroughness and ability to ask the right question at the right time. More than once he has brought insight and depth to topics I had since abandoned as stagnant or no longer capable of producing useful information. I have also enjoyed his great sense of humor and penchant for innovative theories (i.e., the "deer hypoopthesis"). The tools he has given me to succeed are innumerable and I would like to extend my deepest thanks for his effort and time spent on this project.

To Paul J. Harmon, I express my thanks for his friendship and priceless importance to this project. Rarely have I known a man who puts as much energy (God does he have energy!) and thought into a project like PJ. Although he won't admit it, he is also one of the finest botanists around. This project would not have been possible without his coordination and collaborative efforts with the U.S. Navy, and for that I am grateful.

To my father and mother, Rodney and Linda, my grandmother, Dolores, and my wife, Courtney, I am thankful for the love and support they have given and continue to give me everyday of my life. Everything I am today, I owe to the ways in which they let me grow through the years. And to any one I mistakingly left out..........

Table of Contents

List of Tables

List of Figures

CHAPTER I: INTRODUCTION

Shale barren rock cress (*Arabis serotina* Steele; Brassicaceae) was listed as a federally endangered species on 14 August 1989 (Morgan 1989). It is listed by The Nature Conservancy's conservation science division as critically imperilled globally (G1) and by the West Virginia Natural Heritage Program and the Virginia Natural Heritage Program as critically imperilled in each state (S1) (P. J. Harmon, pers. comm.). The G1 and S1 ratings indicate there are five or fewer occurrences of a species or very few individuals. It is endemic to the mid-Appalachian shale barrens of West Virginia and Virginia and is limited to only 55 known populations. In 1990 the U.S. Navy and the West Virginia Natural Heritage Program (WVHP) entered into a five-year cooperative agreement to study the *A. serotina* population at Little Fork Shale Barren (LFSB) in Pendleton County, West Virginia. Due to its location on federally owned and restricted land, the site offered the unique opportunity for observation without threat of human disturbance.

The current study is the result of an agreement between the Department of the Navy, Atlantic Division, Naval Engineering Facilities Command; Naval Security Group Activity, Sugar Grove; and WVHP. Researchers at Marshall University in Huntington, West Virginia, were subcontracted through WVHP to design and conduct a detailed ecological study at the Little Fork site.

The objectives of this study were:

(1) To provide baseline information on the population dynamics of *A. serotina* at

LFSB.

(2) To describe in detail the vascular plant community associated with *A. serotina.*

(3) To describe on-site physical parameters of LFSB and those abiotic and biotic factors influencing the presence/abundance of *A. serotina* at LFSB.

The Ecology of Rare and Endangered Plants

The conservation of rare and endangered plant species is currently the center of both concern and controversy in the scientific community. Numerous theories about the causes of endangerment and the mitigative measures necessary for the conservation of species exist, but the practicality of such measures is often questionable (Schemske et al. 1994). The purpose of the remainder of this chapter is to present commonly cited causes of rarity in plant species and discuss those topics relevant to the current study.

Begon et al. (1986) listed the following common causes for the rarity of species:

i. A species may be rare because its habitable areas are rare or small;

ii. A species may be rare because habitable sites only remain habitable for short periods;

iii. A species may be rare because the presence of other species make some sites uninhabitable due to predation, parasitism, or competitive exclusion;

iv. A species may be rare because of the low availability of a limiting resource;

v. A species may be rare because the genetic variation of the population narrowly limits its habitable range;

vi. A species may be rare because the phenotypic plasticity of its individuals limits the habitable range; and

vii. A species may be rare because competitors, predators, parasites, or human collectors maintain its populations below the level set by available resources within habitable areas.

The first three causes are factors which influence the number and size of populations, while the other causes influence the density of individuals within a population (Begon et al. 1986). Because these causes, acting alone or in conjunction with one another, can influence the abundance of a species at a wide range of spatial and temporal scales, the problem of the conservation of rare and endangered plants seems all the more difficult. Another important factor, but not the least significant, is habitat destruction and alteration by human activities.

Many rare species are endemic to rare habitat types (Hart 1980, Keener 1983, Murdy 1968, Platt 1951, Snyder et al. 1994, Steele 1911). Serpentine rock formations, granite outcrops, cedar (limestone) glades, and shale barrens are all known to support floras specifically adapted to these often-severe habitats. Whether or not some endemics are substrate specific or restricted due to a lack of competitive ability in other habitats is often unclear. For instance, *Arabis serotina* has only been found on barrens underlain by shale of the Braillier Formation, while *Paronychia montana*, another shale barren endemic, has been found on other formations (Riefner 1981, Wherry 1953). Also thought to be endemic to Devonian age shale, *Calystegia spithamaea ssp. purshiana* has been found on shale of Silurian age (Morse 1983). Apparently, some species may be somewhat restricted to these substrate types, while the other endemic species require some physiochemical aspect of these substrates for growth and reproduction.

Baskin and Baskin (1988) suggested that shade intolerance is a major cause of endemism in rock outcrop communities of the unglaciated eastern United States. However, few studies have focused on the competitive abilities of endemic species (Baskin and Baskin 1988). A recent study of *Echinacea tennesseensis*, an endemic species of the middle Tennessee cedar (limestone) glades with only six known populations, concluded that a lack of competitive ability could not account for the narrow endemism of this species (Snyder et al. 1994). The study compared *E. tennesseensis* with two closely related, but geographically widespread species (*E. pallida* and *E. angustifolia*). Based on relative yield, biomass (dry weight), and leaf area, *E. tennesseensis* had a greater competitive ability than *E. angustifolia*. *Echinacea pallida* showed greater competitive ability than either of the other two species (Snyder et al. 1994).

Because shale barrens are in a sense 'islands' surrounded by a 'sea' of land, the theory of island biogeography is also applicable to these rare habitat types. MacArthur and Wilson's (1967) 'equilibrium theory of island biogeography' states that the number of species on an 'island' is maintained by a dynamic balance between immigration and extinction. Rates of immigration and extinction on 'islands' are influenced by both the area of the 'island' and its distance to the 'mainland' (Simberloff 1974). According to this theory, as the immigration rate (species richness) increases on an 'island' the rate of extinction also increases. The higher rate of extinction would be due to the higher likelihood of competitive exclusion by immigrant (or non-endemic) species. Also, small 'islands' have higher rates of extinction than larger 'islands' (MacArthur and Wilson 1967, Simberloff 1974). Species-area curves show that the larger the 'island', the greater the number of species found on that island (MacArthur and Wilson 1967). Therefore, the size of an 'island' could influence the effects of immigration on rare populations. Taking into account species-area relationships, this theory would suggest that shale barrens with a larger area would be able to support a greater number of species and have lower extinction rates than shale barrens with smaller areas. However, high temperatures and low moisture at the soil surface of shale barrens appear to inhibit seedling establishment by species not tolerant of these conditions (Platt 1951). Therefore, the mid-Appalachian shale barrens potentially inhibit immigration (and subsequent extinction) because severe conditions on these barrens limit the number of species able to successfully immigrate into the shale barren plant community.

The distance (or remoteness) of an 'island' from the 'mainland' also impacts the species richness and species composition of that 'island', and its influence on rates of immigration and extinction cannot be overlooked. Simberloff (1974) observed that 'islands' located farther from the 'mainland' have fewer species than 'islands' closer to the 'mainland'. This difference is due to the varying dispersal capabilities of different species. For instance, a wind-borne seed might have the ability to disperse farther than a seed carried by ants or in the digestive tract of a bird. Also, birds which have a greater range than other birds could disperse seed to 'islands' farther away from the 'mainland' (or another 'island'). Similarly, birds or mammals that selectively feed and disperse seed via their digestive tracts will disperse only those species on which they feed. Because poorly dispersing species as are "differentially absent" from distant 'islands' (suggesting a non-random event), the species composition of distant islands will consist of species with good dispersal ability (Simberloff 1974). However, numerous studies suggest that once dispersed to 'islands', these species (both plant and animal) exhibit dramatic reductions in dispersal potential when compared with their 'mainland' counterparts (Cody and Overton 1996, Carlquist 1966a).

The numerous ways in which seed and/or pollen are dispersed within and among populations are simply specific means to the same end—gene flow. The genetic diversity of a population is maintained by gene flow with other populations and an effective population size (not necessarily the number of individuals in a population) (Lacy 1987). Low genetic variation has been reported in numerous populations of rare and endangered species, but its relative importance to the conservation of rare and endangered species is still subject to debate (Maki et al. 1996, Schemske et al. 1994).

Schemske et al. (1994), in a review of the recovery plans for 98 plants listed as threatened and endangered by the U.S. Fish and Wildlife Service, suggested the study of rare and endangered species begin at a larger scale and then narrow in scope. The following three steps were recommended: (1) collect demographic data to determine the biological status of the species and its population (increasing, decreasing, or stable); (2) determine the life history stage(s) that have the greatest impact on population growth; and (3) determine the biological causes of variation in the life history stage(s) that have the greatest demographic impact on the population.

CHAPTER II: STUDY OF THE SHALE BARREN PLANT COMMUNITY

Introduction

The mid-Appalachian shale barrens are located in the Ridge and Valley Physiographic Province of West Virginia and Virginia. The term shale barren was first used by Steele (1911) to describe these habitats with "exposures of shale in different stages of disintegration." Platt (1951) observed that shale barrens are typically found on south facing slopes greater than 20 degrees from horizontal, and that the barrenness increases with increasing slope. The soils of most mid-Appalachian shale barrens are derived from shale of the Upper Devonian, which is sometimes referred to as the Brallier Formation (Platt 1951, Keener 1983).

The soils at Little Fork Shale Barren (LFSB) are in the Berks-Weikert series and are classified as channery silt loams (United States Department of Agriculture 1992). The term "channery" refers to the thin, flat fragments of shale which make up 15 to 35 percent (by volume) of the soils in this series. Shale barren soils characteristically lack a B horizon, and the A horizon is poorly developed. The C horizon, however, is similar to surrounding north-facing slopes and retains comparable nutrient and moisture levels (Platt 1951).

The presence of herbaceous vegetation unique to the mid-Appalachian shale barrens has long been reported (Steele 1911, Allard 1946, Core 1952, Wherry 1953). However, Core (1952) observed that some mid-Appalachian endemic species occurred on formations other than the Brallier Formation. Keener (1983) reported 18 herbaceous species endemic to these unique habitats. Platt (1951) reported 19 endemic species. Eight species, including *Arabis serotina*, are considered to be strict endemics and the rest are preferential or disjunct species (*sensu* Keener 1983). Overstory vegetation consists primarily of a sparse scrubby growth of oak, hickory, and pine species.

Allard (1946) observed that there were ecological differences between the crests and bases of these shale slopes, and that the transition to the "shale barren proper" was often difficult to delimit. The transition in species composition from forest to barren appears to be influenced by slope. The sparse vegetation on shale barrens has been attributed to high surface temperatures (due to the increased insolation of the south facing slopes) and low surface moisture, both of which are influenced by slope and the shale substrate (Platt 1951). This combination of features hinders seedling establishment and survival on the barren.

This chapter focuses on the vascular plant community at LFSB in Pendleton County, West Virginia. Due to the current paucity of quantitative data available on shale barren vegetation, this study was crucial for a better understanding of the community associated with *Arabis serotina*. Detailed sampling of herbaceous and overstory vegetation was coupled with analysis of on-site physical parameters.

Materials and Methods

STUDY SITE. Research was conducted at LFSB, Naval Security Group Activity, Sugar Grove, West Virginia (38°30′51″ N, 79°16′35″ W). The site has a south-southeast aspect and is one of seven shale barrens in the valley of the South Fork of the South Branch of the Potomac River (Bartgis 1987). The top of the ridge lies at 2100 m and the slope is undercut by the Little Fork of the South Fork of the South Branch of the Potomac River and by the Little Fork Road. Mean monthly precipitation (cm) and mean monthly temperature (C°) for nearby Franklin, West Virginia, are presented in Figures 1 and 2, respectively. Annual precipitation for nearby Franklin, West Virginia, averages 84 cm yr^{-1} (Kochenderfer et al. 1996). Climatic data were provided by the National Climatic Data Center in Asheville, North Carolina.

Orographic effects account for major differences in annual precipitation between the eastern and western sides of the Allegheny Mountains in West Virginia (Kochenderfer et al. 1996). As air with a high water-vapor content moves across these mountains, it rises and cools, which causes the condensation of this vapor and subsequent precipitation on the western (or windward) side of the mountains. On the eastern (or leeward) side of the mountains, the air warms as it decreases in elevation and precipitation rapidly decreases. Based on 30-year data from West Virginia, annual precipitation ranges from 127 cm yr^{-1} at Weston, on the western side of the Alleghenies, to 84 cm yr^{-1} at Franklin, on the eastern side of the Alleghenies (National Oceanic and Atmospheric Administration 1985).

FIELD SAMPLING and ANALYSIS. Herbaceous vegetation was sampled in 40 circular plots (1 m^2) located randomly within a 1.6-ha grid previously established by Harmon (1992) to facilitate monitoring of *A. serotina* at the Little Fork site. The grid was 50 m x 320 m, with the longest side paralleling the crest of the ridge and was marked off in 10 m x 10 m

Figure 1. Mean monthly precipitation (cm) from Franklin, West Virginia, based on a 30-yr period between 1964 and 1994.

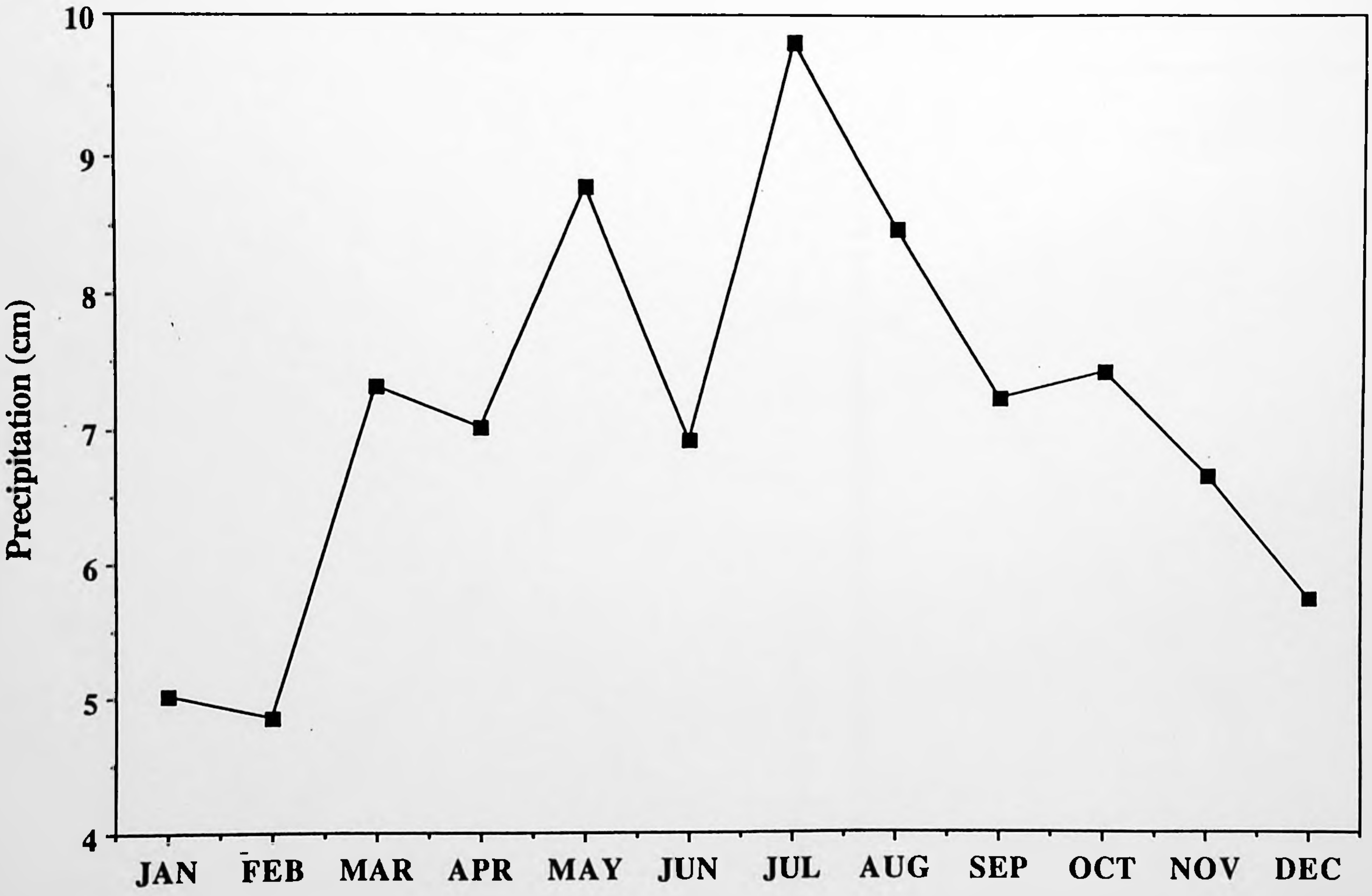
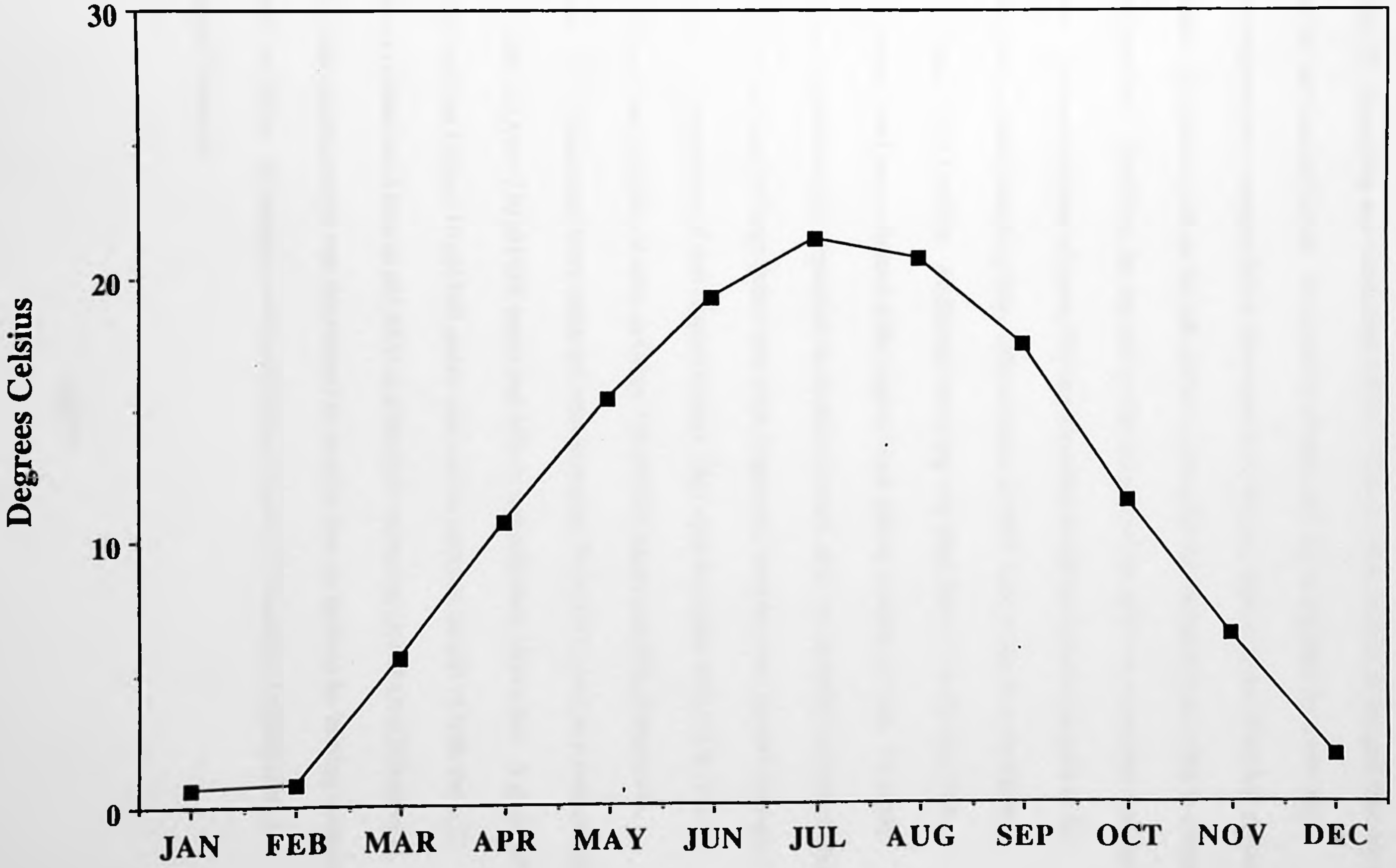

10
9
8
7
6
5
4
Precipitation (cm)
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Figure 2. Mean monthly temperature (C°) from Franklin, West Virginia, based on a 30-yr period between 1964 and 1994.


Degrees Celsius
30
20
10
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

cells (Fig. 3). Sampling was conducted within a 50 m x 200 m section of the grid that did not overlap the surrounding forest. The position of each cell was designated by a row and column number that corresponded to the location of the grid marker in the lower left corner of the cell. The bottom cell on the left portion of the grid was designated as being in column one and row one. Therefore, the top cell on the left side of the grid was in column one and row five. A visual estimate of cover (%) was recorded for all taxa present in each of the circular plots on each sampling date. Observations in 1994 were made on a weekly basis from 31 August to 6 October. Additional sampling was done from 11 to 13 July 1995.

Mineral soil was collected at the edge of each plot to a depth of 5 cm. To avoid unnecessary impacts to the vegetation in monitored areas, soil was sampled outside of each plot. For the removal of large debris and shale fragments, samples were passed through a 2-mm sieve. Subsamples of soil (approximately 25g) were extracted with 1N KCl (10:1; v:w) and analyzed for NH_4-N with an Orion 720 pH/ISE meter and NH_4-N electrode. Separate 25-g subsamples were extracted with deionized H_2O (10:1; v:w) and analyzed for NO_3-N with an Orion 720 pH/ISE meter and NO_3-N and reference electrodes. A glass pH electrode with an Orion 710 pH/ISE meter was used to measure the pH of both the KCl extraction (abbreviated here as pH-KCl) and the H_2O extraction (pH-H_2O) (Gilliam et al. 1996). Soil organic matter was determined by percent loss on ignition by heating subsamples at 500 C for 24 hr. All samples were analyzed at Marshall University, Department of Biological Sciences.

Figure 3. Grid layout and location of plots at Little Fork Shale Barren, Sugar Grove, West Virginia. Cells (10 m x 10 m) containing herbaceous community and population plots are denoted with a "+" symbol.

Crest

			15					20					25					30	
				+		+													
		+	+				+		+	+		+				+			+
+				+	+		+		+	+	+	+	+	+		+			+
+				+	+		+		+					+	+	+	+		
+	+		+		+		+					+		+	+		+		+

Base

Overstory vegetation was sampled on LFSB and on a mixed hardwood forest located on the north-northwest facing slope behind LFSB, using three circular plots per aspect. Each plot had a radius of 7.5 m for a total of 0.05 ha sampled per aspect. Plots on LFSB were established along the fourth row of cells in the grid and ran from the 14th through the 20th columns. Plots on the forest slope corresponded with the slope positions of plots on the barren with respect to elevation, distance apart, and position on opposite sides of the slope. Within each plot all woody stems $\geq$ 2.5 cm in diameter (at 1.5 m in height) were recorded, identified to species, and measured for diameter to the nearest 0.1 cm, as described by Gilliam et al. (1993). However, due to the difficulties involved in their identification, individuals of the genus *Carya* were identified to genus only. Also, two samples of mineral soil to a depth of 5 cm were collected near the center of each of the six overstory plots. Sampling of vegetation and soil was done on 16 May 1995. Samples were analyzed at Marshall University for the same soil variables as described previously for the southeast-facing slope.

DATA ANALYSIS. For herbaceous community data, mean cover values (%) per plot were determined for each species recorded during the sampling dates. Relationships among species-plot data and soil variables were assessed using canonical correspondence analysis (CCA) and Pearson product-moment correlation. Canonical correspondence analysis is a multivariate analysis technique used to relate community composition to environmental variables by direct gradient analysis (ter Braak 1986). The environmental variables used in this analysis were those analyzed in mineral soil, including NO_3-N, NH_4-N, pH-H_2O, pH-KCl, and organic matter. Importance values (IV) were also calculated for each species as the average of relative frequency and relative cover.

The Shannon-Wiener index (H′) was used to calculate diversity for the 35 herbaceous plots which had complete soil data. The index is a measure of both species richness and species abundance, and is calculated as follows:

$$H' = -\sum_{i=1}^{s} p_i \ln (p_i)$$

where s is the number of species in the sample, p_i is the relative cover of species i, and $\ln(p_i)$ is the natural logarithm of p_i. Equitability (J) was also calculated for the same plots as follows:

$$J = H' / H'_{max}$$

where H'_{max} is ln (s). Equitability is a measure of evenness, that expresses H′ as a proportion of the maximum possible value H′ would assume if individuals were evenly distributed among the species in the sample.

For overstory vegetation, density (stems/ha) and basal area (m^2/ha) were calculated for each species. Within each overstory community, importance value (IV) was calculated for each species as the average of relative density and relative basal area. A t-test was then used to determine if there were significant differences for species and soil variables between LFSB and the forest slope.

Results and Discussion

HERBACEOUS VEGETATION. A total of 25 species of vascular plants was found in the community plots during this study. Six of these species could not be identified due to immature growth form (e.g., rosettes or seedlings) and lack of infloresence. The following species endemic to shale barrens were noted: *A. serotina* (shale barren rock cress), *Paronychia montana* Pax & K. Hoffm. (shale whitlowwort), *Calystegia spithamaea* (L.) Pursh *ssp. purshianus* (Wherry) Brummitt (shale bindweed), *Antennaria virginica* Stebbins (shale barren pussytoes), *Scutellaria ovata* Hill *ssp. rugosa* (Wood) Epling (heart-leaved skullcap), *Allium oxyphilum* Wherry (wild onion), and *Phlox subulata* L. (mosspink). Based on relative frequency and relative cover, *Carex pensylvanica* (IV = 49.6) dominated the herbaceous layer (Table 1 and 2). *Carex pensylavanica* (Cyperaceae) is common throughout the State of West Virginia and grows on dry or sandy soil in open woodlands (Strausbaugh and Core 1977). In 1994, *C. pensylvanica* constituted 77 % of the total herbaceous cover on LFSB. *Arabis serotina* (IV = 2.35), with less than one percent of the total cover, was not a prominent component of the herbaceous layer. Total cover of herbaceous vegetation in the plots was only 17.8 % of the area sampled. Whereas some differences in IV for specific taxa between 1994 and 1995 can be attributed to seasonal life history patterns on the barren, others may be the result of microclimatic influence.

Individual species did not appear to respond strongly to measured soil variables (Fig. 4). Species that seemed to correlate with particular variables had low frequencies, so the relationship may not be meaningful. For instance, *Phlox subulata* appeared to be correlated

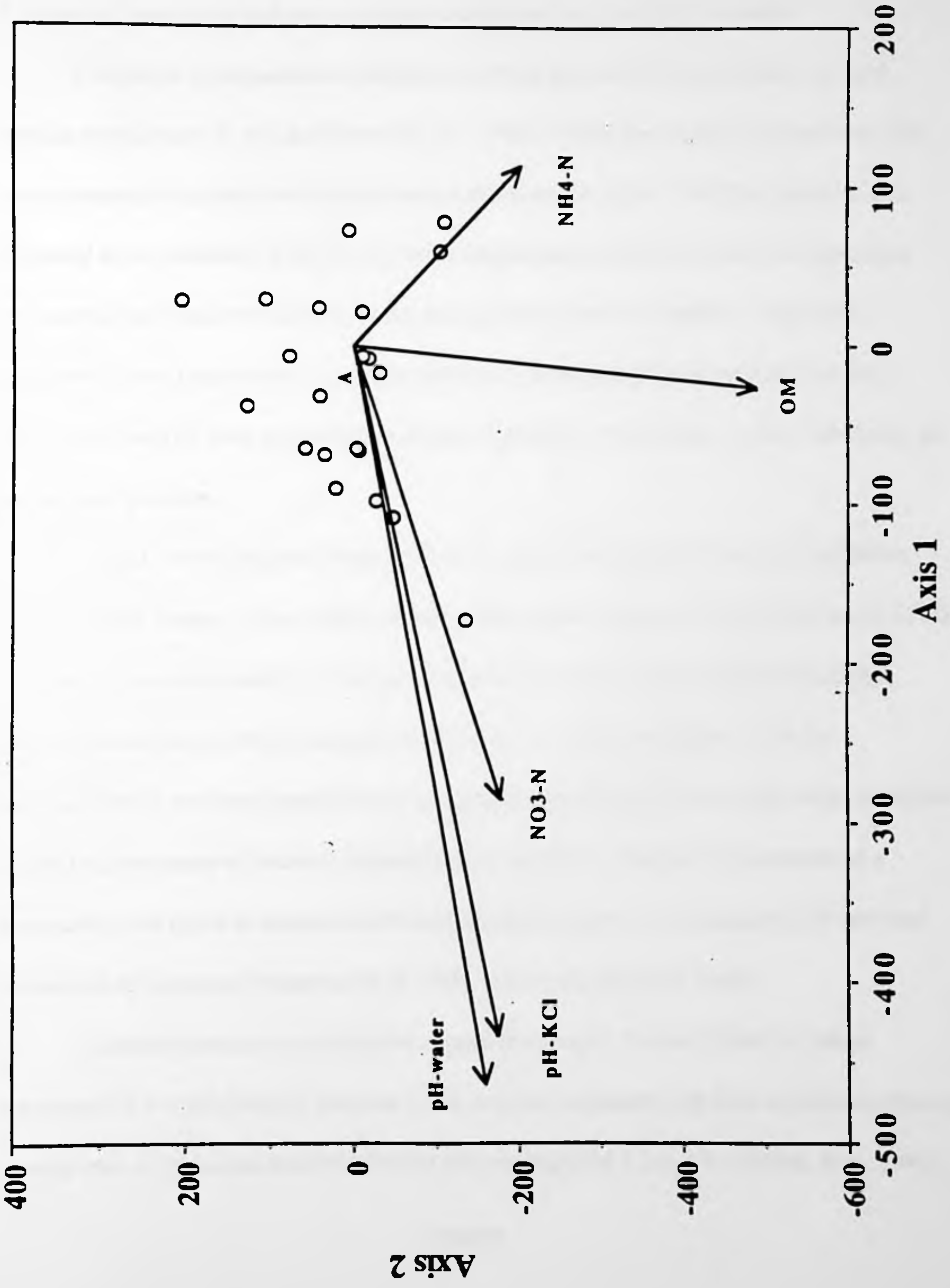
Table 1. Importance values (IV) for herbaceous species from 40 plots at Little Fork Shale Barren, Sugar Grove, WV, for the 1994 growing season. IV for each species is based of the average of relative frequency and relative cover. Data were collected from 31 August to 6 October 1994.

Species	Frequency	Rel. Frequency	Cover	Rel. Cover	IV
Carex pensylvanica	0.88	21.7	13.82	77.5	49.6
Hedyotis nuttalliana	0.50	12.4	0.42	2.4	7.4
Aristida dichotoma	0.38	9.3	0.64	3.6	6.5
Senecio antennariifolius	0.25	6.2	0.94	5.3	5.8
Vaccinium vacillians	0.15	3.7	0.50	2.8	3.3
Unknown	0.23	5.6	0.08	0.4	3.0
Asplenium platyneuron	0.20	5.0	0.14	0.8	2.9
Arabis serotina	0.18	4.3	0.07	0.4	2.4
Lespedeza repens	0.13	3.1	0.21	1.2	2.2
Unknown	0.15	3.7	0.06	0.3	2.0
Paronychia montana	0.15	3.7	0.04	0.2	2.0
Unknown	0.10	2.5	0.16	0.9	1.7
Allium oxyphillum	0.10	2.5	0.14	0.8	1.7
Phlox subulata	0.08	1.9	0.07	0.4	1.2
Pinus virginiana	0.08	1.9	0.08	0.4	1.2
Scutellaria ovata	0.08	1.9	0.04	0.2	1.1
Pinus spp.	0.08	1.9	0.04	0.2	1.1
Antennaria virginica	0.08	1.9	0.03	0.1	1.0
Unknown	0.05	1.2	0.12	0.7	1.0
Convolvulus purshianus	0.05	1.2	0.10	0.6	0.9
Unknown	0.05	1.2	0.07	0.4	0.8
Quercus spp.	0.05	1.2	0.04	0.2	0.7
Unknown	0.05	1.2	0.03	0.2	0.7
Huechera spp.	0.03	0.6	0.03	0.2	0.4
Total	4.03	99.8	17.84	100.0	100.0

Table 2. **Importance values (IV) for herbaceous species from 40 plots at Little Fork Shale Barren, Sugar Grove, WV, for the 1995 growing season. IV for each species is based on the average of relative frequency and relative cover. Data were collected from 11 to 13 July 1995.**

Species	Frequency	Rel. Frequency	Cover	Rel. Cover	IV
Carex pensylvanica	0.80	22.4	13.33	67.8	45.1
Hedyotis nuttalliana	0.43	12.9	0.76	3.9	8.4
Senecio antennariifolius	0.28	7.7	1.15	5.9	6.8
Aristida dichotoma	0.28	7.7	1.00	5.1	6.4
Paronychia montana	0.20	5.6	0.44	2.2	3.9
Asplenium platyneuron	0.20	5.6	0.25	1.3	3.5
Vaccinium vacillans	0.15	4.2	0.55	2.8	3.5
Pinus virginiana	0.18	4.9	0.36	1.8	3.4
Lespedeza repens	0.13	3.5	0.49	2.5	3.0
Allium oxyphillum	0.13	3.5	0.23	1.1	2.3
Quercus spp.	0.10	2.8	0.15	0.8	1.8
Convolvulus purshianus	0.10	2.8	0.14	0.7	1.8
Arabis serotina	0.10	2.8	0.06	0.3	1.6
Scutellaria ovata	0.10	2.8	0.06	0.3	1.6
Unknown	0.08	2.1	0.14	0.7	1.4
Unknown	0.05	1.4	0.08	0.4	0.9
Phlox subulata	0.05	1.4	0.05	0.3	0.9
Unknown	0.03	0.7	0.15	0.8	0.8
Unknown	0.05	1.4	0.03	0.1	0.8
Antennaria virginica	0.05	1.4	0.03	0.1	0.8
Unknown	0.03	0.7	0.13	0.6	0.7
Huechera spp.	0.03	0.7	0.05	0.3	0.5
Unknown	0.03	0.7	0.01	0.1	0.4
Sedum spp.	0.03	0.7	0.01	0.1	0.4
Euphorbia spp.	0.03	0.7	0.03	0.1	0.4
Total	3.58	101.1	19.66	100.0	101.1

Figure 4. Ordination of species (circles) and soil variables (vectors) from 34 plots at Little Fork Shale Barren based on canonical correspondence analysis. *Arabis serotina* is represented by the letter "A".


Axis 1
Axis 2
-500
-400
-300
-200
-100
0
100
200
400
200
0
-200
-400
-600
NH4-N
OM
NO3-N
pH-KCl
pH-water
A

with NH_4-N, but this was based on only three occurrences. Soil samples taken at additional *P. subulata* sites might indicate a stronger correlation with a different variable.

Canonical correspondence analysis of plots does indicate some response of total species composition to soil gradients (Fig. 5). These variations in species composition did not correspond noticeably with elevational position on the slope. The first canonical axis appeared to be correlated with NO_3-N, but a comparison of plots with their corresponding elevational position (row number) along this gradient showed no pattern. Apparently, gradients of soil factors vary in a patchy fashion—perhaps dependent on historical and concurrent rates of litter accumulation around vegetation—rather than in direct relation to an elevational gradient.

Allard (1946) observed deep pockets of organic detritus that collect around fallen trees on shale barrens. The presence of these litter dams, which were also observed on LFSB, may enrich the surrounding soil and provide a more suitable environment for seedling establishment and growth of species more tolerant of mesic conditions. With the immigration of new and possibly more competitive species, these litter dams could contribute to the fragmentation of endemic populations on the barren. Spatial fragmentation of a population can result in enhanced herbivory along the edges of a population or in the local extinction of a species (Schemske et al. 1994, Fahrig and Merriam 1994).

Species richness in sample plots ranged from one to 14 taxa (Table 3). Mean diversity (H' = 0.81) from 35 plots on LFSB was low compared with four watersheds from a nearby mid-Appalachian hardwood forest (H' ranging from 1.2 to 1.9; Gilliam, et al. 1995).

Figure 5. Ordination of herbaceous community plots (circles) and soil variables (vectors) from 34 plots at Little Fork Shale Barren based on canonical correspondence analysis.

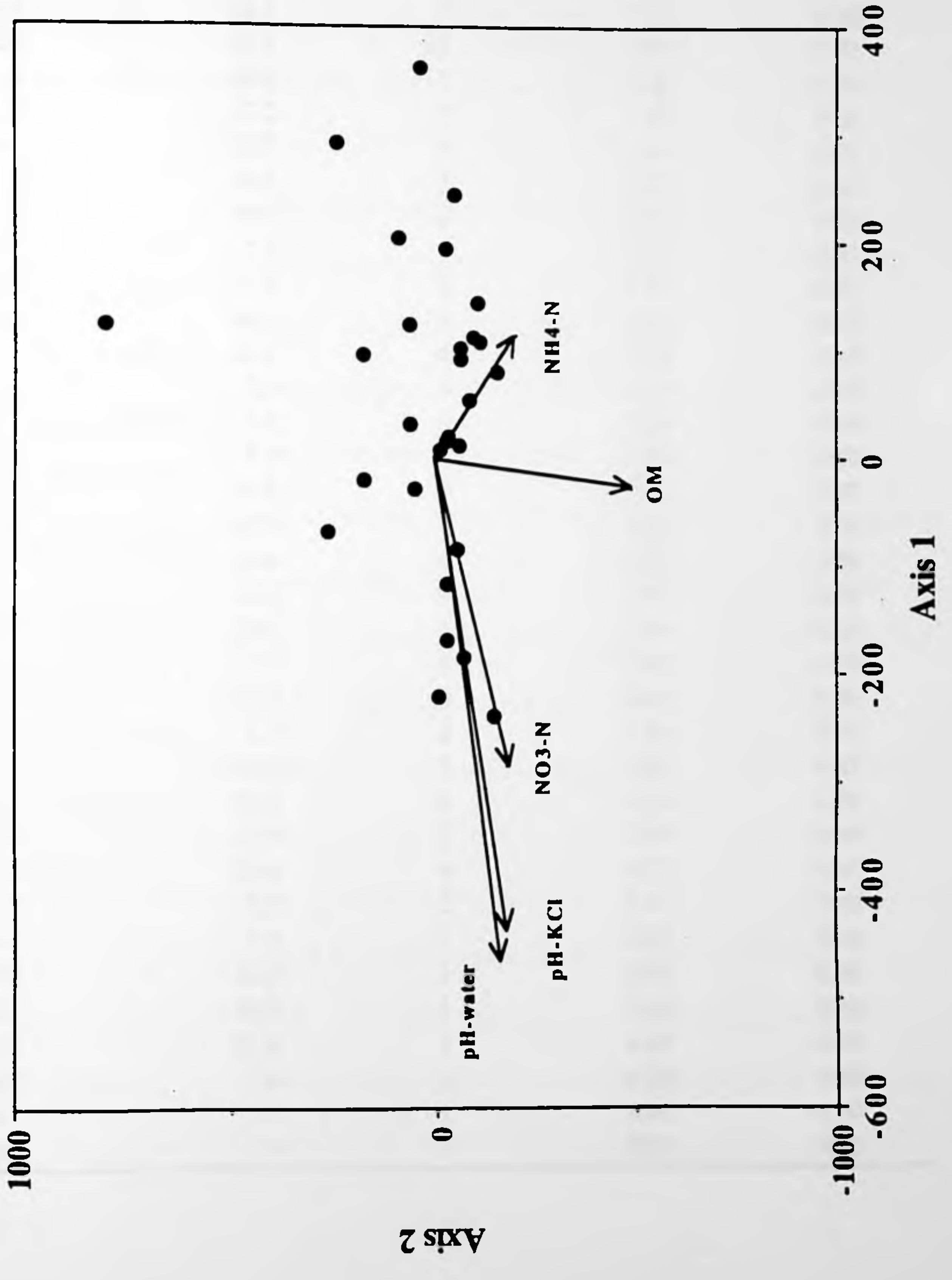

Axis 1
Axis 2
400
200
0
-200
-400
-600
1000
0
-1000
NH4-N
OM
NO3-N
pH-KCl
pH-water

Table 3. Shannon-Weiner diversity (H') and Equitability (J) from 35 plots at LFSB, Sugar Grove, WV. Plots are listed by diversity from the highest to lowest values.

Plot	Cover (%)	Richness (species/plot)	Diversity (H')	Equitability (J)
4-18	18.0	9	2.07	0.94
1-14	28.5	9	1.72	0.78
2-20	26.5	10	1.67	0.72
2-16	30.0	7	1.58	0.81
5-17	12.5	5	1.50	0.93
2-11	21.5	5	1.34	0.83
1-18	34.5	7	1.20	0.62
2-15	49.0	6	1.19	0.66
3-18	7.0	4	1.15	0.83
4-14	14.0	5	1.15	0.72
3-16	48.5	5	1.13	0.70
1-23	33.0	4	1.09	0.79
3-22	2.0	3	1.04	0.95
1-12	8.0	3	0.98	0.89
4-13	8.5	3	0.88	0.80
4-23	29.0	3	0.84	0.77
3-30	12.5	3	0.82	0.75
1-25	25.0	4	0.81	0.59
1-11	14.0	4	0.81	0.59
1-28	29.0	4	0.69	0.50
1-26	7.0	2	0.68	0.99
3-23	12.0	2	0.64	0.92
1-30	1.5	2	0.64	0.92
3-25	34.0	2	0.58	0.83
2-26	30.5	4	0.54	0.39
3-24	13.0	3	0.54	0.49
2-25	24.0	4	0.52	0.37
4-30	3.5	2	0.41	0.59
3-21	1.5	1	0.00	0.00
3-20	25.0	1	0.00	0.00
4-27	30.0	1	0.00	0.00
2-28	21.0	1	0.00	0.00
2-27	7.0	1	0.00	0.00
3-11	0.5	1	0.00	0.00
3-15	1.0	1	0.00	0.00

The four watersheds are located in the Fernow Experimental Forest (FEF) in Tucker County, West Virginia. The FEF is in the Allegheny Mountain Physiographic Province of West Virginia, however, with a mean annual precipitation of 143 cm yr^{-1} (Gilliam et al. 1996). The differences in mean annual precipitation between LFSB and FEF (84 cm yr^{-1} and 143 cm yr^{-1}, respectively) may account in part for differences in the species diversity of these communities. Mean annual precipitation has been shown to influence both species richness and primary productivity in some communities (Begon et al. 1996). The higher herbaceous cover (%) and species richness at FEF may be the result of the higher mean annual precipitation, which possibly contributed to higher species diversity at FEF.

Other factors may also have contributed to lower species diversity at LFSB. The prominence of *C. pensylvanica* in the herbaceous layer at LFSB accounted in part for the low diversity, because the evenness component of the diversity index treats other taxa as rare occurrences in light of the high percent cover of *C. pensylvanica*. The low herbaceous cover on the barren (17.8 % of the area sampled) also contributed to low species diversity. Low cover may be attributable to the difficulty of seedling establishment on shale barrens due to low annual precipitation and high temperatures (Platt 1951). Platt (1951) also observed that the majority of "characteristic" shale barren plants are either geophytes, with perennating organs below ground, or hemicryptophytes, with perennating organs just above the soil surface (*sensu* Raunkiaer 1934). Platt (1951), suggesting that root-shoot allocations of shale barren species may account for low herbaceous cover, noted that these species had relatively reduced aerial shoots and extensive root systems. Reduced aerial growth (and subsequent low herbaceous cover) appears to result from temperature and moisture extremes at the soil surface.

SOILS. Analysis of soils showed significant differences in NO_3-N and pH-H_2O at $p \leq 0.05$ between the north-northwest facing forest slope behind LFSB and the shale barren slope (Table 4). The lower amounts for NO_3-N pools on the forest slope may be attributable to greater seasonal uptake of NO_3-N, due to an increase in sustainable biomass. There were also significant differences in pH-KCl and percent organic matter (OM) at $p \leq 0.10$. While the pH at LFSB was typical of this soil series, OM (mean = 8.42 %) was greater than the average 0.5 to 3 percent (USDA 1992). Platt (1951) observed that the amount of organic matter on shale barrens was approximately half that of the surrounding forest slopes. The greater OM on LFSB could be attributable to either the sampling depth or the date of sampling. Platt (1951) noted that shale barren soils vary from 10 to 30 cm deep and OM decreased with soil depth. For example, samples taken at a depth of 5 cm would have higher OM than samples taken at 10 cm. Since the decomposition of OM by soil microbes is influenced by moisture and temperature regimes (Begon et al. 1986), seasonal variations in precipitation and temperature (particularly in drought years) could also influence levels of OM in the soil horizon.

WOODY VEGETATION. Nine woody species were encountered on the shale barren and 11 species were encountered on the forest slope, for a total of 14 distinct taxa for both site types combined. Three species (*Quercus velutina*, *Amelanchier* sp., and *Crataegus* sp.) on the barren were not found within the sample plots on the forest slope and four species

Table 4. Soil data collected from three plots on LFSB, Sugar Grove, WV, and three plots on the forest slope behind LFSB. Two soil samples were taken in each plot. Data were collected on 16 May 1995.

Site	pH KCl	NH_4 (mg / kg)	NO_3 (mg / kg)	pH H_2O	% Organic Matter
shale barren	4.25^b	0.60	3.16^a	5.87^a	8.4^b
forest	3.77^b	0.38	2.15^a	5.15^a	7.3^b

a - indicates significant differences between sites at $p \leq 0.05$.
b - indicates significant differences between sites at $p \leq 0.10$.

(*Acer rubrum*, *Pinus strobus*, *Nyssa sylvatica*, and *Kalmia latifolia*) on the forest slope were not found on the barren. It should be noted, however, that *P. strobus* does occur on LFSB in relatively small numbers, but is restricted to a small area near rows 3 through 5 and column 20 (Fig. 3).

Based on relative basal area and relative density, *Q. prinus* was the dominant species on both the shale barren and the forest slope (Tables 5 and 6). Apart from this similarity, the remaining dominants on the barren are typical of more xeric habitats (*P. virginiana* and *Carya* spp.) and the dominants on the forest slope (*P. strobus* and *Hamamelis virginiana*) of more mesic habitats. The abundance of *Q. prinus*, which tends to prefer drier soils (Whittaker 1956), on both the forest and the shale barren slopes can be attributed to the low annual precipitation for this physiographic province in which the majority of rainfall is blocked by the Allegheny Mountains to the west.

A notable difference between the two communities was for stem density, wherein the forest slope had nearly twice the density found on the barren (805 stems/ha vs. 408.7 stems/ha respectively). In comparison, two ~ 20 yr old, even-aged stands at nearby FEF had greater than double the density (~ 2100 stems/ha) of that found on the forest slope at LFSB (Gilliam et al. 1995). However, the density of the forest slope at LFSB was greater than that of a mature (> 70 yr old) uneven-aged stand at FEF (854 stems/ha). Basal area was much greater on the forest slope at LFSB (31.2 m^2/ha) than on the barren (18.2 m^2/ha). Basal area on the forest slope at LFSB was greater than the two even-aged stands at FEF, but less than the two uneven-aged stands (Gilliam et al. 1995).

Table 5. **Importance values (IV) for woody species from the forest slope behind Little Fork Shale Barren, Sugar Grove, WV. IV for each species is based on the average of relative basal area (BA) and relative density (D). BA is expressed as m^2/ha. D is expressed as # stems/ha.**

Species	BA	Rel. BA	D	Rel. D	IV
Quercus prinus	18.66	59.79	81.77	10.16	34.98
Pinus strobus	6.25	20.03	188.67	23.44	21.74
Hamamelis virginiana	0.34	1.08	194.97	24.22	12.65
Cornus florida	1.38	4.42	144.67	17.97	11.20
Acer rubrum	0.54	1.72	81.77	10.16	5.94
P. virginiana	2.40	7.68	12.57	1.56	4.62
Q. velutina	0.35	1.13	37.73	4.69	2.91
Carya spp.	0.84	2.68	25.17	3.13	2.91
Q. alba	0.30	0.95	18.87	2.34	1.65
Nyssa sylvatica	0.15	0.49	12.57	1.56	1.03
Kalmia latifolia	0.01	0.02	6.3	0.78	0.40
Total	31.21	99.99	805.03	100.01	100.03

Table 6. **Importance values (IV) for woody species from the shale barren slope at Little Fork Shale Barren, Sugar Grove, WV. IV for each species is based on the average of relative basal area (BA) and relative density (D). BA is expressed as m^2/ha. D is expressed as # stems/ha.**

Species	BA	Rel. BA	D	Rel. D	IV
Quercus prinus	9.71	53.31	106.93	26.16	39.74
Carya spp.	2.95	16.19	125.8	30.77	23.48
Pinus virginiana	4.34	23.84	50.3	12.30	18.07
Cornus florida	0.21	1.17	44.03	10.77	5.97
Q. ilicifolia	0.34	1.85	37.73	9.23	5.54
Q. velutina	0.54	2.98	12.57	3.07	3.03
Q. alba	0.09	0.48	12.57	3.07	1.78
Amelanchier spp.	0.03	0.15	12.57	3.07	1.61
Crataegus spp.	0.01	0.04	6.3	1.54	0.79
Total	18.21	100.01	408.8	99.98	100.01

Summary and Conclusions

The vascular plant community within the sample plots at LFSB consisted of nine woody species and 25 herbaceous species. It is possible, however, that other species were located outside of the plots and were not included. Seven of the herbaceous species, including *A. serotina*, are endemic to the mid-Appalachian shale barrens. Although 25 herbaceous species were noted within the sample plots at LFSB, *C. pensylvanica* accounted for 77% of the total herbaceous cover in 1994 and 67% in 1995. Most of the other species (75% in 1994 and 60% in 1995) accounted for less than one percent of the total herbaceous cover. In addition, only 17.8% of the area sampled was covered with vegetation.

Because of the prominence of *C. pensylvanica* in the herbaceous layer and the relatively low amount of herbaceous cover, species diversity was low ($H' = 0.81$) on LFSB. Due to the lack of data from other barrens, however, the comparison was made between LFSB and a nearby mid-Appalachian hardwood forest. Therefore, the determination that LFSB has "low" species diversity may only be a relative comparison between the two different community types. Future studies should compare these results with data from other shale barren communities to determine if species diversity varies from barren to barren or is relatively constant.

The results of multivariate analyses in this study are inconclusive, although there appears to be some correlation between individual species/total species composition and measured soil variables. Sampling which focuses on individual species may prove more beneficial in determining significant correlations with soil variables. Additional parameters such as soil depth, soil texture, soil temperature, insolation, aspect, slope, topography, and other mineral nutrients may also prove significant in shale barren communities.

This study of the vascular plant community at LFSB has provided researchers with a more quantitative view of LFSB and its differences from the surrounding forest slopes, however, the resulting view is still narrow in scope. The temporal changes in both species composition and the barren landscape (and their causative factors) should also be studied. Due to the loose shale substrate and typically steep slopes, the barren landscape is subject to frequent and sudden change. The resulting litter accumulation and increased insolation around fallen trees and the erosion of barren soils (in combination with other factors) may have significant effects on barren vegetation.

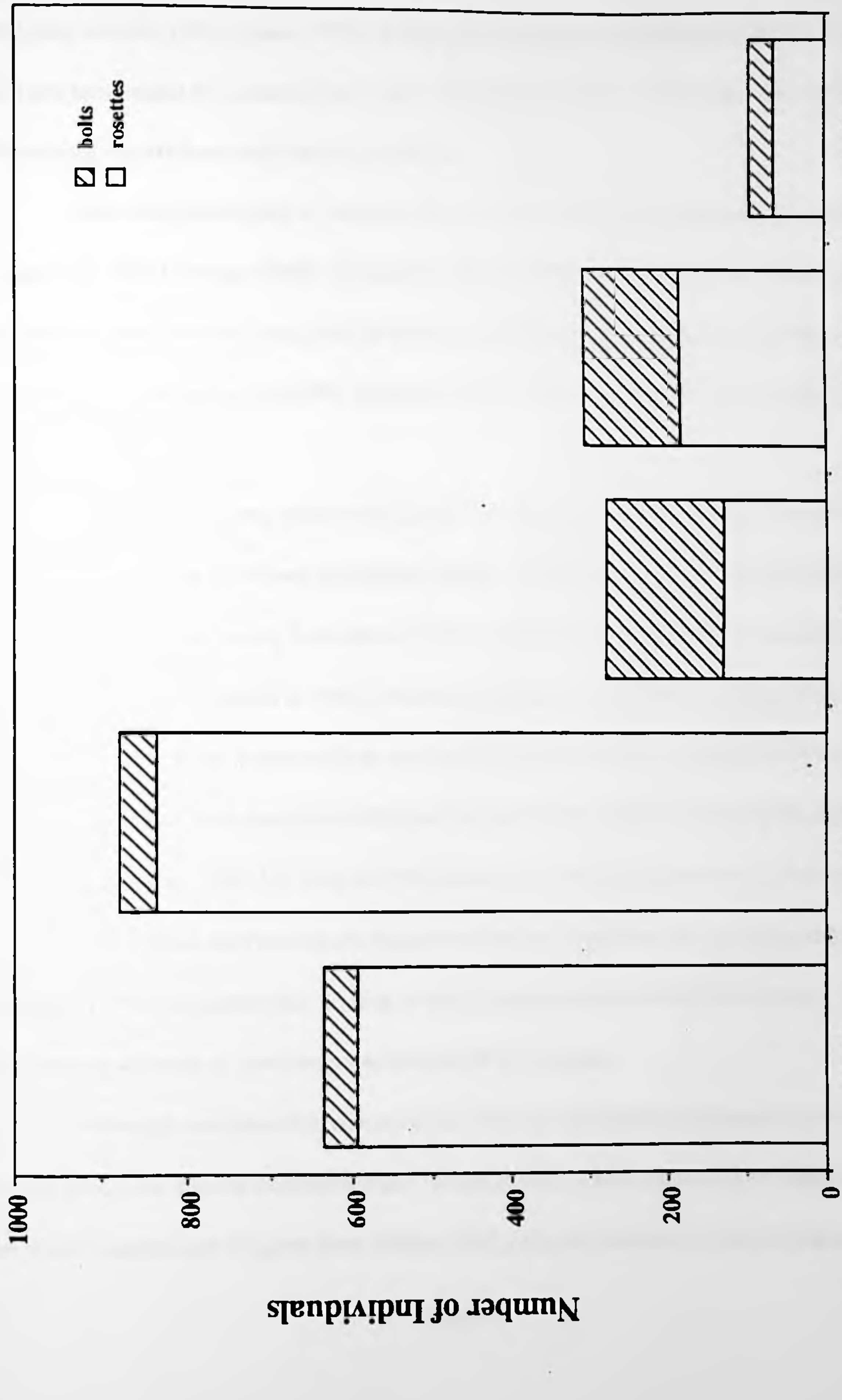
CHAPTER III: STUDY OF SHALE BARREN ROCK CRESS POPULATION

Introduction

Shale barren rock cress (*Arabis serotina* Steele) is an endemic species of the mid-Appalachian shale barrens which are in the Ridge and Valley Physiographic Province of West Virginia and Virginia. *Arabis serotina* is limited to only 55 extant populations found in six Virginia counties and three West Virginia counties (P. J. Harmon, pers. comm.). In West Virginia, seven populations are located in the valley of Anthony Creek in Greenbrier County and six populations are located in the valley of the South Fork of the South Branch of the Potomac River (Bartgis 1987). Throughout its range, population size varies from one shale barren to another. Population size can range from less than 10 to well over 100 individuals (US Fish and Wildlife Service 1991). The largest known population of 880 individuals was recorded in 1992 at Little Fork Shale Barren (LFSB) in Pendleton County, West Virginia, data for which are included in this study (Fig. 6).

Arabis serotina is a member of the Brassicaceae (mustard family), first collected by Edward S. Steele in 1906 near Millboro, Bath County, Virginia (Steele 1911). It is considered by most authors to be a facultative biennial with the nonreproductive stage being a basal rosette comprised of leaves with a lobed margin. The term 'facultative biennial' is preferred over 'monocarpic perennial', because it allows for the distinction between short-lived and relatively long-lived species (Kelly 1985). The rosette, which may reach 7 cm in diameter, may persist for one or more years until the inflorescence is produced (US Fish and

Figure 6. Number of individuals of *Arabis serotina* located within the grid at Little Fork Shale Barren, Sugar Grove, WV, from 1991 through 1995.


Number of Individuals
0
200
400
600
800
1000
1991
1992
1993
1994
1995
bolts
rosettes

Wildlife Service 1991, Rouse 1993). Bolting plants reach a height between 40 and 100 cm and are terminated by a raceme with small white flowers (Steele 1911, Wieboldt 1987). Flowering occurs from mid-July to September.

As mentioned earlier, *A. serotina* was listed as a federally endangered species in August of 1989 (Morgan 1989). Drought, habitat destruction, and herbivory by deer, insects, or other animals have all been cited as potential factors adversely affecting *A. serotina* populations (Bartgis located 1987, Morgan 1989, US Fish and Wildlife Service 1991, Rouse 1993).

Drought stress may determine, in part, the degree of reproductive success of *Arabis serotina*. Within an undefined population, Bartgis (1987) observed substantial reproductive failure in *A. serotina* during a drought in 1987, wherein only 12 individuals produced seed as opposed to 136 individuals in 1985. Evidence of herbivory on bolting plants also indicates another threat to those bolts which do successfully produce seed. Although herbivory of bolting plants has been previously attributed to deer (Bartgis 1987, West Virginia Division of Natural Resources 1989, US Fish and Wildlife Service 1991), observations by Rouse (1990) of herbivory within deer exclosures suggests additional organisms are also responsible. Harmon (1992) suggested that grazing by sheep and goats has probably been most destructive of some *A. serotina* populations in West Virginia.

Although evidence of herbivory on *A. serotina* individuals is substantial, the identity of the herbivore species remains unclear. Rouse (1993), while monitoring six shale barrens in West Virginia and Virginia from 1990 to 1992, observed herbivory in 63 % of monitored rosettes in 1991 and 34 % in 1992, but the organism responsible (presumed by Rouse to be an insect) was never located. Other reports of herbivory on bolting plants of *A. serotina* are believed to be erroneous (Bartgis 1987, Morgan 1989, US Fish and Wildlife Service 1991).

This chapter focuses on the population dynamics of *A. serotina* at LFSB. The study was designed to provide baseline information on the life history of *A. serotina* and assess any biotic or abiotic factors which potentially influence the survivorship of this federally endangered species.

Materials and Methods

STUDY SITE. Research was conducted at Little Fork Shale Barren (LFSB), Naval Security Group Activity, Sugar Grove, West Virginia. The population was sampled within the 1.6 ha grid described in the previous chapter for the community study at LFSB. Population counts of the *Arabis serotina* population found within this grid have been conducted by the West Virginia Natural Heritage Program (WVHP) since 1991 (Harmon 1997).

FIELD SAMPLING and ANALYSIS. Population dynamics of *A. serotina* were assessed by periodic observation of 40 (2-m x 2-m) sample plots located randomly within the grid. The observations made at each plot included: (1) presence/absence of *A. serotina*, (2) developmental stage (seedling, rosette, or bolt), (3) location of individuals within the plot, (4) plant height and diameter, (5) silique production, (study 6) evidence of browsing or herbivory, and (7) presence/absence of stolon. Additional plants not within the plots were also monitored. Because the community plots were nested within the population plots, the same soil samples were used to assess any relationship between *Arabis serotina* and soil nutrient levels. Observations were made from 31 August to 6 October 1994 and 11 to 13 July 1995.

Total population summaries within the grid from 1991 through 1995 were provided by WVHP. An additional survey of the *A. serotina* population was made from 20% of the barren on 12 July 1995. These counts were done in 20 randomly-selected 10-m x 10-m cells. Total numbers of rosettes and bolting plants were recorded along with any evidence of herbivory.

DATA ANALYSIS. To determine the dispersion pattern of *A. serotina* on LFSB, population data from 1994 and 1995 were assessed with the Poisson distribution. The Poisson distribution assumes a random dispersion of individuals within a community. The observed frequency distribution of *A. serotina* within the 40 sample plots was compared with the expected frequency distribution according to the Poisson distribution. The expected frequency distribution was calculated as follows:

$$F(X) = (e^{-m})(m^{x} / x!)(n)$$

where m is the total number of plants observed (from all samples) divided by the number of samples observed, x is the number of plants per sample (from a single sample), and n is the observed number of quadrats. For clarity, the observed frequency distribution would be the number of quadrats containing x individuals. Therefore, the expected frequency distribution predicts that proportion of quadrats with x individuals. A chi-square goodness-of-fit test was then used to compare the two frequency distributions.

Canonical correspondence analysis (CCA) and the Pearson product-moment correlation were also used to determine any relationship between measured soil variables and the occurrence of *A. serotina* individuals. A modified life history table was compiled using data from 1994. The life history table does not follow the entire life cycle of a single cohort. but probably contains several cohorts and only covers the time of sampling. Additionally, temperature and precipitation data from nearby Franklin, West Virginia, were used to assess the significance of climate on the population at LFSB. Comparisons of climatic data were made between 30-yr means and data from 1992, 1993, and 1994. Climatic data covered the period from 1964 to 1994. Variations from the mean were then compared with annual fluctuations in the *A. serotina* population. Climatic data were provided by the National Climatic Data Center in Asheville, North Carolina.

A comparison of population data collected on 12 July 1995 with WVHP data collected on 2 September 1995 was done for the twenty randomly sampled 10 m x 10 m cells. The percentages of individuals showing signs of herbivory were also calculated for both rosettes and bolting plants from the earlier sampling date.

Results and Discussion

There was a marked decline in the *A. serotina* population between 1992 (880 individuals) and 1993 (282 individuals) (Fig. 6). In 1992, 5% of plants surveyed were in the bolting stage and in 1993 there were 52% bolting plants. The population in 1994 (311 individuals) had 40% bolting plants. In contrast to the decline from 1992 to 1993, a partial survey of LFSB in July 1995 (representing two-fifths of the grid) found 330 plants for a population estimate of ~800 individuals. Of the 330 plants only 16 (4.8%) were bolting plants. However, by 2 September 1995, the population for the entire grid had dropped to only 96 plants. Thus, the *A. serotina* population at LFSB exhibits a high degree of year to year variation, as well as substantial mortality within a single growing season. Because large decreases within natural populations in a relatively short period of time are not uncommon, more data are needed to determine if the recent decrease in the *A. serotina* population at LFSB is the result of natural fluctuations in population size, the result of a "catastrophic" event such as drought, or local extinction due to other factors (Mangel and Tier 1994).

A fungus (*Cladosporium* spp.) had covered bolting plants by the week of 20 September 1994. Fungal infection during the late summer also occurs in *Arabis holboellii*, *Arabis drummondii*, and other species of mustard (Roy 1993). The only bolts infected, however, were those which occurred on the upper slope above the grid. Whether or not the fungus had an effect on seed viability was not determined. Roy and Bierzychudek (1993), commenting on the infection of *Arabis holboellii* with systemic rust disease in western Colorado, observed that infection could severely reduce survivorship and fecundity.

Insect pupae were also found in the stems and branches of bolting plants. These were determined to be wasp pupae (Order Hymenoptera) in the Family Sphecidae (D.A. Adkins, pers. comm.). The presence of these pupae did not appear to have an effect on successful bolting and seed production. Future monitoring efforts should note the extent of this relationship among *A. serotina* populations. There were no pupae found in 1995, but this could be due to the earlier sampling — July as opposed to September — relative to 1994.

Canonical correspondence analysis of community data and soil variables suggests that *A. serotina* showed little response to soil gradients on the barren (Fig. 4). However, analysis of the limited data available suggests that observed population fluctuations may be related to variation in climatic variables, particularly temperature and precipitation. A comparison of monthly temperature and precipitation from 1992, 1993, and 1994, to a 30-yr mean appears to account for some of this seasonal variation in population size. In 1992, when the population was the largest ever recorded for *A. serotina*, temperatures were slightly lower than the 30-yr mean (Fig. 7). Temperatures in 1994, however, were higher than the 30-yr means for every month except January (Fig. 8). The mean temperature for April in 1994 was even greater than the mean maximum values of the 30-yr mean. Particularly, the months of June, July, and August, when *A. serotina* blooms, had greater temperatures than the 30-yr mean. In 1993, when the largest decline in population occurred, mean temperatures were again higher in June, July, and August (Fig. 9).

Precipitation in 1992 was slightly higher than the 30-yr mean during the early growing season, but then declined and dropped much lower than the mean during the remainder of the year (Fig. 10). In contrast, data from 1994 show greater variation with much higher than normal precipitation in winter and late summer, but lower in April and June (Fig. 11). Precipitation in 1993 was also much lower than the 30 yr mean from May

Figure 7. Comparison of mean monthly temperature (C°) between 1992 and a 30-yr mean. Data were collected in Franklin, West Virginia, and were reported by the National Climatic Data Center, Asheville, North Carolina.

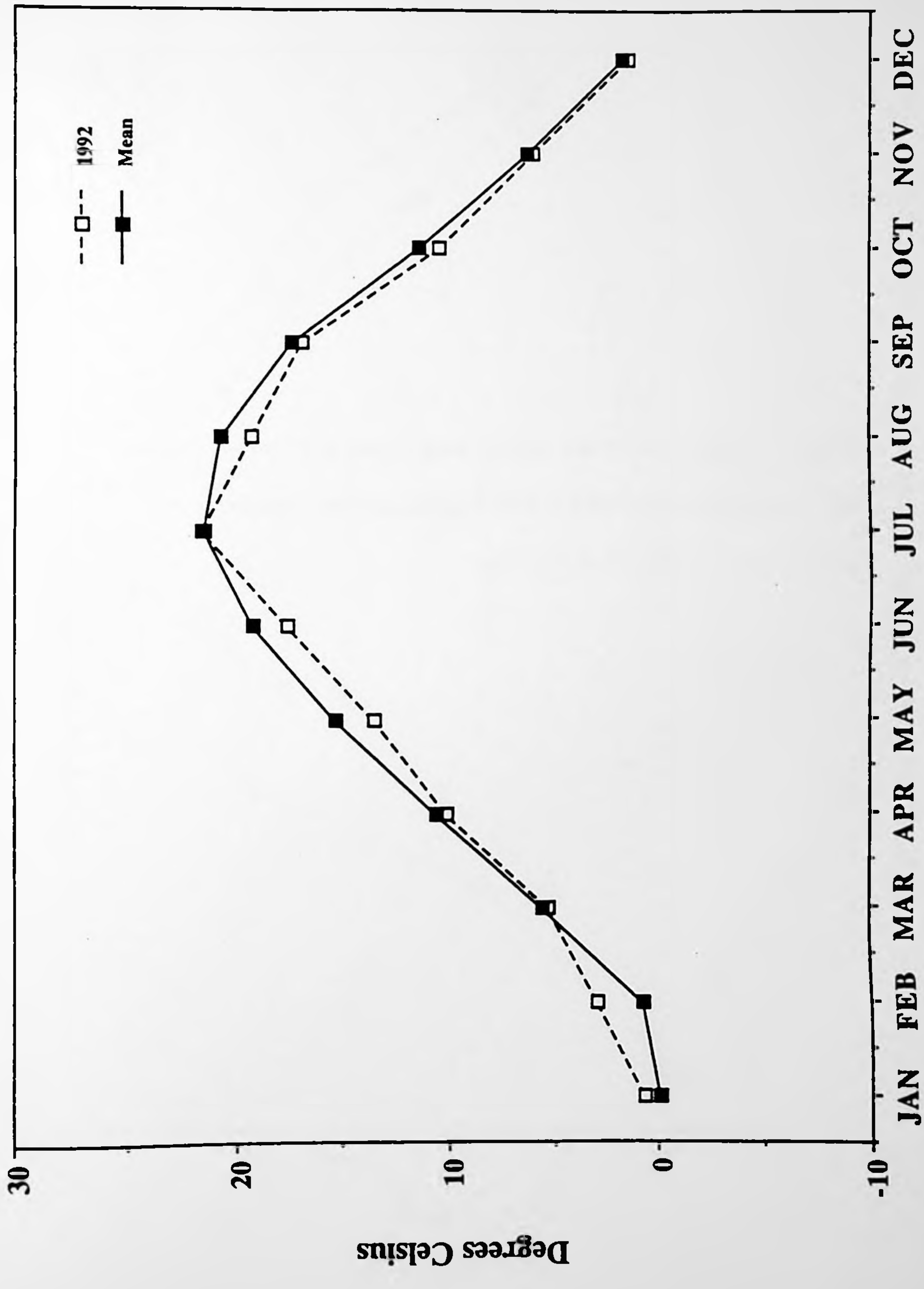
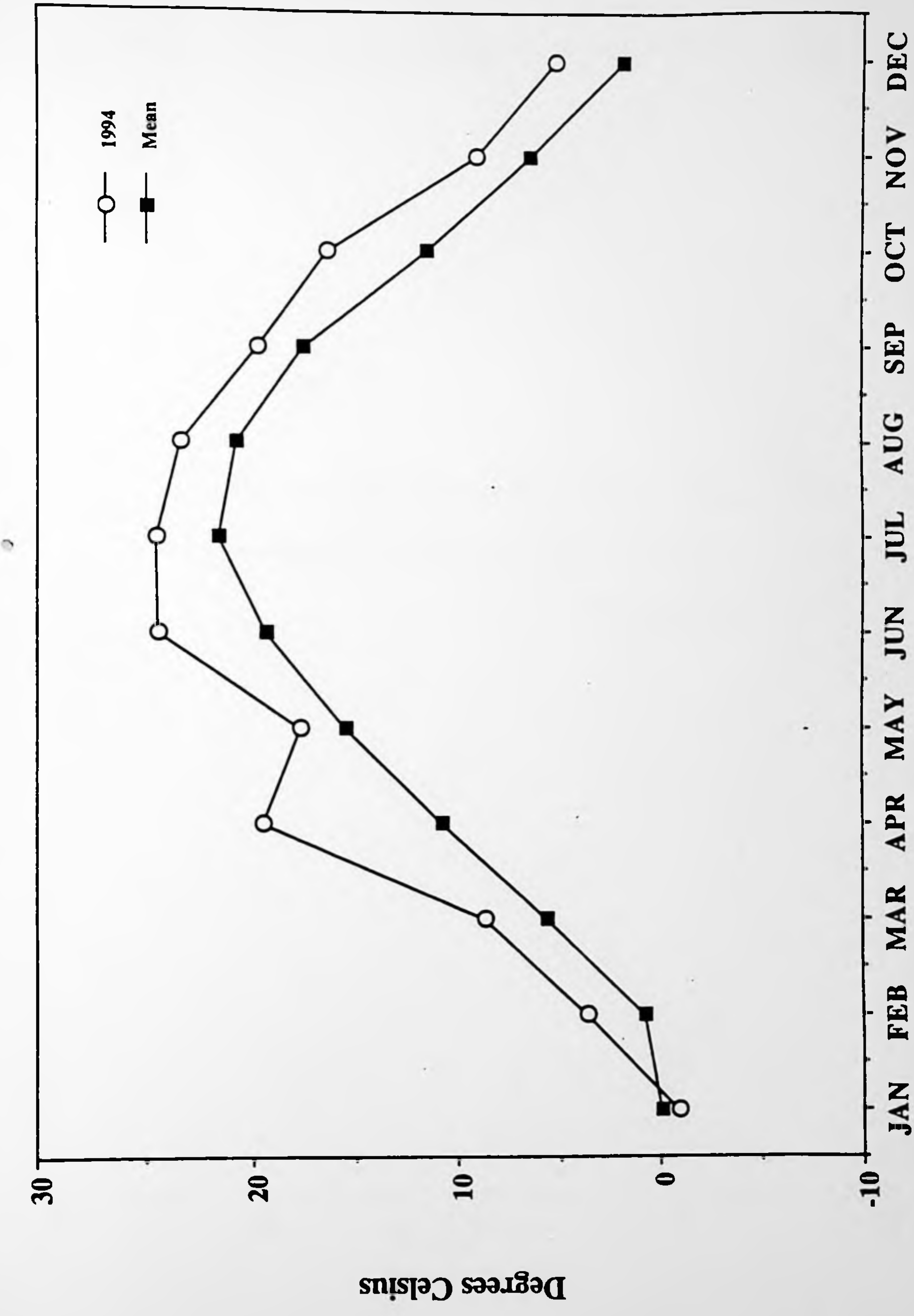

1992
Mean
30
20
10
0
-10
Degrees Celsius
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Figure 8. Comparison of mean monthly temperature (C°) between 1994 and a 30-yr mean. Data were collected in Franklin, West Virginia, and were reported by the National Climatic Data Center, Asheville, North Carolina.



1994
Mean
Degrees Celsius
30
20
10
0
-10
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Figure 9. Comparison of mean monthly temperature (C°) between 1993 and a 30-yr mean. Data were collected in Franklin, West Virginia, and were reported by the National Climatic Data Center, Asheville, North Carolina.

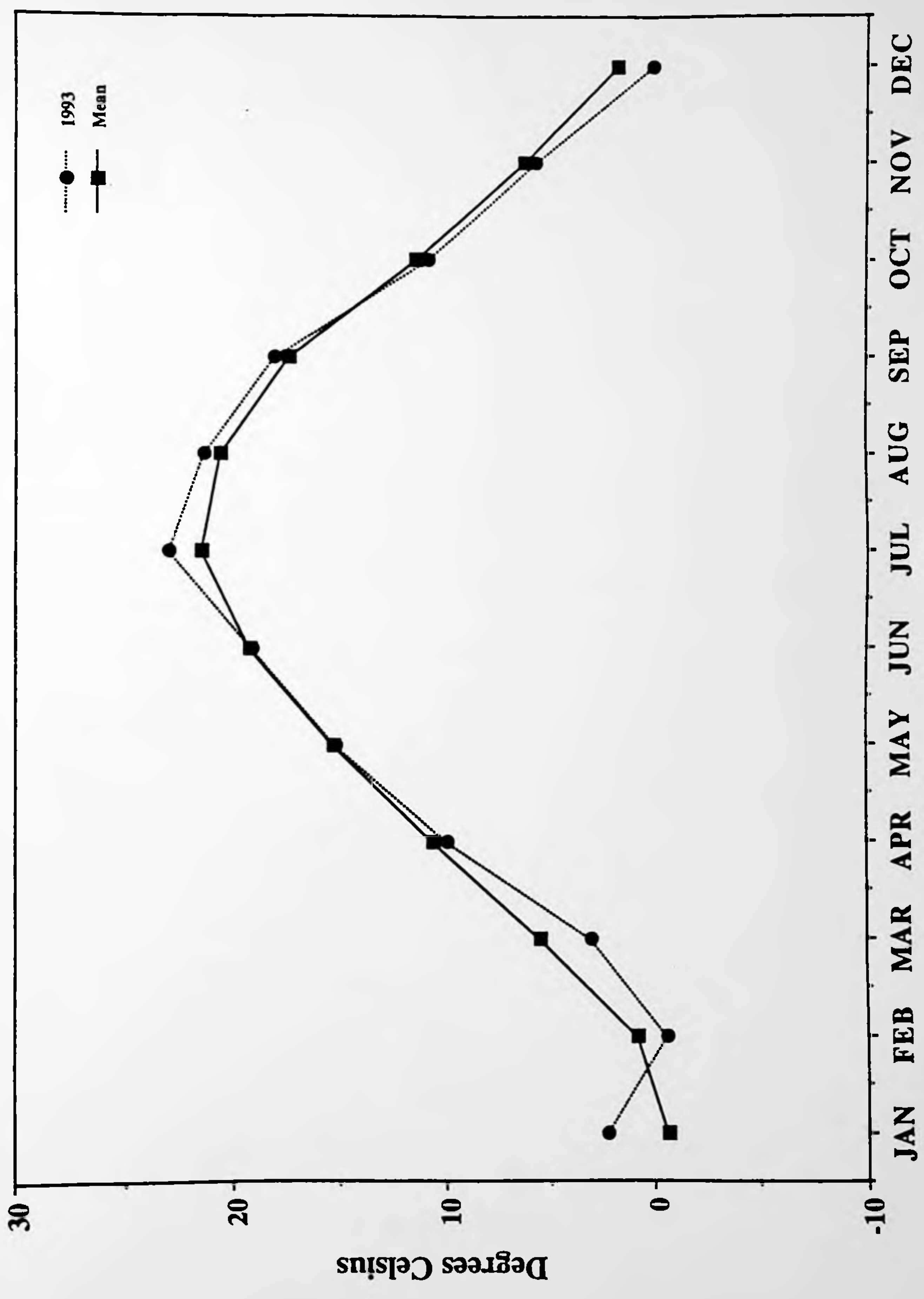

1993
Mean
Degrees Celsius
30
20
10
0
-10
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Figure 10. Comparison of mean monthly precipitation (cm) between 1992 and a 30-yr mean. Data were collected in Franklin, West Virginia, and were reported by the National Climatic Data Center, Asheville, North Carolina.

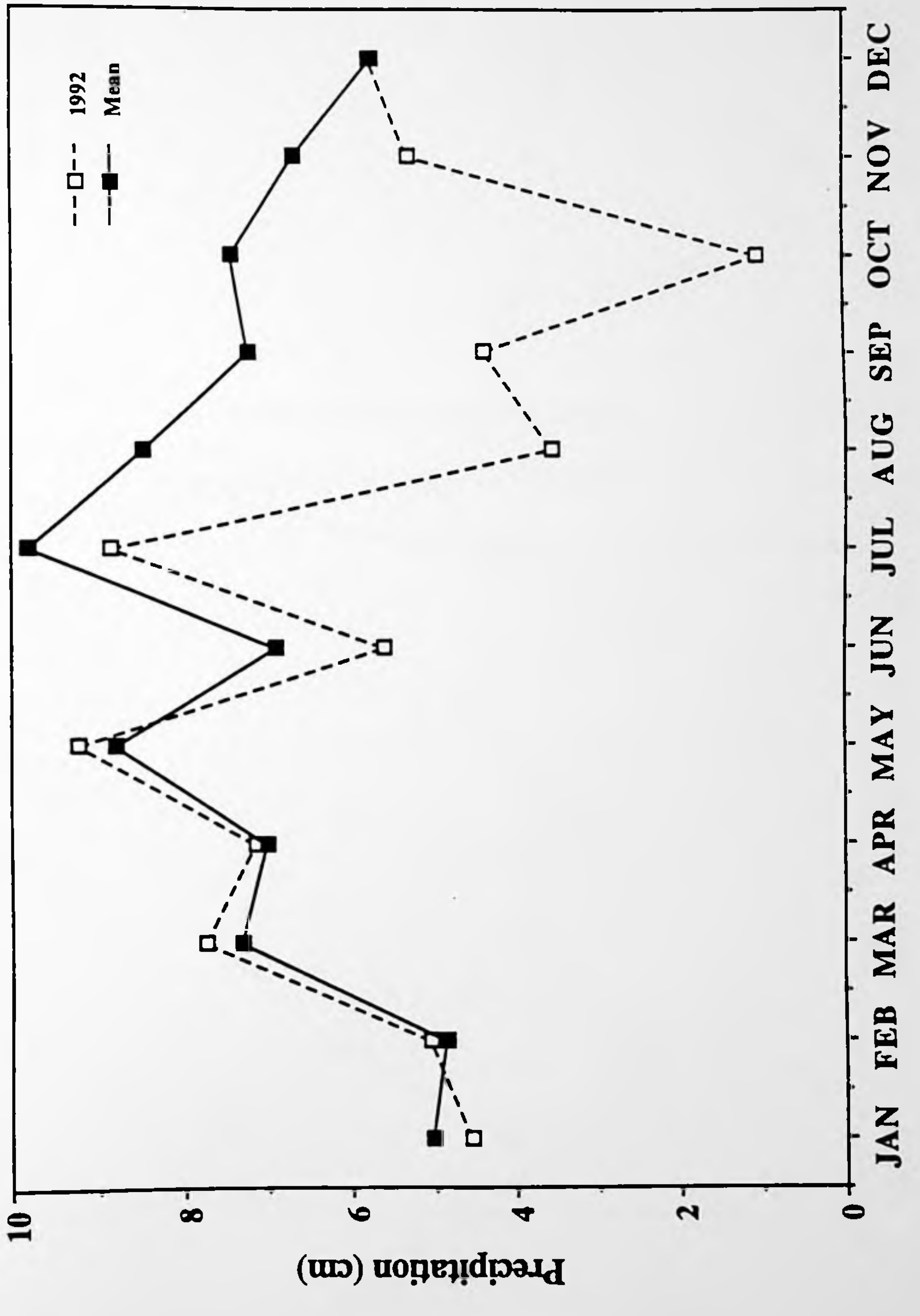
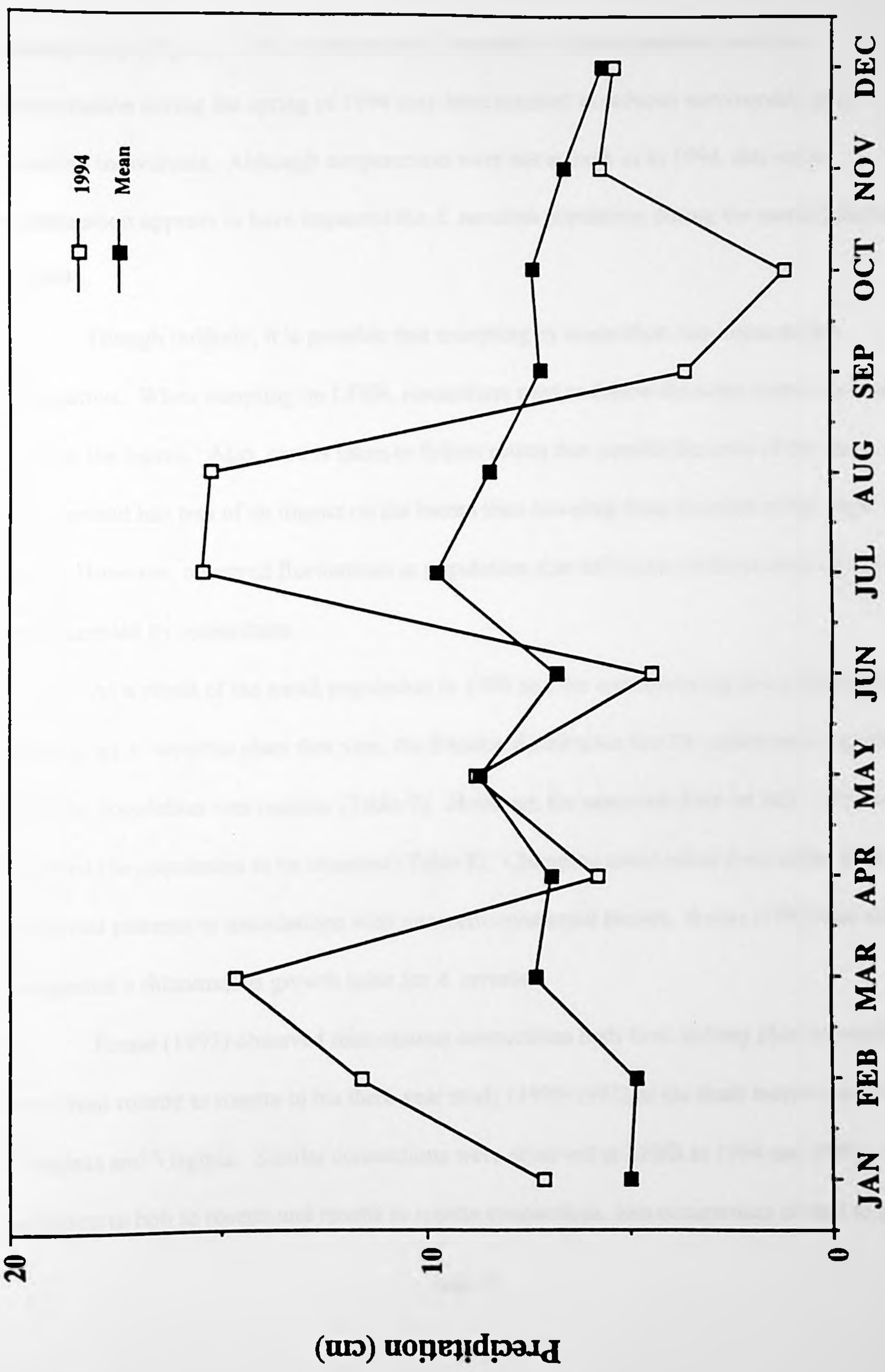

Precipitation (cm)
0
2
4
6
8
10
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1992
Mean

Figure 11. Comparison of mean monthly precipitation (cm) between 1994 and a 30-yr mean. Data were collected in Franklin, West Virginia, and were reported by the National Climatic Data Center, Asheville, North Carolina.


Precipitation (cm)
0
10
20
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1994
Mean

through July (Fig. 12). The combination of unusually high temperatures and low precipitation during the spring of 1994 may have resulted in reduced survivorship of *A. serotina* individuals. Although temperatures were not as high as in 1994, this same combination appears to have impacted the *A. serotina* population during the marked decline in 1993.

Though unlikely, it is possible that trampling by researchers has impacted the population. When sampling on LFSB, researchers tried to follow the same routes upon each visit to the barren. Also, care is taken to follow routes that parallel the crest of the slope, as this method has less of an impact on the barren than traveling from the crest of the slope to its base. However, observed fluctuations in population size still occur on those areas of the grid not trampled by researchers.

As a result of the small population in 1994 and the corresponding low probability of finding an *A. serotina* plant that year, the Poisson distribution test for randomness suggested that the population was random (Table 7). However, the same test done on July 1995 data showed the population to be clumped (Table 8). Clumping could result from either seed dispersal patterns or associations with microenvironmental factors. Rouse (1993) has also suggested a rhizomatous growth habit for *A. serotina.*

Rouse (1993) observed rhizomatous connections both from bolting plant to rosette and from rosette to rosette in his three year study (1990-1992) of six shale barrens in West Virginia and Virginia. Similar connections were observed at LFSB in 1994 and 1995. In addition to bolt to rosette and rosette to rosette connections, two occurrences of bolt to bolt

Figure 12. Comparison of mean monthly precipitation (cm) between 1993 and a 30-yr mean. Data were collected in Franklin, West Virginia, and were reported by the National Climatic Data Center, Asheville, North Carolina.

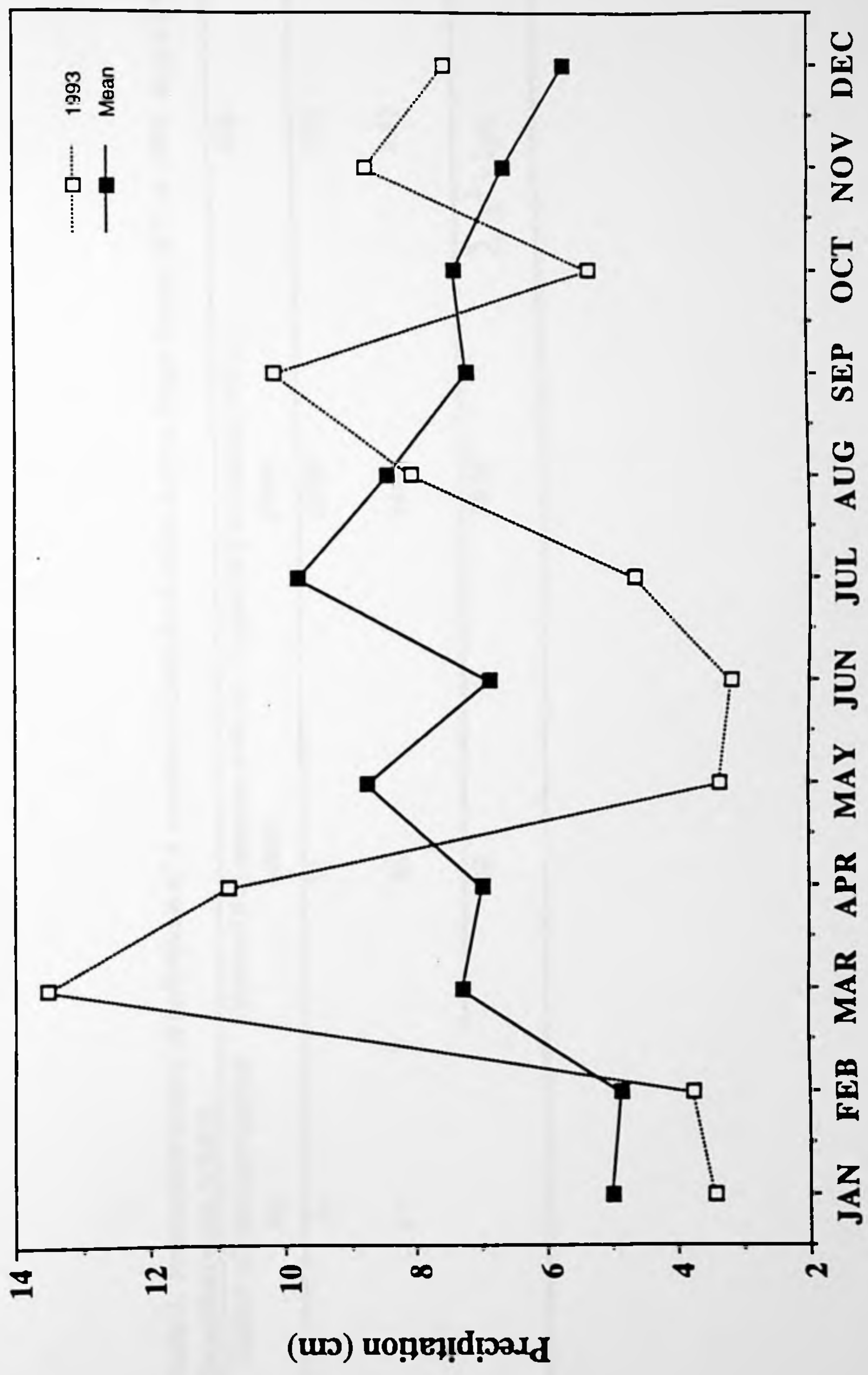

Precipitation (cm)
14
12
10
8
6
4
2
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1993
Mean

Table 7. Poisson distribution of individuals of *A. serotina* at Little Fork Shale Barren, Sugar Grove, WV, in 1994. At $p \leq 0.05$, the critical value is 3.841.

Number of plants per quadrat (x)	Observed # of quadrats with (x) plants	Expected # of quadrats with (x) plants	d^2/e
0	30	24.90	1.04
1 +	10	14.63	1.47
	40	39.53	$\sum \chi^2 = 2.51$

Table 8. Poisson distribution of individuals of *A. serotina* at Little Fork Shale Barren, Sugar Grove, WV, in 1995. At $p \leq 0.05$, the critical value is 3.841.

Number of plants per quadrat (x)	Observed # of quadrats with (x) plants	Expected # of quadrats with (x) plants	d^2/e
0	32	24.90	2.02
1 +	8	15.06	3.31
	40	39.96	$\sum \chi^2 = 5.33$

connections were observed in 1995. In both cases, the bolting plants successfully produced seed. Connections between bolting plants from the 1993 season (the aboveground portion without noticeable viable tissue) and bolting plants from the 1994 season (viable and seed producing) were also observed. Also, in 1994 a bolting plant was observed with seven rosettes attached by rhizomatous connections. In 1995, the same seven rosettes were observed, but the previous year's bolting plant was absent. Whether or not the bolting plant was absent due to senescence or browsing could not be determined.

Some clonal plant species selectively alter rhizome (or stolon) internode length in response to their immediate microenvironment (de Kroon and Hutchings 1995). This type of adaptive response is referred to as "plant foraging" and is derived from analogous theories of animal foraging (Slade and Hutchings 1987). According to this theory, the clonal rosettes of *A. serotina* may be responding to their microenvironment by "foraging" for suitable habitat to complete their life cycle (Cain et al. 1996). The significance (if any) of these ramet-microenvironment interactions to the overall population dynamics of *A. serotina* cannot be determine at this time, although the presence of clonal growth in this species appears to be common.

The life history table showed very little change in the *A. serotina* population at LFSB during the time of sampling (Table 9). Life history data taken from 1 September to 6 October 1994 give an almost static view of the *A. serotina* population. Mortality was low or nonexistent during some time intervals and the population appeared to be static until the last week when seven rosettes had senesced. Survivorship at the final sampling is misleading,

Table 9. Modified life history table for *Arabis serotina* individuals from LFSB, Sugar Grove, WV. Sampling was done from 1 September to 6 October 1994.

time interval (days) (x - x')	length of interval (days) D_x	number surviving to day x N_x	survivorship l_x	number dying during interval d_x	average mortality rate per day q_x / D_x
0 - 8	8	33	1.0000	0	0.0000
8 - 15	7	32	0.9697	1^a	0.0045
15 - 29	14	32	0.9697	0	0.0000
29 - 36	7	25	0.7576	7^b	0.0400

a - browsed bolting plant.
b - rosettes.

however, when viewed in light of the July and September population comparison (Table 10). On 12 July 1995, 72% of sampled rosettes and 91% of sampled bolts exhibited evidence of some type of herbivory. Between 12 July and 2 September 1995 the number of rosettes decreased from 237 to just 13 and the number of bolting plants decreased from 11 to four. The number of bolting plants decreased by 64 percent. By the time life history data were taken in September 1994 — the usual sampling month for *A. serotina* research (P.J. Harmon, pers. comm.) — these data suggest a large percentage of the population had already succumbed to the effects of herbivory and/or high temperatures and drought.

Summary and Conclusions

The results of this study demonstrate that the population of *A. serotina* at LFSB is extremely variable both spatially and temporally. The observed population changes appear to result from the sensitivity of this species to variations in climatic variables. The effects of herbivory, fungal infection, stochastic processes, and human disturbance could also be involved. Since 1991, when annual monitoring of the *A. serotina* population at LFSB began, the population within the grid has fluctuated from a high of 880 plants to a low of only 96. Slight increases occurred from 1991 to 1992 and from 1993 to 1994, but significant mortality occurred between 1992 and 1993. This decline appears to be related to the combination of high temperature and low precipitation in the summer of 1993.

Life history and population data show that mortality is highest from July through August. The effects of herbivory, particularly on rosette mortality, could be a factor.

Table 10. Comparison of *Arabis serotina* population data collected at LFSB, Sugar Grove, WV, on 12 July 1995 and 2 September 1995. Percent of total individuals sampled showing signs of herbivory is noted in parentheses from the earlier sampling date. Weighted % herbivory is shown in brackets.

	rosettes (% herbivory)		bolts (% herbivory)	
plot	July	Sept.	July	Sept.
3-30				
3-27	4 (100)			
2-25	6 (100)	3	1 (100)	
3-23	3 (67)		1 (100)	
2-19	22 (82)		1 (100)	
4-17	5 (80)		1 (100)	1
3-16				
3-15	6 (83)		1 (100)	
4-13	14 (29)	1		
3-13	7 (86)		2 (50)	
5-15	12 (50)			
5-21	3 (100)			
5-22	3 (67)			
5-24	15 (100)			
5-25	13 (85)	1	1 (100)	2
5-29	17 (35)	4		
4-21	31 (48)	4		
4-23	27 (89)			
4-25	48 (81)		3 (100)	1
4-26	1 (100)			
Total	237 [72.1]	13	11 [90.0]	4

However, this conclusion is based on data from two growing seasons and therefore may not be significant. The monitoring plan agreed upon by the *A. serotina* Recovery Task Force (RTF) and the Shale Barren Protection Strategy Group (SBPSG) (two groups of scientists studying shale barren rock cress and shale barren communities throughout the central Appalachians) currently recommends sampling of *A. serotina* populations between August 15 and September 5 to reduce the likelihood of mistaking the rosettes of *A. laevigata* var. *burkii* for those of *A. serotina* (P.J. Harmon, pers. comm.). These data indicate that for a more complete understanding of the life history of this species, future research should begin earlier than the sampling period recommended by the RTF and SBPSG.

The question of the long term survival of this population remains. If we consider the population dynamics of *A. serotina* at LFSB during the extent of this study, both the sharp decrease in population size from 1992 to 1993 and the low numbers of plants from 1993 to 1995 seem to be a cause for alarm. However, these fluctuations may be a regular occurrence in populations of *A. serotina*.

Based on the ability of *A. serotina* to produce large numbers of seed (Keener 1983, US Fish and Wildlife Service 1991, and WVDNR 1989), it is possible there is a substantial seed bank for this species and the population in the last few seasons has been low due to the absence of conditions suitable for germination. Seed banks are known to play an essential role in the life cycles of many semelparous species, such as desert annuals (Beatley 1974, Baskin et al. 1993, Begon et al. 1986, Fowler 1986). Assuming climatic patterns similar to those observed at LFSB during the extent of this study have occurred periodically in the past, then this scenario has probably been played over and over again. Since one of the Recovery Tasks outlined in the Shale Barren Rock Cress (*Arabis serotina*) Recovery Plan is to "develop guidelines as to what constitutes a self-maintaining population" (US Fish and Wildlife Service 1991), future research should determine what significance (if any) seed banks have in the persistence of local populations of *A. serotina*. These studies should also determine the length of time the seed of *A. serotina* remain viable in the seed bank.

Clearly, long-term data need to be collected in order to more clearly assess the relationship between climate and fluctuations in *A. serotina* populations. Also, the effects of herbivory on rosette individuals should be given closer consideration. Since the number of rosettes will influence the number of bolting plants (and subsequent seed production) in following years, the total number of surviving rosettes at the end of the growing season may help researchers assess the long term survival of this and other *A. serotina* populations. These data will help us to better understand and predict population changes and the probability of survival of this endangered species.

Causes of Rarity for *Arabis serotina*

This study has focused on those abiotic and biotic factors which influence the size and dynamics of the *A. serotina* population at LFSB. Annual climatic variation and herbivory appear to be the primary factors affecting population size at LFSB, and therefore, also influence metapopulation size. However, a study focusing on the rarity of *A. serotina* must also consider those factors that influence the number of *A. serotina* populations. Although beyond the scope of this study, consideration can be given to some of these other factors in light of current ecological theory and the results of this study.

The 55 known populations of *A. serotina* are endemic to the mid-Appalachian shale barrens. Populations of *A. serotina* have only been found on shale barrens underlain by shale of the Braillier Formation. Whether *A. serotina* is substrate specific (i.e., requiring some physiochemical aspect of Upper Devonian age shale for growth and reproduction) or is restricted due to limited competitive ability in other communities (a view for which there is currently a lack of supportive data), *A. serotina* and other shale barren endemics can be viewed as rare because of the rarity of this habitat type. Shale barrens also cover a relatively small area (between 0.2-ha and 20-ha or more; Keener 1983) when compared to surrounding forests.

The theory of island biogeography may also help researchers to understand the present distribution of *A. serotina* populations among the widely scattered mid-Appalachian shale barrens. When considering the dispersal of seed and/or pollen from one barren to another, the distance between barrens and the method(s) of dispersal are the primary barriers to the establishment of a new population or gene flow between existing populations. A secondary barrier to establishment (limited to seed dispersal) is the presence/absence of a niche in the newfound community for successful growth and reproduction of the immigrant species. The presence of this niche may be influenced by several factors, including area of the barren, spatial heterogeneity of the environment, the competitive abilities of species in the endemic community, and microenvironmental factors unique to the newfound shale barren.

The ability of *A. serotina* to disperse seed to shale barrens currently uninhabited by this species, therefore, is influenced by the mechanism of dispersal, the distance between barrens, and the ecology of the newfound barren and community. The genetic variation between populations of *A. serotina* may give insight into the barriers to gene flow, but the relative importance of genetic diversity to the conservation of this species may not be relevant.

Although the rarity of *A. serotina* can be attributable to a variety of factors, the conservation of this shale barren endemic can currently only be accomplished by the preservation of the unique habitat to which it is endemic. Ecological theory is inherently limited in its application to the conservation of rare and endangered species, a result of its observational nature and the difficulty of differentiating correlation from causation. Thus, further study is required to provide researchers with a better understanding of the ecology of this species.

Literature Cited

Allard, H.A. 1946. Shale barren associations on Massanutten Mountain. Virginia. Castanea 11:71-124.

Bartgis, R.L. 1987. Distribution and status of *Arabis serotina* Steele populations in West Virginia. Proc. of WV Acad. Sci. 59:73-81.

Baskin, C.C., Chesson, P.L., and J.M. Baskin. 1993. Annual seed dormancy cycles in two desert annuals. J Ecology 81:551-556.

Beatley, J.C. 1974. Phenological events and their environmental triggers in Mojave Desert ecosystems. Ecology 55:856-63.

Begon, M., Harper, J.L., and C.R. Townsend. 1986. Ecology: individuals, populations, and communities. Sinauer Associates, Inc., Sunderland, Massachusetts, USA.

Cain, M.L., Dudle, D.A., and J.P. Evans. 1996. Spatial models of foraging theory in clonal plant species. Am J Botany 83(1):76-85.

Carlquist, S. 1966a. The biota of long-distance dispersal. I. Principles of dispersal and evolution. Quarterly Reviews in Biology 41:247-270.

Cody, M.L. and J. McC. Overton. 1996. Short-term evolution of reduced dispersal in island plant population. J Ecology 84:53-61.

Core, E.L. 1952. Ranges of some plants of the Appalachian shale barrens. Castanea 17:105-116.

de Kroon, H. and M.J. Hutchings. 1995. Morphological plasticity in clonal plants: the foraging concept reconsidered. J Ecology 83:143-152.

Fahrig, L. and G. Merriam. 1994. Conservation of fragmented populations. Conservation Biology 8(1):50-59.

Fowler, N. 1986. The role of competition in plant communities in arid and semiarid regions. Ann. Rev. Ecol. Syst. 17:89-110.

Gilliam, F.S., Yurish, B.M., and L.M. Goodwin. 1993. Community composition of an old growth forest: relationship to soil texture. Bull. Torrey Bot. Club 120(3): 287-294.

Gilliam, F.S., Turrill, N.L., and M.B. Adams. 1995. Herbaceous-layer and overstory species in clear-cut and mature Central Appalachian hardwood forests. Ecol. Applic. 5(4):947-955.

Gilliam, F.S., Adams, M.B., and B.M. Yurish. 1996. Ecosystem nutrient responses to chronic nitrogen inputs at Fernow Experimental Forest, West Virginia. Can. J. For. Res. 26:196-205.

Harmon, P.J. 1992. Progress report: *Arabis serotina* long term study, GRID, Little Fork Shale Barren. W.Va. Natural Heritage Program, Division of Natural Resources, Elkins, WV.

Harmon, P.J., Norris, S.J., and D.M. Mitchell. 1997. Progress report: endangered species (plants), E-2-10. W.Va. Nongame Wildlife and Natural Heritage Program, Wildlife Resources Section, Division of Natural Resources, Elkins, West Virginia. 33pp.

Hart, R. 1980. The coexistence of weeds and restricted native plants on serpentine barrens in southeastern Pennsylvania. Ecology 61:688-701.

Jesse, C.M. 1994. Shale barren communities of West Virginia. Unpublished report to the West Virginia Natural Heritage Program, West Virginia Division of Natural Resources, Elkins, WV. 18pp.

Keener, C.S. 1983. Distribution and biohistory of the endemic flora of the mid-Appalachian shale barrens. Bot. Rev. 49:65-115.

Kelly, D. 1985. On strict and facultative biennials. Oecologia 67:292-294.

Kochenderfer, J.N., Helvey, J.D., Patric, J.H., and W.E. Kidd, Jr. 1996. Woodlot owner's guide to water in the forest: a primer on forest hydrology in the Appalachian region. USDA Forest Service, Northeastern Forest Experiment Station, Timber and Watershed Laboratory, Parsons, W.Va.

Lacy, R.C. 1987. Loss of genetic diversity from managed populations: interacting effects of drift, mutation, immigration, selection, and population subdivision. Conservation Biology 1:143-158.

MacArthur, R.H. and E.O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, New Jersey.

Maki, M., Masuda, M. and K. Inoue. 1996. Genetic diversity and hierarchical population structure of a rare autotetraploid plant, *Aster kantoensis* (Asteraceae). Am J Botany 83(3):296-303.

Mangel, M. and C. Tier. 1994. Four facts every conservation biologist should know about persistence. Ecology 75(3):607-614.

Morgan, S.W. 1989. Endangered and threatened wildlife and plants; "Arabis serotina" (Shale Barren Rock Cress) determined to be an endangered species. Federal Register 54(103):29655-29658.

Morse, L.E. 1983. A shale barren on Silurian strata in Maryland. Castanea 48:206-208.

Murdy, W.H. 1968. Plant speciation associated with granite outcrop communities of the Southeastern Piedmont. Rhodora 70:394-407.

National Oceanic and Atmospheric Administration. 1985. Climatography of the United States. No. 20. 24 pp.

Platt, R.B. 1951. An ecological study of the mid-Appalachian shale barrens and of the plants endemic to them. Ecol. Monogr. 21:269-300.

Raunkiaer, C. 1934. The life forms of plants and plant geography. Oxford University Press, Oxford.

Riefner, R.E., Jr. 1981. Notes on some proposed rare and endangered vascular plant species in Maryland. Phytologia 47:397-403.

Rouse, G.D. 1990. Study of the life history of Arabis serotina (Shale Barren Rock Cress). Interim report to the Virginia Department of Agriculture and Consumer Services. 12pp.

--------. 1993. Shale Barren Rock Cress (*Arabis serotina* Steele) life history study. Unpublished report to U.S. Fish and Wildlife Service.

Roy, B.A. 1993. Floral mimicry by a plant pathogen. Nature 362:56-58.

Roy, B.A. and P. Bierzychudek. 1993. The potential for rust infection to cause natural selection in apomictic *Arabis holboellii* (Brassicaceae). Oecologia 95:533-541.

Schemske, D.W., Husband, B.C., Ruckelshaus, M.H., Goodwillie, C., Parker, I.M., and J.G. Bishop. 1994. Evaluating approaches to the conservation of rare and endangered plants. Ecology 75(3):584-606.

Simberloff, D.S. 1974. Equilibrium theory of island biogeography and ecology. Ann. Rev. Ecol. Syst. 5:161-182.

Slade, A.J. and M.J. Hutchings. 1987a. The effects of nutrient availability on foraging in the clonal herb *Glechoma hederacea*. J Ecology 75:95-112.

Snyder, K.M., Baskin, J.M., and C.C. Baskin. 1994. Comparative ecology of the narrow endemic *Echinacea tennesseensis* and two geographically widespread congeners: relative competitive ability and growth characteristics. Int. J. Plant Sci. 155(1):57-65.

Stausbaugh, P.D. and E.L. Core. 1977. Flora of West Virginia. 2nd ed. Seneca Books, Inc., Grantsville, West Virginia. 1079 pp.

Steele, E.S. 1911. New or noteworthy plants from the eastern United States. Contr. U.S. National Herb. 13:359-374.

ter Braak, C.J.F. 1986. Canonical correspondence analysis: A new eigenvector technique for multivariate direct gradient analysis. Ecology 67(5):1167-1179.

United States Department of Agriculture (USDA). 1992. Soil Survey of Pendleton County, West Virginia. Soil Conserv. Serv. 274pp., illus.

United States Fish and Wildlife Service. 1991. Shale Barren Rock Cress (Arabis serotina) Recovery Plan. Newton Corner, Massachusetts. 40 pp.

West Virginia Department of Natural Resources. 1989. Performance Report -- Shale Barren rockcress recovery, Project No. E-2-2, Unpublished report submitted to U.S. Fish and Wildlife Service. 19 pp.

Wherry, E.T. 1953. Shale barren plants on other geological formations. Castanea 18:64-65.

Whittaker, R.H. 1956. Vegetation of the Great Smoky Mountains. Ecol. Monogr. 26(1):1-80.

Wieboldt, T.F. 1987. The shale barren endemic Arabis serotina (Brassicaceae). Sida 12(2):381-389.

Personnel Cited in Personal Communications

Dean A. Adkins, Entomologist, Department of Biological Sciences, Marshall University, Huntington, WV.

Paul J. Harmon, Botanist, W.Va. Natural Heritage Program, Wildlife Resources Division, Division of Natural Resources, Elkins, WV.