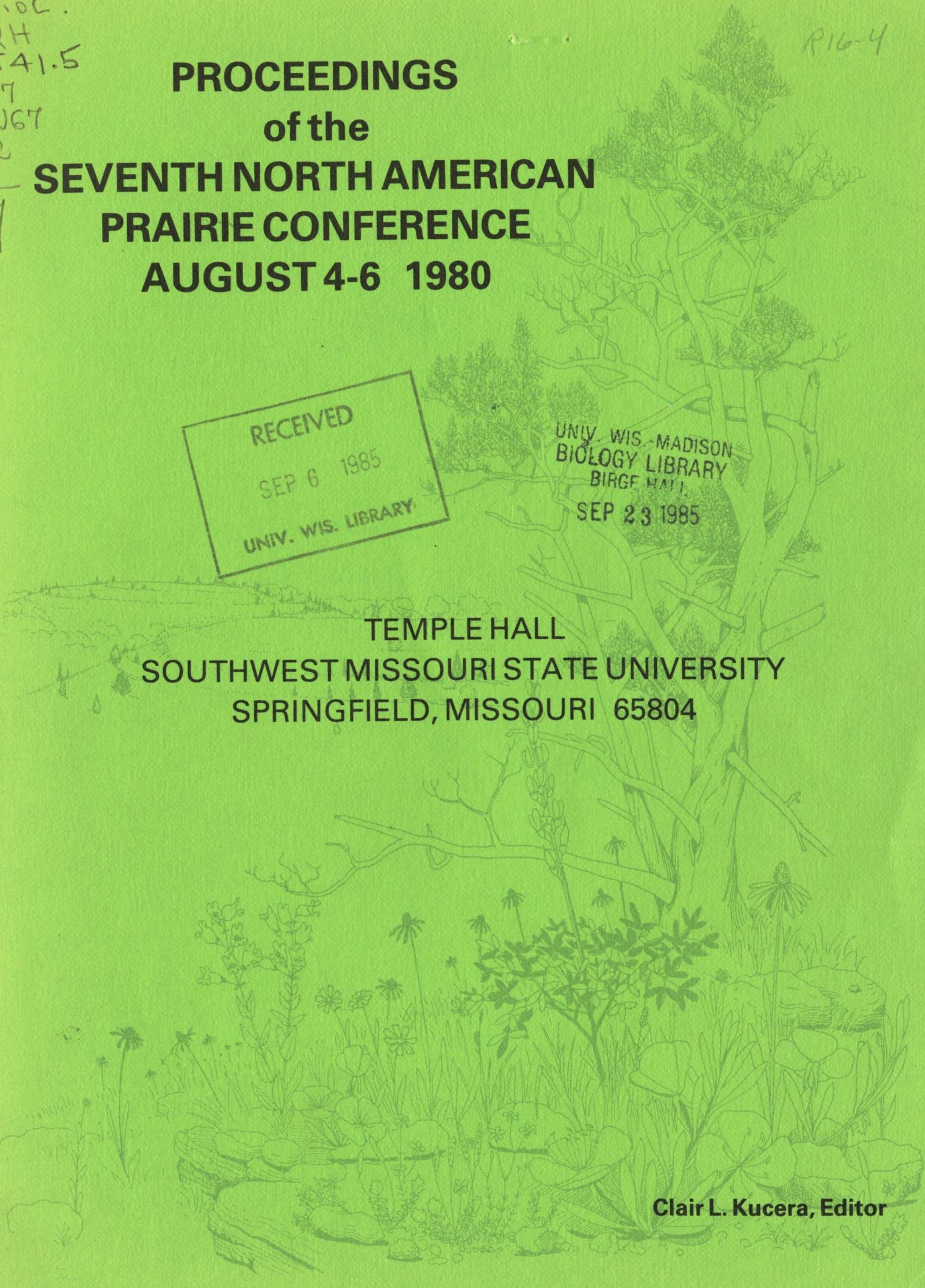
Proceedings of the Seventh North American Prairie Conference, August 4-6, 1980, Temple Hall, Southwest Missouri State University, Springfield, Missouri. No. 7 1983

Springfield, Missouri: Southwest Missouri State University, 1983

https://digital.library.wisc.edu/1711.dl/762KMJLLLMRC29D

PROCEEDINGS of the SEVENTH NORTH AMERICAN PRAIRIE CONFERENCE AUGUST 4-6 1980



TEMPLE HALL
SOUTHWEST MISSOURI STATE UNIVERSITY
SPRINGFIELD, MISSOURI 65804

Clair L. Kucera, Editor

Biol.

ERRATA SHEET

Proceedings of the Seventh North American Prairie Conference:

p. viii, p. 157, should read Kapustka

p. 39, col. 1, 2nd. para., The Nature Conservancy for the Nature Conservancy, also p. 43; same page, 3rd. para., last line should read "eastern slope...."

p. 47, Table 1, occurrence for occurence.

p. 54, include Weaver, J.E. and F.W. Albertson, 1956. Grasslands of the Great Plains. Johnsen Publ. Co., Lincoln., cited on p. 46.

p. 62, col. 2, 2nd. para., glad occurence for glade occurrence.

p. 63, col. 1, 1st. para., 166,000 ha (415,000 acres) for 162,000 ha (40,000 acres), col. 2, 2nd. para., 160,000 ha for 120,000 ha.

p. 65, col. 2, 2nd. para., last line, 2,000 for 200.

p. 67, col. 1, 3rd. para., last line, 8,000 for 8.000.

p. 179, col. 1, 2nd. para., 4th. line, should read "and pesticide and herbicide...."; col. 2, 1st. para., should read "in our own nests..."

p. 185, Table 2, Dactylis for Dactyli.

p. 321, col. 2, Stevenson citation, Brochure for Brochue.

PROCEEDINGS
of the
SEVENTH NORTH AMERICAN PRAIRIE CONFERENCE
AUGUST 4-6 1980

TEMPLE HALL
SOUTHWEST MISSOURI STATE UNIVERSITY
SPRINGFIELD, MISSOURI 65804

Clair L. Kucera, Editor
Division of Biological Sciences
University of Missouri, Columbia

Hosted By
Southwest Missouri State University
and
The Missouri Prairie Foundation
In Cooperation With
The Missouri Department of Conservation
Missouri Department of Natural Resources
Society for Range Management - Southern Section
The Missouri Botanical Garden
The Nature Conservancy

cover drawing by Paul Nelson

PREFACE

The Seventh North American Prairie Conference held on the campus of Southwest Missouri State University represented a wide range of interests in conservation and study of prairie.

Underlying this diversity of endeavor by both laymen and professionals is a unifying theme of mutual intent and purpose, a common goal of increasing our knowledge about the structure and workings of a unique ecosystem. For by learning more about the prairie which once spread through half a continent from north to south and east to west, we can better protect and manage those areas still intact. Indeed we can even put back lost diversity in those fragments of prairie in critical need of restoration.

The resurgence and momentum developed by public interest in prairies as an invaluable ecological resource must be maintained. Since the first Prairie Conference held in 1968 at Knox College, there has been a many-fold increase in participation. It is only through the sustained efforts and enthusiasm of concerned and dedicated people that the progress observed to date will be carried forward in future meetings. Such are the "prairie watchers" coming from all walks, who, in a kind of convergent evolution of philosophy and practice, are drawn together by these biennial conferences to exchange views and communicate ideas on prairie.

This publication is divided by sessions as they appeared in the Conference program. Some minor changes in sequence were effected to provide subject continuity. All papers read at the Conference are represented here, a limited number in abstract form. I wish to thank the contributors for their cooperation and assistance during the editing of manuscripts. Opinions expressed are those of the author only.

We are indebted to representatives of SMSU for hosting a successful conference. The coordinating committee, which included individuals from private and public organizations, gave leadership for developing an agenda of read papers, field trips, and special events. For these varied efforts sincere appreciation is expressed to Don Christisen, Bill Crawford, Richard Daley, Grant Pyrah, Paul Redfearn, Jr., and Wallace Weber. The presentation of Sassafras, an Ozark Odyssey produced by JoNell Beall, Pat Goslee, Robert Flanders, and Russel Keeling of SMSU was especially appreciated. We also thank Steve Timme for his color-slide showing of prairie plants. I thank Virginia Whittington and her printing staff for their collective patience in putting this work together, and to Ruth Dalke at UMC for typing and secretarial assistance.

A brief note is in order dealing with financial support for producing this volume. The cost of publication was underwritten by the Missouri Prairie Foundation. Conference-generated funds as were available were also used.

Finally, I wish to thank personally Don Christisen, Bill Crawford, Paul Nelson, and Wallace Weber for their work on the Editorial Committee.

Let us attend the Ninth Prairie Conference to be held in 1984 at Moorhead State University and wish it every success.

Clair L. Kucera
Columbia, MO

DEDICATION

In the process of producing this publication, there developed an interest by the conference host organizations to dedicate the volume to a person who has been a pioneer in the native prairie preservation and management movement.

Long before there was any solid interest in native prairie preservation, Donald M. Christisen, a senior wildlife research biologist with the Missouri Department of Conservation was on the trail of locating and sizing up native prairie tracts. By 1951 he was very active in seeking out the native prairie ranges in Missouri for purchase in prairie chicken restoration programs.

Since that time and up to the present, Don has been an active force in the native movement, both for Missouri and on a national scale. His association with and encouragement given to private organizations dedicated to native tallgrass prairies have been outstanding. His working relationship with both the public and private sectors has been long term and he currently helps maintain the prairie heritage of Missouri through activities in research, management and acquisition.

It is a distinct pleasure for us to dedicate this volume to Donald M. Christisen, a pioneer in preservation of the tallgrass prairie.

Bill T. Crawford

Table of Contents

SESSION IV. LANDSCAPING AND RESTORATION WITH PRAIRIE PLANTS.

SESSION V. PRAIRIE MANAGEMENT AND PRESERVATION.

SESSION I. Composition, Mapping, and Classification of Prairies.
Grant L. Pyrah, Presiding

In this initial session attention is given to the descriptive aspects of prairie, mainly its taxonomy and distribution. The fine paper by Schroeder on pre-settlement prairie in Missouri is especially well-documented. Thom's paper deals also with Missouri prairie providing indicator plant and animal taxa on a geographic basis for this and other natural divisions in the State. Papers by Keith, and Bacone and Campbell, discuss presettlement distributions in Indiana, while Borowski and Heitlinger describe relic stands along railroad rights-of-way in Minnesota. Species composition of more extensive prairies from western Minnesota is provided by Dziadyk and Clambey. Finally, the paper by Wagner from Wisconsin describes research observations over many years on the native mound-building ant, *Formica cinerea,* and the age-structure relationship of its colonies.

The Natural Divisions of Missouri: An Introduction to the Natural History of the State

Richard H. Thom
and
James H. Wilson
Natural History Section
Missouri Department of Conservation
Jefferson City, Missouri 65102

Abstract. The Natural Divisions of Missouri constitute a hybridized regionalization scheme which divides the state into 6 major Divisions by integrating geologic history, soils, bedrock geology, topography, plant and animal distribution, presettlement vegetation, and other natural factors. These divisions are the Glaciated Plains, Big Rivers, Ozark Border, the Ozark Region, Osage Plains, and the Mississippi Lowlands. This paper serves as an introduction to the natural history of Missouri. Particular emphasis is given to the distribution of presettlement prairie communities in the several Natural Divisions. Presettlement prairie occurred in every Natural Division, being most widespread in the Osage Plains (72%) and the Glaciated Plains (45.5%), and the least extensive in the Mississippi Lowlands (1.6%).

Introduction

Several geographic regionalization schemes have been developed for Missouri and portions of Missouri based on specific natural features of the land. Marbut (1896 in Sauer 1920) divided the state into various plains, platforms and lowlands separated by escarpments. Sauer (1920) subdivided the Ozark Highland into 8 geographic regions based on geography, topography, drainage, soils, minerals, water supply and vegetation. A modification of this scheme recognized 7 Natural Regions of the Ozark Province based on geology, physiography and forest cover (Cozzens 1939). Fenneman (1938) considered Missouri to contain portions of 3 major physiographic provinces: The Coastal Plain in the southeast, the Ozark Plateau in the south, and the Central Lowland in the north and west. Both physical and cultural features and 3 major physiographic areas formed the basis of Collier's (1955) 21 Geographic Regions of Missouri.

The Missouri General Soil Map and Soil Association Descriptions (Allgood and Persinger 1979) placed the state's soil associations into 10 separate Land Resource Areas as described by Austin (1965). Palmer and Steyermark (1935) divided the state into 3 major plant regions based on flora and vegetation. The Zoogeographic Regions of Missouri (Bennitt and Nagel 1937) were comprised of 7 areas making up 4 major regions (Northern Glacial, Western Prairie, Ozark Highland, and Mississippi Lowland). Other examples of classification were presettlement vegetation (Kucera 1961), timber resource regions (Spencer and Essex 1972), and divisions based on the fish fauna (Pflieger 1975).

Although Missouri has been variously subdivided none of the previous regionalizations were devised mainly to provide a general understanding of Missouri's ecology and natural history. It was for this reason that we devised a Natural Divisions classification for Missouri.

Methods

The Natural Divisions of Missouri follows concepts used in the Natural Divisions of Illinois (Schwegman 1973). We divided Missouri into 6 relatively distinctive natural divisions (Fig. 1), by integrating natural factors such as geography, physiography, drainage, bedrock geology, plant and animal distribution and presettlement vegetation.[1] The scheme was simplified whenever possible to facilitate general understanding and use. The 6 divisions are subdivided into 19 natural sections based on the same distinctions as the former, but of lesser magnitude. The divisions and sections are not based on, or named for any single natural community type (prairie, forest, glade), because even a very small region has many types of natural features. It is the composition and relative abundance of the various natural features that characterize the regions.

The exact boundaries of divisions and sections are, of course, arbitrary to some extent. Where possible we have followed drainages or escarpments, but the designations actually integrade just as do natural communities. The boundaries, therefore, are approximations. Thus, the Natural Divisions scheme does not describe and distinguish every small parcel of Missouri. It does provide a categorization of the state into distinctive subdivisions about which numerous natural history generalizations can be made.

---

[1] For information on presettlement vegetation, particularly prairie (see table and graph), we studied unpublished maps based on the original U.S. Land Office surveys prepared by Walter Schroeder and generously loaned to us for the project. For a discussion of how the maps were prepared see Schroeder (1978).

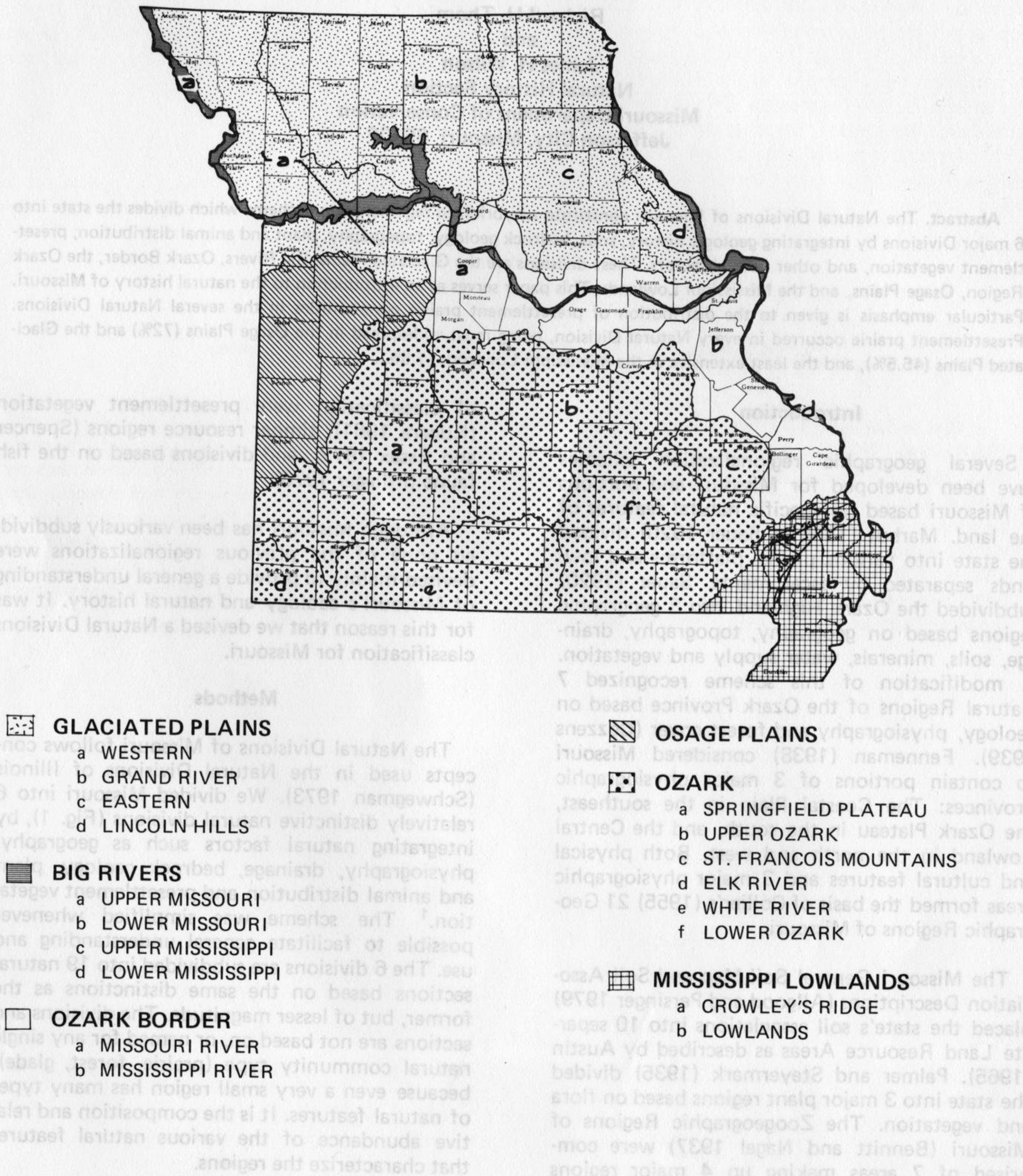


Fig. 1. Location of Natural Divisions and constituent sections.

Glaciated Plains

Roughly including the northern third of the state, the Glaciated Plains Natural Division extends southward from Iowa to the Osage Plains and the Ozark Border Natural Divisions. The division is characterized by soils and topography that resulted from the influence of the Kansan stage of Pleistocene glaciation. Soils are formed from loess and glacial till, or from alluvium. The topography is younger than that of the unglaciated portions of the state, although much of the region has been moderately dissected. Upland deciduous forest and prairie were the main presettlement vegetation, prairie comprising about 45% of the Division (Table 1, Fig. 2). There are also extensive prairies and forests in the bottomlands. Sections are based primarily on differences in soils, biota, geographic position, river drainages, and presettlement vegetation.

Characteristic animals[1] include bigmouth shiner (*Notropis dorsalis* [Agassiz]), plains leopard frog (*Rana blairi* Mecham et al.), massasauga rattlesnake (*Sistrurus catenatus* Rafinesque), horned lark (*Eremophila alpestris* [L.]), Franklin's ground squirrel (*Spermophilus franklinii* [Sabine]), and badger (*Taxidea taxus* [Schreber]).

Characteristic plants include snow trillium (*Trillium nivale* Riddell), choke cherry (*Prunus virginiana* L.), bluejoint grass (*Calamagrostis canadensis* [Michx.] Beauv.), and pussy toes (*Antennaria neglecta* Greene).

---

1 The term "characteristic" is used for species that are typical or representative of the region but not necessarily restricted or endemic to it. Characteristic species are associated with the region to a high degree.

Table 1. Approximate area and percent by Natural Divisions and Sections and constituent prairie in each category

Natural Division and Section	Area $km^2 (mi^2)$	% Area of Missouri	Presettlement Prairie $km^2 (mi^2)$	% Prairie
I. Glaciated Plains	58,298 (22,509)	32.3	28,308 (10,912)	45.5
Western	16,441 (6,348)		9,282 (3,584)	56.4
Grand River	21,103 (8,148)		10,727 (4,132)	50.8
Eastern River	18,656 (7,203)		8,206 (3,168)	44.0
Lincoln Hills	2,014 (788)		94 (36)	4.6
II. Big Rivers	6,498 (2,509)	3.6	1,572 (607)	24.2
Upper Missouri	3,450 (1,332)		1,113 (430)	32.3
Lower Missouri	1,235 (477)		6 (2)	0.4
Upper Mississippi	1,305 (504)		479 (185)	36.7
Lower Mississippi	508 (196)		0 (0)	0.0
III. Ozark Border	23,825 (9,199)	13.2	1,622 (626)	6.8
Missouri River	12,919 (4,988)		1,315 (508)	10.1
Mississippi River	10,699 (4,131)		307 (119)	2.9
IV. Osage Plains	14,079 (5,436)	7.8	10,140 (3,915)	72.0
V. Ozark Natural Division	68,223 (26,341)	37.8	6,522 (2,024)	9.5
Springfield Plateau	15,895 (6,137)		4,582 (1,769)	28.8
Upper Ozark	21,080 (8,139)		478 (184)	2.3
St. Francois Mnts.	3,683 (1,422)		0 (0)	0.0
Elk River	2,251 (869)		160 (62)	7.1
White River	10,370 (4,004)		16 (6)	0.1
Lower Ozark	15,009 (5,795)		7 (3)	0.4
VI. Mississippi Lowlands	9,386 (3,624)	5.2	151 (58)	1.6
Crowley's Ridge	826 (319)		0 (0)	0.0
Lowlands	8,560 (3,305)		151 (58)	1.8

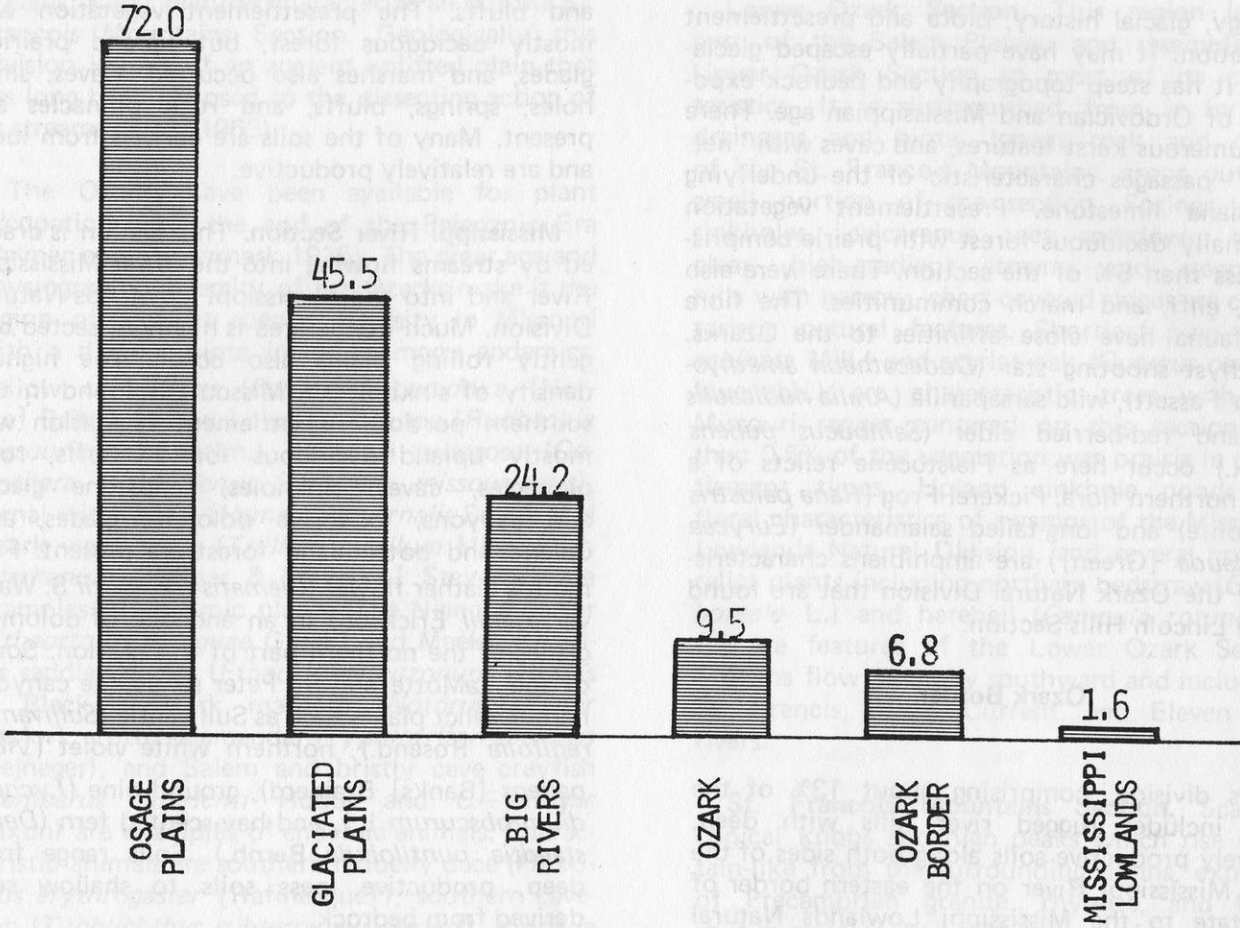


Fig. 2. Percent presettlement prairie by Natural Divisions.

Western Section. The western section of the Division is characterized by loess-dominated topography and soils and the driest climate in the state. In presettlement times over half of the region was prairie, which occupied much of the stream drainages as well as the uplands. Deciduous forest occurred along some of the drainages. Streams are low-gradient, turbid, and of variable water level. Steep loess mounds along the Missouri River are a striking feature of this section. Prairie vegetation on these mounds has floral elements of the Great Plains such as hairy and blue grama (*Bouteloua hirsuta* Lag. and *B. gracilis* [HBK] Lag.), large-flowered penstemon (*Penstemon grandiflorus* Nutt.), soapweed (*Yucca glauca* Nutt. var. *glauca*), and downy painted cup (*Castilleja sessiliflora* Pursh). The plains hognose snake (*Heterodon nasicus nasicus* Baird and Girard) is an animal that is restricted in Missouri to this area. The Platte, Nodaway, Crooked, and Little Blue rivers are in this section.

Grand River Section. The central section of the Glaciated Plains Division is characterized by soils derived from loess and glacial till in the uplands and by moderately dissected topography. Streams in this section flow into the Grand and Chariton river systems and form extensive bottomlands. The region is differentiated on the basis of soils, river drainages, and geographic position. Original vegetation was about equally divided between deciduous forest and prairie, with the prairie interfingering between the forested breaks along the stream drainages. Decidous forest, wet prairie, and marsh communities were associated with the major rivers, especially the Grand and the Chariton. Prairie frequently occurred along the rivers.

Eastern Section. The region is drained by streams that flow eastward into the Mississippi or southward into the lower Missouri, excluding the Lincoln Hills Section. It includes a region of flat, claypan soils typified by the Audrain plains, and rugged river breaks such as those along Salt River. Upland soils are primarily of till derivation. Presettlement vegetation was prairie in the more level uplands and deciduous forest in the rugged areas. Bottomland forest communities predominated along the rivers, with very little wet prairie.

Lincoln Hills Section. This section is distinguished from the rest of the division by bedrock geology, glacial history, biota and presettlement vegetation. It may have partially escaped glaciation. It has steep topography and bedrock exposures of Ordovician and Mississippian age. There are numerous karst features, and caves with "network" passages characteristic of the underlying Louisiana limestone. Presettlement vegetation was maily deciduous forest with prairie comprising less than 5% of the section. There were also glade, cliff, and march communities. The flora and fauna have close affinities to the Ozarks. Amethyst shooting star (*Dodecatheon amethystinum* Fassett), wild sarsaparilla (*Aralia nudicaulis* L.), and red-berried elder (*Sambucus pubens* Michx.) occur here as Pleistocene relicts of a more northern flora. Pickerel Frog (*Rana palustris* Le Conte) and long-tailed salamander (*Eurycea longicauda* [Green]) are amphibians characteristic of the Ozark Natural Division that are found in the Lincoln Hills Section.

Ozark Border

This division, comprising about 13% of the state, includes rugged river hills with deep, relatively productive soils along both sides of the lower Mississippi River on the eastern border of the state to the Mississippi Lowlands Natural Division. While most of the Ozark Border Division is physiographically part of the Ozark Plateau Province (Fenneman 1938), some of the region is not normally thought of as being part of the Ozarks. The Ozark border is a broad ecotonal belt in which the Ozarks grade into bordering natural divisions on the north and east. It is distinguished by its soils, topography, plant, and animal distribution, and geographic location. Sections are differentiated from each other by river drainages, geography, biota, and presettlement vegetation. The river hills topography characterizes the division, although a few isolated rolling plains are present. Sandstone and limestone cliffs and pinnacles along the rivers are features of the division. Upland deciduous forest was the main presettlement vegetation; however, glade, prairie, and bottomland forest communities were also present. Prairie accounted for less than 10% of the presettlement vegetation.

Missouri River Section. This section is drained by streams flowing into the Missouri River. Most of the region is highly dissected but there are isolated rolling plains in the western part, and gently sloping ridgetops and valley bottoms occur throughout. There are more perennial streams, and these are generally larger and more turbid than in the Ozark Natural Division. St. Peter Sandstone crops out in several areas and stream cutting has formed steep-sided sandstone canyons and bluffs. The presettlement vegetation was mostly deciduous forest, but upland prairies, glades, and marshes also occurred. Caves, sinkholes, springs, bluffs, and rock pinnacles are present. Many of the soils are derived from loess and are relatively productive.

Mississippi River Section. This section is drained by streams flowing into the lower Mississippi River and into the Mississippi Lowlands Natural Division. Much of the area is highly dissected but gently rolling plains also occur. The highest density of sinkholes in Missouri is found in the southern portion. Presettlement vegetation was mostly upland deciduous forest. Bluffs, rock pinnacles, caves, sinkholes, sandstone glades and canyons, extensive dolomite glades, and upland and bottomland forest are present. Fremont's leather flower (*Clematis fremontii* S. Wats. var. *riehlii* Erickson) in an endemic of dolomite glades of the northern part of this section. Some of the LaMotte and St. Peter sandstone canyons harbor relict plants such as Sullivantia (*Sullivantia renifolia* Rosend.), northern white violet (*Viola pallens* [Banks] Brainerd), ground pine (*Lycopodium obscurum* L.), and hay-scented fern (*Dennstaedtia puntilobula* Bernh.). Soils range from deep, productive loess soils to shallow soils derived from bedrock.

Ozark Natural Division

The Ozark Division, comprising almost 40% of the state, is an unglaciated region of greater relief and elevation than the surrounding areas. It is characterized by thin, often stony residual soils, with loess being very thin or absent. Elevation ranges from about 400 feet to almost 1800 feet and local relief of 300 or more ft is common. Topography is very steep to nearly level and the ridgetops within a given area are generally similar in elevation. Caves, springs, bluffs, and high gradient, clear-flowing streams with entrenched meanders are characteristic features. Limestone and dolomite of Ordovician age underlie most of the Ozark Division, but sandstone, shale, chert and igneous rock also occur. Bedrock commonly crops out along streams and ridges.

Deciduous, pine-oak and pine forests formed the predominat vegetation in presettlement times. Glades, some of them extensive, commonly occur where bedrock surfaces. Calcareous wet meadows are distinctive plant communities along some of the streams. Extensive areas of prairie and savanna occurred in the Springfield Plateau and isolated, small areas of prairie occurred elsewhere. Bottomland Deciduous forest and gravel bar communities are common along many of the streams. Karst features characterize all but the St. Francois Mountains Section. Geologically this Division is part of an ancient uplifted plain that has long been exposed to the dissecting action of its streams (Bretz 1965).

The Ozarks have been available for plant occupation since the end of the Paleozoic Era (Palmer and Steyermark 1935). The great age and physiographic diversity of the Ozarks make it the region of greatest species diversity in Missouri with a distinct biota including many endemics. Yellow coneflower (*Echinacea paradoxa* [Norton] Britt.), Missouri blackeyed susan (*Rudbeckia missouriensis* Engelm.), Missouri primrose (*Oe-nothera missouriensis* Sims var. *missouriensis*), vernal witch hazel (*Hamamelis vernalis* Sarg.), and Ozark wake robin (*Trillium pusillum* Michx. var. *Ozarkanum* [Palmer & Steyerm.] Steyerm.) are examples of endemic plants. The Niangua darter (*Etheostoma nianguae* Gilbert and Meek), Arkansas saddled darter (*Etheostoma euzonum* [Hubbs & Black]), Ozark madtom (*Notorus albater* Taylor), grotto salamander (*Typhlotriton spelaeus* Stejneger), and Salem and bristly cave crayfish (*Cambarus hubrichti* Hobbs and *C. setosus* Faxon) are examples of endemic animals. Characteristic animals are southern redbelly dace (*Phoximus erythrogaster* [Rafinesque]), southern cavefish (*Typhlichthys subterraneus* Girard), rosyface shiner (*Notropis rubellus* [Agassiz]), northern hog sucker (*Hypentelium nigricans* [Lesueur]), broadhead skunk (*Eumeces laticeps* [Schneider]), eastern coachwhip snake (*Masticophis flagellum* [Shaw]), pickerel frog (*Rana palustris* Le conte), cave salamander (*Eurycea lucifuga* Rafinesque), white-eyed vireo (*Vireo griseus* [Boddaert]), eastern wood rat (*Neotoma floridana* [Ord]), and bobcat (*Lynx rufus* [Schreber]). The 6 sections are differentiated by geologic history, stream drainages, geographic position, soils, biota, and presettlement vegetation.

Upper Ozark Section. Geologically this section is part of the Salem Plateau. Most of the area is highly dissected and was originally forested, although large, broad, gentle plains also occur, some of which had prairie and savanna vegetation. Prairie made up only about 2% of the area. Bottomland deciduous forest is common due to the number and the size of the streams, Limestone and sandstone glades and bluffs, caves, springs, calcareous wet meadows, losing streams, and streams with entrenched meanders are common features of the Upper Ozark Section. Streams flow generally northward and include the Gasconade, Niangua, Lower Osage, Bourbeuse, and Meramec rivers.

Lower Ozark Section. This region is also part of the Salem Plateau and resembles the Upper Ozark Section in most of its characteristics. It is distinguished from it by river drainages and biota. Igneus rock and outlier of the St. Francois Mountains, crops out in a small portion of the section. Springs, caves, sinkholes, calcareous wet meadows, glades, clear, high-gradient streams and steep-sided hills with narrow, chert-covered ridges are characteristic natural features. Shortleaf pine (*Pinus echinata* Mill.) and scarlet oak (*Quercus coccinea* Muenchh.) are characteristic trees with their Missouri ranges centered on this section. Less than 0.5% of the vegetation was prairie in presettlement times. Upland sinkhole ponds with floral characteristics of swamps of the Mississippi Lowlands Natural Division, and several northern relict plants including northern bedstraw (*Galium boreale* L.) and harebell (*Campula rotundifolia* L.) are features of the Lower Ozark Section. Streams flow generally southward and include the St. Francis, Black, Current, and Eleven Point rivers.

St. Francois Mountains Section. Scattered conical knobs and high peaks which rise mountain-like from the surrounding basins, exposures of Precambrian granite, rhyolite, and felsite, shut-in streams, and the absence of karst features and presettlement prairie characterize this small region in the southeastern Ozarks. Although they lie near the edge of the Ozark Division, the St. Francois Mountains actually form the geologic center of the Ozark Dome, and their crystalline rocks reach the highest altitude of these Precambrian formations (Bretz 1965, Sauer 1920). The greatest relief and elevation in Missouri occur here, with as much as 1000 feet elevational change between the peaks and basins. The basins between the knobs are underlain by dolomite and sandstone. Soils have formed from the igneous and sedimentary bedrocks and range from deep to very shallow. Most of the streams are small, and they drain the region in a complex pattern. Igneous glades and erosional formations are special features. There are few springs, caves, and other karst features. Original vegetation was pine, mixed pine-oak, and deciduous forests and glades.

White River Section. The region contains the White, North Fork, and part of the James river basins. The White River and its tributaries have dissected the limestone bedrock into series of long, steep-sided ridges and high buttes making one of the most rugged landscapes in the state. Extensive limestone glades, known locally as cedar glades, are common features and have a distinct flora. Original vegetation was pine, mixed pine, and deciduous forests and glades.

Cliffs, caves, springs, and sinkholes are common. Streams are fast and clear. Several plants and animals are endemic to this section and many more have their Missouri distributions centered on it. Ozark spiderwort (*Tradescantia ozarkana* Anderson and Woodson), Ashe's juniper (*Juniperus ashei* Bucholz), Ozark chinquapin (*Castanea ozarkensis* Ashe), penstemon (Penstemon cobaea Nutt. var. *purpureus* Pennell), and yoke darter (*Ethiostoma jullae* Meek) are examples of endemics. Some species with Missouri distributions centered on the section are smoke tree (*Cotinus obovatus* Raf.), fringe tree (*Chionanthus virginica* L.), yellow wood (*Cladrastis lutea* [Michx. f.] K. Kock), Trelease's larkspur (*Delphinium treleasei* Bush), duskystripe shiner (*Nortopis pilsbryi* Fowler), gray-bellied salamander (*Eurycea multiplicata griseogaster* Moore and Hughes), Ozark red-back salamander (*Plethodon serratus* Grobman), and Bachman's sparrow (*Aimophila aestivalis* [Lichtenstein]).

Elk River Section. This section includes rolling plains and rugged hills in the drainages of the Elk and Grand rivers. Presettlement vegetation was mainly upland deciduous and pine forest, with prairie comprising about 7% of the rest. Glades are not nearly so numerous nor so extensive as in the White River Section. Prairie and savanna occurred where this section blends with the Springfield Plateau Section. The Missouri ranges of the redsopt chub (*Nocomis asper* Lachner and Jenkins) and the Oklahoma salamander (*Eurycea tynerensis* Moore and Hughes) are centered here.

Springfield Plateau Section. Physiographically most of this section is part of the Springfield Plateau of the Ozark Province. It is less highly dissected than the rest of the Ozarks. Its topography, soils, and presettlement vegetation give it characteristics of a western Ozark border where the prairies of the Osage Plains graded into the forests of the Ozarks. The Springfield Plateau Section is differentiated from the Osage Plains Natural Division by higher elevation, numerous karst features, Ozark border soils, and Mississippian and Ordovician bedrock. Prairie, deciduous forest, glade, and savanna were characteristic in presettlement times, prairie occupying about 29% of the region. Glades formed on solid chert of the Grand Falls Formation are an unusual feature of this section. An endemic plant, geocarpon (*Geocarpon minimum* Mackenzie), occurs on sandstone glades of the Springfield Plateau Section. Spiderwort (*Tradescantia tharpii* Anderson and Woodson), royal catchfly (*Silene regia* Sims), fringed poppy mallow (*Callirhoe digitata* Nutt), western dwarf dandilion (*Krigia occidentalis* Nutt.), Selenia (*Selenia aurea* Nutt.) and saxifrage (*Saxifraga texana* Buckl.) are characteristic plants.

Osage Plains

This division, occupying about 8% of the state, is an unglaciated plains region in southwest Missouri with gently rolling topography and soils derived from Pennsylvania shale, sandstone, and limestone residuum or from shallow loess. The upland prairie of this division has a greater proportion of southwestern plants and animals, a lesser proportion of northern species, and a greater diversity in streamside woody vegetation than the prairies of the Glaciated Plains. More than 70% of the region was prairie in presettlement times. Savanna, upland and bottomland deciduous forest and marsh also occurred. Streams commonly have shallow valleys and broad floodplains with many sloughs and marshes. Most of the common plants and animals of the Osage Plains are also found in the Glaciated Plains, and many have widespread distributions in Missouri. Several characteristic species of the division are prairie anemone (*Anemone caroliniana* Walt.), meadow beauty (*Rhexia interior* Pennell), marsh pink *Sabatia campestris* Nutt.), willow-leaved sunflower (*Helianthus salicifolius* A. Dietr.), great plains skunk (*Eumeces obsoletus* Baird and Girard), blotched water snake (*Nerodia erythrogaster transversa* [Hallowell]), prairie chicken (*Tympanuchus cupido* [Linnaeus]), upland sandpiper (*Bartramia longicauda* [Bechstein]), Bell's vireo (*Vireo bellii* Audobon), Henslow's sparrow (*Ammodramus henslowii* [Audubon]), and badger (*Taxidea taxus* [Schreber]). The Osage Plains Division grades almost imperceptably into the regions bordering it on the north, east, and south. Differences within the Osage Plains Division are too slight for subdividing into separate sections.

Big Rivers

This division, comprising about 5% of the state, includes the floodplains and terraces of the largest rivers, primarily the Missouri and Mississippi, but also the lower Grand and the lower Des Moines. Soils are mostly alluvial, deep, and productive. Presettlement natural features included mesic to wet prairie, bottomland and upland forests, marshes, sloughs, islands, sand and mud bars, oxbow ponds, and rivers. Bedrock is generally covered by alluvial deposits.

The Big Rivers Division has a distinct aquatic fauna, and Pflieger (1975) treates it as a separate Fish Faunal Region. It forms the center of distribution in Missouri for 30 fishes and 10 species are restricted to it. A few of the many characteristic plants are river bulrush (*Scirpus fluviatilis* [Torr.] Gray), bush cinquefoil (*Potentilla paradoxa* Nutt.), peach-leaved willow (*Salix amygdaloides* Anders.), cottonwood (*Populus deltoides* Marsh.), silver maple (*Acer saccharinum* L.), pecan (*Carya illinoensis* [Wang] K. Koch), and pin oak (*Quercus palustris* Muenchh.).

In presettlement times, and until drastic channel modification began in the early 1900's, the Missouri River was a braided stream with many chutes, sloughs, islands, and channels. Between 1879 and 1972, about 50% of the original surface of the river was lost. The surface area of islands was reduced by more than 90% between 1879 and 1954 (Funk and Robinson 1974). Backwater habitat was eliminated and the main channel was deepened and narrowed. Most of the original vegetation has been replaced by agriculture.

The Mississippi River, although less changed than the Missouri, has experienced the same basic trends as well as the addition of locks and dams which have converted portions of the Mississippi into a series of large pools.

The 4 sections are distinguished by physical characteristics of the rivers, soils, geography, biota, and presettlement vegetation.

Upper Missouri River Section. This section extends from Iowa to a constriction of the floodplain near Glasgow in Howard County and includes a large area along the lower Grand River. Presettlement terrestrial vegetation was about one-third prairie in contrast to the Lower Missouri Section, which was essentially devoid of prairie. Seaside crowfoot (*Ranunculus cymbalaria* Pursh) and spurge (*Euphorbia glyptosperma* Engelm.) are 2 plants that are generally restricted to this section. Reed (*Phragmites communis* Trin.), great bulrush (*Scirpus acutus* Muhl.), and dock (*Rumex mexicanus* Rafinesque), flathead chub (*Hybopsis gracilis* Richardson), western silvery minnow (*Hybognathus argyritis* Girard), and western massasauga rattlesnake (*Sistrurus catenatus tergeminus* Say) are animals characteristic of this region.

Lower Missouri River Section. This section includes the reach of the Missouri from the Upper Missouri River Section to its confluence with the Mississippi. Bottomland deciduous forest was the predominant presettlement vegetation (prairie made up only about 0.4%). Characteristic plants and animals include swamp white oak (*Quercus bicolor* Willd.), spicebush (*Lindera benzoin* [L.] Blume), deciduous holly (*Ilex decidua* Walt.), flathead chub (*Hybopsis gracilis* Richardson), and freshwater drum (*Aplodinotus grunniens* Rafinesque).

Upper Mississippi River Section. This section includes the Mississippi River terraces and flood plain upstream from its confluence with the Missouri River, and an area along the lower Des Moines River. The water of the Mississippi River in this section is much less turbid than that of the other 3 sections. Deciduous bottomland forest was the predominant terrestrial vegetation, although mesic and wet prairie was also significant, accounting for about 37%. Characteristic plants and animals include bulrush (*Scirpus cyperinus* [L.] Junth), swamp white oak (*Quercus bicolor* Willd.), silver maple (*Acer saccharinum* L.), spottail shiner (*Notropis hudsonium* Clinton), yellow bass (*Morone mississippiensis* Jordan), river carpsucker (*Carpiodes carpio* Rafinesque), Illinois mud turtle (*Kinosternon flavescens spooneri* Smith), and Blandings turtle (*Emydoidea blandingi* Holbrook).

Lower Mississippi River Section. This section includes the Mississippi River and associated land from its confluence with the Missouri River downstream to the Arkansas border. Increased turbidity, current, and volume from the Missouri River and increased volume from the Ohio River are reflected in a somewhat different aquatic biota. The area is quite narrow on the Missouri side of the river until it reaches the Mississippi Lowlands Natural Division. At this point the Lower Mississippi River Section, except for the river channel itself, essentially blends with the Lowlands Division and is considered as part of the Mississippi Lowlands. Presettlement vegetation was bottomland and swamp forests. Bald cypress swamps occurred in the lower part of the Section. Characteristic plants and animals include overcup oak (*Quercus lyrata* Walt.), raccoon grape (*Ampelopsis cordata* Michx.), swamp privit (*Forestiera acuminata* [Michx.]), butterweed (*Senecio glabellus* Poir.), blue catfish (*Ictalurus furcatus* Lesueur), bowfin (*Amia calva* Linnaeus), and mimic shiner (*Notropis volucellus* Cope).

Mississippi Lowlands

This Division, comprising about 5% of the state, is a region of mostly flat, alluvial plain and low terraces at the head of the Mississippi Embayment. It was formed by past action of the Mississippi and other rivers. Crowley's Ridge is the most prominent topographic feature. Elevation ranges from over 500 ft to about 230 ft, the lowest point in Missouri. This division's distinctive biota contains many coastal plains species, many of which reach their northern range limits here Sections are differentiated by topography, geological history, soils and biota.

Lowlands Section. Most of this section was bald cypress and tupelo swamp forest, mixed deciduous bottomland forest, and low upland deciduous forest until extensive clearing and draining began in the early 1900's. Relief is slight, and much of the section is less than 300 ft above sea level. Drainage and coversion to agriculture has been almost total, and only small remnants of natural forest and swamp remain. The major ditches have permanent flow and run clear much of the time. These ditches are the main habitat for the region's aquatic life. Characteristic plants and animals are bald cypress (*Taxodium distichum* [L.] Rich), tupelo (*Nyssa aquatica* L.), snowbell (*Styrax americana Lam.), pumpkin ash (Fraxinus tomentosa* Michx. f.), corkwood (*Leitneria floridana* Chapm.), copper iris (*Iris fulva* Ker), Cypress darter (*Etheostoma proeliare* [Hay]), banded pigmy sunfish (*Elassoma zonatum* Jordan), Mississippi mud turtle (*Graptemys kohni* [Baur]), western mud snake (*Farancia abacura reinwardti* Schlegel), green tree frog (*Hyla cinerea* [Schneider]), prothonotary warbler (*Protonotaria citrea* [Boddaert]), rice rat (*Oryzomys palustris* Harlan), and swamp rabbit (*Sylvilagus aquatica* [Bachman]). Windblown sand dunes and swale ponds are present. Soils are formed from deep alluvium and from eolian deposits over alluvium.

Crowley's Ridge Section. This section rises above the surrounding lowlands in a disjunct series of low hills. The hills are diverse geologically, containing sands, gravels, clays and bedrock of several geologic formations. Spring-fed streams and seep areas occur on the lower slopes in the sandy and gravelly soils. creating habitats for several plants restricted to this section in Missouri. American beech (*Fagus grandifolia* Ehrh.), holly (*Ilex opaca* Ait.), black chokeberry (*Pyrus melanocarp* Michx. Willd.), and spring cavefish (*Chologaster agassizi* Putnam) are species that reach or are near their western range limits in this section.

Summary

The Natural Divisions scheme regionalizes Missouri by integrating a number of physical and biological characteristics of the landscape. The scheme has been used in several specific applications, and it may be useful in other areas of resource conservation, natural history interpretation, education and research. It would be interesting to look into the distributional relationships of other life forms, for example, insects and lower plants, in the context of the Natural Divisions classification.

Acknowledgements

Walter Schroeder, Department of Geography, University of Missouri, Columbia, loaned us his unpublished county maps of presettlement prairie and aided us in their interpretation. Elizabeth Cook and Jay Raveill prepared the area statistical data for the table. Judy Gentili prepared the graphics. We are also grateful to William Crawford, John Faaborg, William Pflieger, Paul Nelson, Walter Schroeder, Charles and Elizabeth Schwartz, Jerry Vineyard, and John Wylie for their comments and suggestions on the project. The project was done largely with the resources of the Missouri Department of Conservation.

Literature Cited

Allgood, Ferris P. and Ival D. Persinger. 1979. Missouri general soil map and soil association descriptions. U. S. Dept. Agri., Soil Conservation Service, Columbia, Mo. 73 pp.

Austin, Morris E. 1965. Land resource regions and major land resource areas. Agri. Handbook 296. U. S. Dept. Agri., Soil Conservation Service, Wash., D.C. 82 pp.

Bennitt, Rudolf, and Werner O. Nagel. 1937. A Survey of the Resident Game and Furbearers of Missouri. The University of Missouri Studies Vol. 12, No. 2., Columbia.

Bretz, J. Harlen. 1965. Geomorphic History of the Ozarks of Missouri. Missouri Division of Geol. Survey and Water Resources, Rolla.

Collier, James E. 1955. Geographic regions of Missouri. Annals Assoc. Am. Geogr. 45: 368-392.

Cozzens, Arthur B. 1939. Analyzing and mapping natural landscape factors of the Ozark province. Trans. Acad. Sci. St. Louis. 30:37-63.

Fenneman, Nevin M. 1938. Physiography of Eastern United States. McGraw-Hill Book Company, Inc., New York.

Funk, John L., and John W. Robinson. 1975. Changes in the channel of the lower Missouri River and effects on fish and wildlife. Aquatic

Series No. 11. Missouri Dept. of Conservation, Jefferson City. 52 pp.

Kucera, Clair L. 1961. The Grasses of Missouri. University of Missouri Press, Columbia.

Marbut, C. F. 1896. Surface features of Missouri. Missouri Geol. Serv. Rep. 10:14-109.

Palmer, Ernest J., and Julian A. Steyermark. 1935. An annotated catalogue of the flowering plants of Missouri. Annals of the Missouri Bot. Garden 22:375-758.

Pflieger, William L. 1975. The Fishes of Missouri. Missouri Dept. of Conservation, Jefferson City.

Sauer, Carl O. 1920. The geography of the Ozark highland of Missouri. Bull. Geogr. Soc. Chicago No. 7. University of Chicago Press, Chicago. 187 pp.

Schroeder, Walter A. 1978. Mapping the presettlement prairies of Missouri. Proc. Fifth Midwest Prairie Conf., pp. 19-24, D. C. Glenn-Lewin and Roger Q. Landers, eds. Iowa State University, Ames.

Schwegman, John E. 1973. Comprehensive plan for the Illinois Nature Preserves System. Part 2. The natural divisions of Illinois. Illinois Natures Preserves Commission, Rockford. 32 pp.

Spencer, John S. Jr., and Burton L. Essex. 1976. Timber in Missouri. Resource Full. NC-30. U. S. Dept. Agri., Forest Serv. North Carolina Forest Expt. Sta., St. Paul, Minn. 108 pp.

Reprinted with the permission of the Missouri Academy of Science, from Trans. Missouri Acad. Sci. 14:9-23.

[illegible] which reach their northern range limits here. Sections are differentiated by topography, geological history, soils and biota.

Lowlands Section. [illegible] deciduous forest until extensive clearing and draining began in the early 1900's. Relief is slight [illegible] The major ditches have permanent flow and run [illegible] These ditches are the main habitat for [illegible] aquatic life. Characteristic plants and animals are bald cypress (*Taxodium distichum* [L.] Rich), tupelo (*Nyssa aquatica* L.), snowbell (*Styrax americana* Lam.), pumpkin ash (*Fraxinus tomentosa* Michx. f.), corkwood (*Leitneria floridana* Chapm.), copper iris (*Iris fulva* Ker), Cypress darter (*Etheostoma proeliare* [Hay]), banded pigmy sunfish (*Elassoma zonatum* Jordan), Mississippi mud turtle (*Graptemys kohni* [Baur]), western mud snake (*Farancia abacura reinwardti* Schlegel), green tree frog (*Hyla cinerea* [Schneider]), prothonotary warbler (*Protonotaria citrea* [Boddaert]), rice rat (*Oryzomys palustris* Harlan), and swamp rabbit (*Sylvilagus aquaticus* [Bachman]). Wind-blown sand dunes and swale ponds are present. Soils are formed from deep alluvium and from eolian deposits over alluvium.

Crowley's Ridge Section. This section rises above the surrounding lowlands in a disjunct series of low hills. The hills are diverse geologically, containing sands, gravels, clays and bedrock of several geologic formations. Spring-fed streams and seep areas occur on the lower slopes in the sandy and gravelly soils, creating habitats for several plants restricted to this section in Missouri. American beech (*Fagus grandifolia* Ehrh.), holly (*Ilex opaca* Ait.), black chokeberry (*Pyrus melanocarpa* Michx. Willd.), and spring cavefish (*Chologaster agassizi* Putnam) are species that reach or are near their western range limits in this section.

Summary

The Natural Divisions scheme regionalizes Missouri by integrating a number of physical and biological characteristics of the landscape. The scheme has been used in several specific applications, and it may be useful in other areas of resource conservation, natural history interpretation, education and research. It would be interesting to look into the distributional rela-

[illegible] forests [illegible] insects and lower plants [illegible] Natural Divisions classification.

[illegible] Walter Schroeder, Department of Geography, University of Missouri, Columbia, loaned us his unpublished county maps of presettlement prairies [illegible] prepared the graphics. We are also grateful to William Crawford, [illegible], William Pflieger, Paul Nelson, Walter Schroeder, Charles and Elizabeth Schwartz, Jerry Vineyard and John Wylie for their comments and suggestions on the project. The project was done largely with the resources of the Missouri Department of Conservation.

Literature Cited

Allgood, Ferris P. and Ival D. Persinger. 1979. Missouri general soil map and soil association descriptions. U. S. Dept. Agri., Soil Conservation Service, Columbia, Mo. 73 pp.

Austin, Morris E. 1965. Land resource regions and major land resource areas. Agri. Handbook 296. U. S. Dept. Agri., Soil Conservation Service, Wash., D.C. 82 pp.

Bennitt, Rudolf, and Werner O. Nagel. 1937. A Survey of the Resident Game and Furbearers of Missouri. The University of Missouri Studies Vol. 12, No. 2., Columbia.

Bretz, J. Harlen. 1965. Geomorphic History of the Ozarks of Missouri. Missouri Division of Geol. Survey and Water Resources, Rolla.

Collier, James E. 1955. Geographic regions of Missouri. Annals Assoc. Am. Geogr. 45: 368-392.

Cozzens, Arthur B. 1939. Analyzing and mapping natural landscape factors of the Ozark province. Trans. Acad. Sci. St. Louis. 30:37-63.

Fenneman, Nevin M. 1938. Physiography of Eastern United States. McGraw-Hill Book Company, Inc., New York.

Funk, John L., and John W. Robinson. 1975. Changes in the channel of the lower Missouri River and effects on fish and wildlife. Aquatic

A MAP OF PRESETTLEMENT PRAIRIES OF MISSOURI AT 1:500,000

Walter A. Schroeder
Department of Geography
University of Missouri-Columbia
Columbia, Missouri 65211

Abstract. A map of presettlement prairies of Missouri has been prepared using the field notes and township plat maps of the U. S. General Land Office Survey. The dates of the survey range from 1816 into the 1850's. The map is based exclusively on use of the word "prairie" in the field notes. Barrens, glades, long grass, brush, etc. are not included. The physiographic expression of prairies varied widely in Missouri, including extensive wet prairies in northern Missouri, prairie hollows in the Ozarks and upland prairies throughout. Few places on prairies were more than 6 km from timber. Missouri had a total of 47,663 km^2 of presettlement prairie, which was 26.7% of its total area.

Introduction

This paper is a report of the completion of a map of the presettlement prairies of Missouri and a commentary on some geographical characteristics of those prairies. All information for the map was taken from the plat maps and field notes of the U.S. General Land Office survey in the Division of Archives of the Office of Secretary of State, Jefferson City, Missouri. The survey in Missouri began in late 1816 with surveys to confirm Spanish grants, and effectively ended in the 1850's. The survey of any one tract of land was done when settlement of it seemed imminent, so the survey preceded white settlement of any tract by a few years at most. Major exeptions to this were (a) the lands already settled and claimed by Spanish land grants before 1803, (b) lands claimed under New Madrid earthquake certificates, (c) lands occupied by squatters after the Louisiana Purchase of 1803 but before the Land Office began land sales in 1818, and (d) the Platte Purchase country northwest of Kansas City which was not added to Missouri until 1836, after several thousand persons already were living there.

Methodology for construction of the map was previously discussed in a paper before the Fifth Midwest Prairie Conference (Schroeder 1978) and will not be treated here. It should be pointed out, however, that only prairies, so designated with that specific word in the field notes, have been mapped. This includes both upland or dry prairies, as well as bottom or wet prairies. Vegetation types sometimes recognized as prairie today, but not described as prairie by the surveyors, are excluded from the map. Examples of such exclusions are barrens, glades, long grass, scattering timber, brush, and hazel rough. Excluded also are the section corners where the surveyors wrote they could find no trees "within reasonable distance" (up to half a km) to serve as bearing trees. Further exclusions are those tracts of land described as prairie in the accounts of early settlers and explorers, unless they were also described as prairie in the surveyor's field notes. In summary, the map is a strict reconstruction of presettlement prairie according to use of the word "prairie" in the surveyor's field notes. On that single criterion it is both an objective map (that is, not subject to personal interpretation of the field notes) and an accurate map.

The map was originally drawn on separate county maps at 1:125,000. Data were then transferred to a single sheet state map at 1:500,000. The map is not reproducible for this article. Detail of the map may be indicated by its inclusion of isolated prairies as small as 4 ha. Location of prairie boundaries on the map are within 1 km of their true location according to the field notes.

Geographical Characteristics

In northwestern and north-central Missouri, prairies regularly occupied both upland drainage divides and wet tracts in valley bottoms. Most major streams in this region are south-flowing, and in detail the valleys showed a pronounced asymmetry in prairie-timber relationships. Ridge top prairies regularly extended down the east-facing valley slopes, merging into the wet prairies on the wide, poorly drained valley floors. Timber occurred on the east bank of the streams, and extended into draws on the west-facing valley sides. The surveyors commented that prairie occurred right up the the west bank (windward to fire) of the Nodaway River channel, and timber occurred on the east bank (leeward to fire).

The Chariton Hills in north-central Missouri and the dissected hill country of northeastern Missouri had the most intricate pattern of prairies. "Intricacy" is measured by extending several straight lines in random directions across an area and counting the number of prairie boundaries that intersect the lines. Much of what was shown as "timber" on the plat maps is better interpreted as savanna or barrens on the basis of size and distribution of trees. Prairie, barrens, savanna, and true forest intermixed in a most complex mosaic in this region. Most of the prairies on watershed divides in Sullivan County were no more than 2 km wide, often narrowing to a couple hundred m. Wet prairie also was reduced to tracts as small as 4 ha, and the surveyors probably missed many that were located away from the section lines.

The clearest expression of prairie interfingered with narrow ribbons of timber occurred in the low-relief Osage Plains of west-central Missouri. The bands of river-border timber were narrow. Even along the Osage River, the largest river with the widest floodplain, timber usually extended no more than a km away from the channel, so that the wide, wet flood plains of this region were more prairie than timber.

The Western Ozark Border, from Joplin and Springfield to Boonville on the Missouri River, as a region, showed the most clearly defined prairies in the state. The prairie-timber edge was most abrupt in this region, a characteristic probably related to the strong Mississippian bedrock control of topography. Flattish Ozark plateau remnants formed well-defined prairies, while steeply dissected regions along major stream valleys formed extensive timbered tracts. It is no coincidence that this region has, by far, the largest number of named prairies in the state. With clearly perceived limits, the prairies became identifiable units to settlers and their communites and the means to describe locations. Polk County has 19 named prairies, the greatest number of any county in Missouri, while Newton County has 14.

The Ozarks proper included a few praires within the extensive forest. It has been pointed out that settlers of the Ozarks, largely from Kentucky and Tennessee, did not have the term "prairie" in their vocabularies, but instead referred to grassy tracts with such Middle South terms as "barrens," "balds," and "glades" (Sauer 1927). The land surveyors, however, did use "prairie" for 2 kinds of environments in the Ozarks. There were prairies on the rolling uplands, usually karstic. There were also prairie hollows or valleys, as identified by Swallow (1859) for Crawford County: "[The land north of dividing ridge is] traversed by numerous beautiful prairie valleys, bounded by gentle hills. . . .". Both types of prairies occurred in southeastern Camden County and contiguous parts of Laclede County. Long linear prairies followed the broad, shallow valleys of Goodwin Hollow and the Auglaize system, while upland prairie occupied the broad dividing ridge of the Camden-Laclede county line. The uplands are a well-developed karst plateau, while the valleys are usually dry at the surface, occupied by "losing streams" which lose water into the alluvium and bedrock beneath the valley floor.

Perry County along the Mississippi River is an example of how much more ubiquitous grasses may have been in the Ozarks than use of the word "prairie" indicates. The survey notes contains no mention of the word "prairie" for this county. However, the terms "barren" and "long grass" were frequently used to describe the vegetation at the end of each mile of survey. "Barrens" was used for the land around Perryville. "Long grass" was used for most of the southern parts of the county, so that at least one half of the county was described by these 2 terms. With both terms, however, there were enough trees of sufficient size in the environment to serve as witness and bearing trees.

Prairies were not extensive in the Mississippi Alluvial Lowlands of southeastern Missouri. Small prairies were located on low, but well drained, sandy terraces, as the Sikeston Ridge and Kennett Ridge. These prairies were among the first sites selected for white settlement in the region. All these prairies have long had established names and formed delimited communities. Wet prairies occurred in very few places notably within the Mingo Swamp and at Grassy Lake near New Madrid.

St. Louis City and County present a special case because they were settled before the survey of the U. S. General Land Office. In rare cases the survey field notes may describe a landscape already in use for nearly half a century. However, the testimony of land claimants before the U. S. Land Commissioners provides clues to the actual presettlement environment. All sources indicate that the site of St. Louis was timbered only from the river bank to the low limestone bluff, or 1 km from the river. Westward beyond Broadway stretched the prairies. One of the French settlers testified that

> "the spot immediately where the town now stands was very heavily timbered, but back of the town it was generally prairie, with some timber growing, but where the timber did not grow it was entirely free from undergrowth, and the grass grew in great abundance everywhere, and of the best quality; but where the inhabitants used to cut their hay was where Judge Lucas now lives [Locust and 13th streets], and between his house and the cottonwood-trees, (Scharf 1883)

St. Louis may very well lay claim to the title of "first prairie city" of the United States.

The French village of Florissant and its common fields and common pasture were laid out in the broad prairies of north St. Louis County. In fact, the name, Fleurissant, is likely derived from the spectacular beauty of the prairie wildflowers in bloom (Houck 1908).

Wet Prairies

Regrettably, wet prairies were not separately differentiated as the map was being compiled. However, by their topographical position in flood plains, wet prairies can be inferred. Virtually every county in Missouri north of the Missouri River and in west-central Missouri had wet prairies. They were common along the Missouri River beginning at the mouth of the Grand River and continuing upstream to the Iowa line. In Atchison County 80% of the flood plain was prairie, and the Missouri River channel itself cut into prairie. One of the largest uninterrupted prairies of Missouri, the Wakenda Prairie, occupied the wide floodplain in southern Carroll County. Most of the Mississippi bottomland in St. Charles County, near the junction of the Missouri and Mississippi rivers, was wet prairie, and wet prairies occurred along the Mississippi upstream from there. Where the Missouri River cuts across the Ozarks, wet prairies were much less common and very much smaller.

Size of Prairies

Trees could be seen from almost any place in a presettlement prairie. Surveyors noted isolated American elms, bur oaks, and other large trees on the prairie, and also noted timbered draws and scattered groves not topographically distinct. Father O'Hanlon (1890), describing an extensive prairie tract of northeast Missouri, wrote that in summer his "range of vision was mostly closed by hazy-looking woods."

To measure maximum distance to timber, circles of graded sizes were moved about on the map. No place could be found on a prairie which was more than 10 km from timber. One place, in northeastern Jasper County, was more than 9 km. One more place, in adjacent Barton County, was more than 8 km. Not until circle size was reduced to a radius of 5 km did many places (in 14 counties) appear which were that far from timber. One may conclude that Missouri presettlement prairies, though they may have been very attenuated as they stretched along divides and in bottoms, were commonly narrow, so that few places on prairies were more than 6 km from timber.

Summary

There were 47,663 km^2 (18,484 sq miles) of presettlement prairie in Missouri. This reckoning is based on use of the word "prairie" in the field notes, a conservative definition of prairie. Barton County had the highest percentage of its land in presettlement prairie (86%), followed by Atchison (83%), and Nodaway (81%). For the state as a whole, 26.7% of its area was in prairie.

Literature Cited

Houck, L. 1908. A History of Missouri. Vol. 2, p. 66. R. R. Donnelly & Sons Co., Chicago.

O'Hanlon, J. C. 1890. Life and Scenery in Missouri. James Duffy and Co., Dublin, Ireland.

Sauer, C. O. 1927. Geography of the pennyroyal. Series 6, Vol. 25, pp. 123-126, Kentucky Geol. Surv., Lexington.

Scharf, J. T. 1883. History of St. Louis City and County. Vol. 1, p 133. Louis H. Everts and Company, Philadelphia.

Schroeder, W. A. 1978. Mapping the pre-settlement prairies of Missouri. Proc. Fifth Midwest Prairie Conf., pp. 19-24, D. C. Glenn-Lewin and R. Q. Landers, eds. Iowa State University, Ames.

Swallow, G. C. 1859. Geological report of the country along the line of the South-western Branch of the Pacific Railroad, State of Missouri. G. Knapp for the Missouri Geol. Surv., St. Louis.

stretched the prairies. One of the French settlers testified that "the spot immediately where the town stands was very heavily timbered, but back of the town it was generally prairie, with some timber growing; but where the timber did not grow it was entirely free from undergrowth, and the grass grew long and abundance everywhere, and of the best quality, but where the inhabitants used to cut their hay was where Judge Lucas now lives [Locust and 13th streets], and between his house and the cottonwood trees" (Scharf 1883). St. Louis may very well lay claim to the title of "first prairie city" of the United States.

The French village of Florissant and its common fields and common pasture were laid out in the broad prairies of north St. Louis County. In fact, the name, Fleurissant, is likely derived from the spectacular beauty of the prairie wildflowers in bloom (Houck 1908).

Wet Prairies

Regrettably, wet prairies were not separately differentiated as the map was being compiled. However, by their topographical position in flood plains, wet prairies can be inferred. Virtually every county in Missouri north of the Missouri River and in west-central Missouri had wet prairies. They were common along the Missouri River beginning at the mouth of the Grand River and continuing upstream to the Iowa line. In Atchison County 80% of the flood plain was prairie, and the Missouri River channel itself cut into prairie. One of the largest uninterrupted prairies of Missouri, the Wakenda Prairie, occupied the wide floodplain in southern Carroll County. Most of the Mississippi bottomlands in St. Charles County, near the junction of the Missouri and Mississippi rivers, was wet prairie, and wet prairies occurred along the Mississippi upstream from there. Where the Missouri River cuts across the Ozarks, wet prairies were much less common and very much smaller.

Size of Prairies

Trees could be seen from almost any place in a presettlement prairie. Surveyors noted isolated American elms, bur oaks, and other large trees on the prairie, and also noted timbered draws and scattered groves, not topographically distinct. Father O'Hanlon (1890), describing an extensive prairie tract of northeast Missouri, wrote that in summer his "range of vision was mostly closed by hazy-looking woods."

To measure maximum distance to timber, circles of graded sizes were moved about on the map. No place could be found on a prairie which was more than 10 km from timber. One place in northwestern Jasper County was more than 9 km. One more place in adjacent Barton County was more than 8 km. Not until circle size was reduced to a radius of 5 km did many places (in 14 counties) appear which were that far from timber. One may conclude that Missouri presettlement prairies, though they may have been very attenuated as they stretched along divides and in bottoms, were commonly narrow, so that few places on prairies were more than 5 km from timber.

Summary

There were 47,652 km² (18,404 sq miles) of presettlement prairie in Missouri. This reckoning is based on use of the word "prairie" in the field notes, a conservative definition of prairie. Barton County had the highest percentage of its land in presettlement prairie (88%), followed by Atchison (83%) and Nodaway (81%). For the state as a whole, 26.7% of its area was in prairie.

Literature Cited

Houck, L. 1908. A History of Missouri. Vol. 2, p. 66. R. R. Donnelly & Sons Co., Chicago.

O'Hanlon, J. C. 1890. Life and Scenery in Missouri. James Duffy and Co., Dublin, Ireland.

Sauer, C. O. 1927. Geography of the pennyroyal. Series 6, Vol. 25, pp. 123-128. Kentucky Geol. Surv., Lexington.

Scharf, J. T. 1883. History of St. Louis City and County. Vol. 1, p. 153. Louis H. Everts and Company, Philadelphia.

Schroeder, W. A. 1978. Mapping the presettlement prairies of Missouri. Proc. Fifth Midwest Prairie Conf. pp. 19-24. D. C. Glenn-Lewin and R. Q. Landers, eds. Iowa State University, Ames.

Swallow, G. C. 1859. Geological report of the country along the line of the South-western Branch of the Pacific Railroad, State of Missouri. G. Knapp for the Missouri Geol. Surv., St. Louis.

PRESETTLEMENT BARRENS OF HARRISON AND WASHINGTON COUNTIES, INDIANA

James H. Keith
Geosciences Research Associates, Inc.
414 S. Walnut Street
Bloomington, Indiana 47401

Abstract. The barrens of south central Indiana were located mainly in Harrison and Washington Counties. These were apparently similar to the Kentucky barrens in the south, and like the Kentucky barrens, disappeared soon after white settlers moved into the area. Data from the General Land Survey were used to outline the Indiana barrens, and to gain some knowledge of their vegetation and the vegetation of the surrounding forest. The Indiana barrens were confined to areas of sinkhole topography. Evidence that fire played a major role in the maintenance of barrens was found in the relationship of vegetation patterns to streams and topography in Harrison County. Comparison of these data with earlier published reports on Kentucky barrens suggests that frequent fires facilitated by the unique conditions of topography and soil in the sinkhole plains of Indiana and Kentucky maintained the prairie vegetation of the barrens. Archaeological evidence is presented which suggests a shift from closed to open woods in central Kentucky 3-4,000 years ago, and other evidence suggests that the barrens areas of Indiana and Kentucky were open land 10-12,000 years ago. Barrens areas may have undergone several transitions from grassland to forest to grassland again, depending upon the climate. A relatively permanent species pool of prairie plants occupying the uplands around the sinkhole plains could then have rapidly colonized the sinkhole areas when conditions permitted.

Introduction

The barrens of Harrison County, Indiana were described by Collet (1879, 298-299) as ". . .a nearly level plain. In a wild state when visited by the Boones and other hunter pioneers, it was nearly a typical prairie, exhibiting a few knarled (sic) and scotched shrubs or "stools", and covered with a luxuriant growth of tall prairie grass, herbs and vines. These were burned after each autumnal frost, preventing the growth of trees and permanent vegetation." Collett later writes in the same report: "The Barrens" are so-named from the fact that when first visited by white men there were no trees on such areas as had been swept by autumnal fires; but, on the contrary, could afford only a wild growth of annual weeds, prairie grass and low "stool bush." Since the fires have been prevented by settlements, farms, etc., some fifty years ago, quite a forest has sprung up, and the former prairie plains are crowded in places with a young growth from twelve to eighteen inches in diameter."

Today, no trace of the barrens described by Collett has been located in Indiana.

Several authors have decribed the apparently similar Kentucky barrens and their disappearance (Dicken 1935, Garman 1925, McInteer 1942, 1946). None, however, have attempted to describe the Indiana barrens, although many papers describing the presettlement vegetation of Indiana have been produced (Bacone et al. 1980, Blewett et al. 1950, Crankshaw et al. 1965, Finley et al. 1952, Potzger et al. 1950, Rohr et al. 1950, Ross 1950). Transeau's map of the prairie peninsula (1935) also fails to note any prairie vegetation in south central Indiana, due, perhaps, to the fact that Transeau relied upon Gordon's manuscript later published in 1936 to locate Indiana prairie areas. Gordon based his map on observations he made while traversing the state (Potzger et al. 1956).

The purpose of this paper is to describe the extent of the barrens in south central Indiana, to compare the Harrison County barrens (soils data are currently lacking for Washington County) with local topography, soils, streams and local forest vegetation. Data relating to the age of the barrens are also presented and discussed.

Study Area

A map of the prairie peninsula (after Bryant 1977 and Transeau 1935) is shown in Fig. 1. Despite the fact that no prairie vegetation is indicated for south-central Indiana, an initial survey of the

General Land Office Survey field notes (see Methods) revealed that presettlement barrens did occur, primarily in Washington and Harrison Counties. A few references to barrens were found in the notes for Orange County (2) and Crawford County (3), but these were isolated both from one another and the barrens in question. These barrens segments were also very short (less than 2 km in length).

Washington County covers an area of about 107,105 ha and Harrison County covers an area of about 124,000 ha. Neither county was glaciated, except for the northeast corner of Washington County, which will not be considered in this report.

Both counties contain 3 physiographic units (Malott 1922). These are:

1) **Norman Upland.** This easternmost unit is bounded on the east by the eastward facing Knobstone Escarpment. The Norman Upland consists of maturely dissected terrain underlain by lower and middle Mississippian siltstones, shales and thin limestones. Drainage of surface streams is generally west and southwest.

2) **Mitchell Plain.** This middle unit corresponds to the Pennyroyal Plain of Kentucky. It is underlain by massive limestones of middle Mississippian age. The Mitchell Plain is characterized by extensive rock solution and cavern development, comparatively low relief and a lack of surface drainage, with the exception of a few deeply entrenched master streams including Blue River, White River, Indian Creek and Buck Creek. There are many areas of strong sinkhole development where surface water percolates downward and flows underground through channels in the limestone. This water eventually reaches the local master stream after it flows from springs along the stream margin.

3) **Crawford Upland.** This westernmost physiographic unit is underlain by limestone of middle Mississippian age capped by sandstones and shales of upper Mississippian and lower Pennsylvanian age. The caprock is resistant to solution and prevents water from reaching much of the underlying limestone and dissolving it. Thus a high relief is maintained. The landscape is generally very dissected with a well integrated stream network flowing west and southwest. The Crawford Upland is separated from the Mitchell Plain by the Chester Escarpment, with a relief of about 75 m in Harrison County.

The climate of these counties is mid-continental with mean daily summer high temperatures of about 30°C and a mean daily winter low temperature of -7°C. Rainfall averages 105 cm annually.

Methods

The General Land Survey field notes are located in the Archives Room of the Indiana State Library, Indianapolis, Indiana. Photocopies of the field notes are available for public inspection. The surveys of the south central Indiana area were among the first done in Indiana. There were completed between 1804 and 1807. The following data were copied for this study:

1) Species and dbh of witness tress at section and quarter section corners.

2) Presence of barrens along section lines. Terms such as barrens, rocky barrens, brushy barrens, prairie, grassland, no trees, high grass, barrens with grass, open barrens or poor barrens were considered to be barrens.

3) The direction and distance of witness trees from the surveyor's stake.

Fig. 1 The Kentucky barrens followed an accurate course on sinkhole topography from south central Kentucky to the Ohio River. Although the same bedrock and topography continued into Indiana through Harrison and Washington Counties (outline), there was no note of Indiana barrens on Transeau's map (modified from Bryant 1977 and Transeau 1935).

The recorded data were transferred to 6x6 grid forms corresponding to Congressional Townships, to be later recorded on suitable base maps. Soils data for Harrison County were provided by the Soil Survey of Harrison County, Indiana (Soil Conservation Service 1975). United States Geological Survey 7.5 minute topographic maps provided information on topography, streams and landforms. General geologic information was provided by a 1^{o}x2^{o} regional geologic map (Vincennes Sheet). Most of this paper will concern the barrens of Harrison County. A more detailed description of Washington County will be published when more detailed soils information is published for that county.

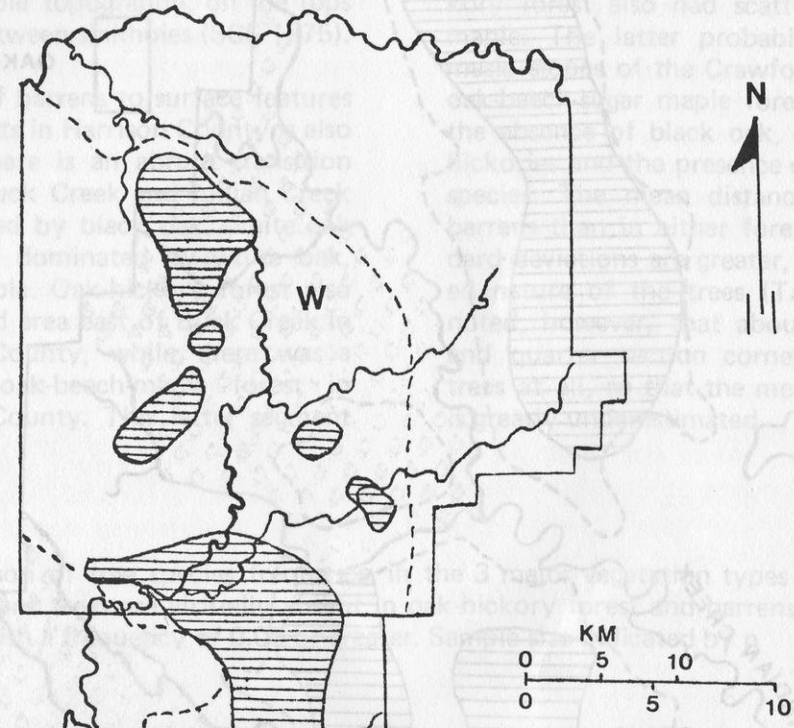


Fig. 2. The presettlement barrens of Harrison and Washington Counties (shaded areas) were confined to the Mitchell Plain (enclosed by dashed lines). The Mitchell Plain is bounded by the Norman Upland to the east and the Crawford Upland to the west (W = Washington County, H = Harrison County).

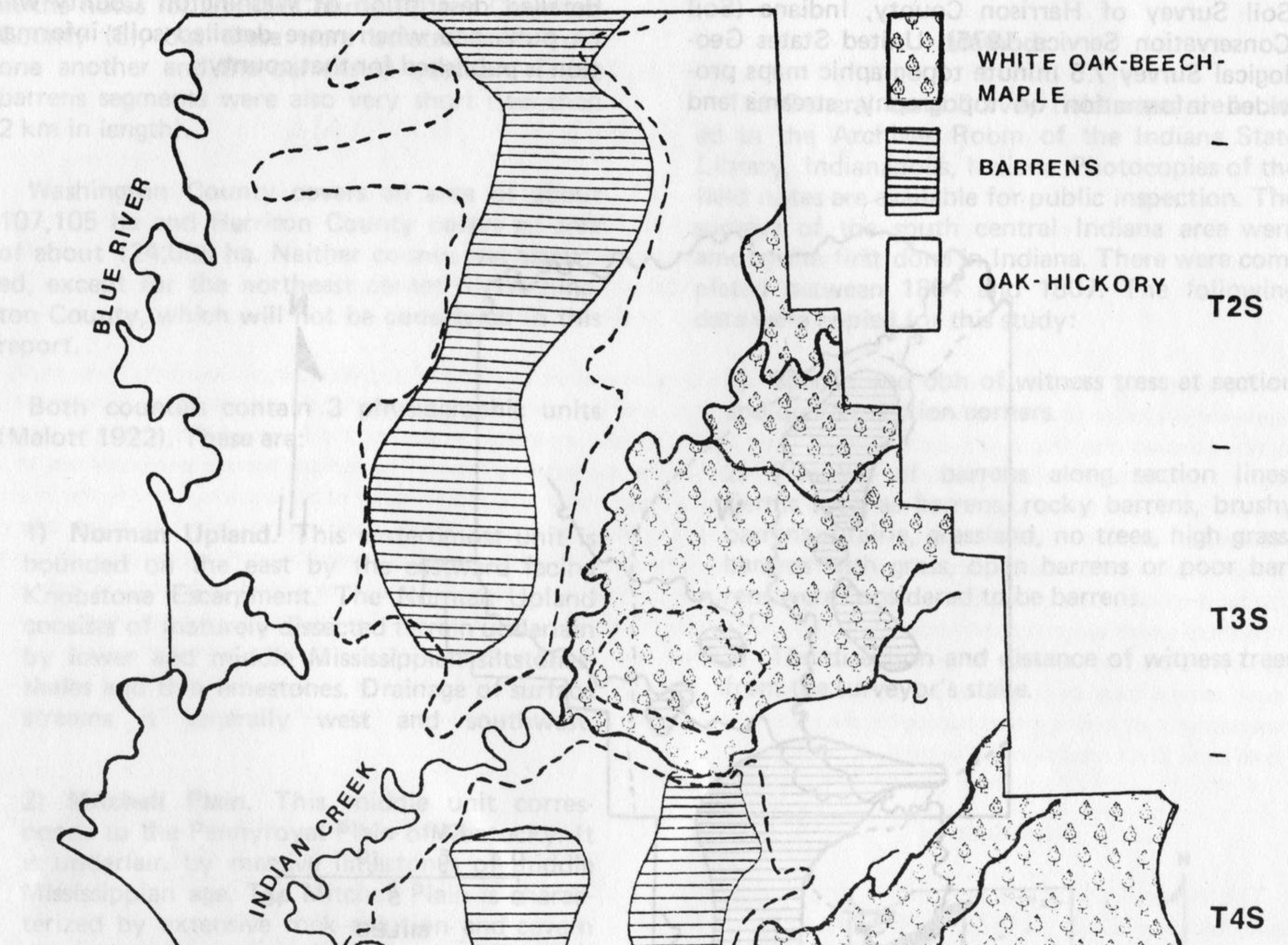


Fig. 3. Barrens in Harrison occurred only on soils of the Baxter-Crider Association (enclosed by dashed lines). Major changes in forest type occurred across Indian Creek, Buck Creek, and in the Crawford Upland of southwestern Harrison County.

Results

The general extent of presettlement barrens is shown in Fig. 2. Barrens once covered about 21,500 ha (17%) of Harrison County and about 11,750 ha (11%) of Washington County. It is also shown that the barrens are confined to the Mitchell Plain. The relationship of the barrens to soil type in Harrison County is shown in Fig. 3. The barrens are found almost entirely on soils of the Baster-Criter Association, which are formed specifically on sinkhole topography, on the tops and sides of ridges between sinkholes (SCS 1975).

The relationship of barrens to surface features and surrounding forests in Harrison County is also shown in Fig. 3. There is an abrupt transition across portions of Buck Creek and Indian Creek from forest dominated by black oak, white oak and hickory to one dominated by white oak, beech and sugar maple. Oak-hickory forest also occupied a fan-shaped area east of Buck Creek in southeast Harrison County, while there was a segment of white oak-beech-maple forest in southwest Harrison County. This latter segment occupied an area of the Crawford Upland bounded on the east by the Chester Escarpment, and by Indian Creek, Buck Creek, and the Ohio River.

Table 1 shows the frequency of the major tree species in the barrens, and in the 2 forest types. The barrens were dominated by white oak, black oak and hickory. Rarely, individual sassafras, tuplip poplar, black walnut and dogwood were mentioned by the surveyors. The oak-hickory forest also had scattered beech and sugar maple. The latter probably grew on the more mesic slopes of the Crawford Upland. The white oak-beech-sugar maple forest is characterized by the absence of black oak, a reduced number of hickories and the presence of a greater number of species. The mean distance is much greater in barrens than in either forest type, and the standard deviations are greater, reflecting the scattered nature of the trees (Table 2). It should be noted, however, that about 40% of the section and quarter section corners in barrens had no trees at all, so that the mean distance in barrens is greatly underestimated.

Table 1. A comparison of tree species frequency in the 3 major vegetation types of Harrison County. Fire-intolerant trees are virtually absent in oak-hickory forest and barrens areas. Major species are those with a frequency of 0.05 or greater. Sample size indicated by n

Species	Barrens (n=392)	Oak-Hickory (n=480)	White Oak-Beech-Sugar Maple (n=425)
White Oak *(Quercus alba)*	0.32	0.29	0.22
Black Oak *(Q. velutina)*	0.29	0.25	–
Hickory *(Carya* spp.*)*	0.25	0.20	0.08
Beech *(Fagus grandifolia)*	–	0.12	0.25
Sugar Maple *(Acer saccharum)*	–	0.05	0.10
Tulip Poplar *(Liriodendron tulipifera)*	–	–	0.08
Black Gum *(Nyssa sylvatica)*	–	–	0.05
Dogwood *(Cornus florida)*	–	–	0.05
Cumlative Frequency	0.86	0.91	0.83

Table 2. Mean distance in links of witness trees from survey stakes in 4 Congressional Townships in Harrison County

Township	Range	Barrens	Oak-Hickory	White Oak-Beech-Sugar Maple
4S	4E	$\bar{x}$ = 43.5 n = 44 s.d. = 39.99	$\bar{x}$ = 28.6 n = 97 s.d. = 18.89	$\bar{x}$ = 24.3 n = 65 s.d. = 10.80
4S	5E	—	$\bar{x}$ = 19.2 n = 62 s.d. = 11.43	$\bar{x}$ = 21.3 n = 142 s.d. = 11.40
1S	3E	$\bar{x}$ = 54.0 n = 38 s.d. = 42.96	$\bar{x}$ = 25.2 n = 59 s.d. = 24.40	—
2S	3E	$\bar{x}$ = 32.8 n = 94 s.d. = 35.13	$\bar{x}$ = 25.6 n = 97 s.d. = 15.73	—

Discussion

Maintenance of the barrens. Dicken (1935), McInteer (1942, 1946) and Collett (1879) state that there were frequent fires in the barrens. It seems likely that these fires were started both by man and by natural causes. Both Dickens and McInteer state that the rolling topography and the lack of surface streams presented few barriers to fires once they started, thus discouraging trees in areas of sinkhole topography.

The underground drainage of the sinkhole plain must also have played a role in the maintenance of the barrens. Water reaching the soil surface as precipitation need travel no more than a few dozen feet in any direction before finding its way deep into the bedrock, unavailable for plant use. The permeability of the bedrock may drastically reduce the capacity of the soil to hold moisture, and, in times of drought, provide an inadequate moisture supply for tree growth and maintenance. This could make trees more vulnerable to destruction by fire (Dicken 1935).

The rapid reforestation of the barrens after settlement may also be due to the indirect effects of fire. Black oaks sprout vigorously from the roots after burning, and fire may stunt individual trees. The presence of scattered trees, particularly black oaks, in the barrens indicates the potential for rapid reforestation of the area after fires were suppressed.

Figure 3 illustrates the combined effects of fire and topography on the barrens and forests of Harrison County. The transition from fire tolerant trees to fire intolerant trees across Indian and Buck Creeks is certainly suggestive of the role of fire in maintaining vegetation patterns in the county. There are no immediate changes in topography across the streams, and it is interesting to note that although the barrens are confined to soils of the Baxter-Crider Association, these soils also support oak-hickory and white oak-beech-sugar maple forests east of the streams. The Crawford Upland segment in southwestern Harrison County is isolated from fires by streams on 3 sides, and by its general upwind position from the barrens to the east. Further north, the Crawford Upland is not isolated to this extent. There are frequent reports of beech and maple trees in the uplands of neighboring Crawford County by the surveyors. There are also references to "brushy ridges" which may be the aftermath of fires. The terminology of the surveyors did not suggest that they considered these brushy areas to be barrens.

From the evidence presented, it would appear that fire, aided by the unique topography and soils conditions of the sinkhole plain, kept the barrens free of trees. Where fire barriers intervene, or where sinkhole topography is lacking, there were no barrens. The white settlers of the area played a major part in the loss of the barrens. It is likely that they actively suppressed fires which posed a threat to their holdings and their livelihood. They also filled the landscape with firebreaks in the form of roads, plowed fields, towns and barnlots. This reduced the effectiveness of fires once they did start, and enabled trees to invade the open areas.

Barrens age and origin. Barrens were unique because they were extensive prairie communities located within the deciduous forest region (Braun 1972). Several authors have written on the origin of the barrens (Dicken 1935, Garman 1925 and McInteer 1942, 1946), but since the barrens no longer exist, it would be very difficult to prove anything about their origin. It would be useful to discuss as well what relationships the barrens had with other plant communities, and to discuss some data relating to the possible age of the barrens.

Garman (1925) wrote that the barrens were a climax grassland, and published a list of 35 plant species common to the Kentucky barrens and the prairies of Illinois. He also wrote that a turf was established on the Kentucky barrens which prevented the invasion of trees. There is no evidence for a prairie turf on the Harrison County barrens. The original vegetation of the Baxter-Crider soils is listed as "hardwood forest", implying that barrens soils were not greatly different from other soils in the county (Soil Conservation Service 1975).

McInteer (1942, 1946) felt that a great drought enabled prairie plants to invade the barrens. Dicken (1935) felt that the barrens of Kentucky represented a phase in a complex transition from forest to temporary grassland back to forest. He cited the combined effects of fire, unique soil and rock characteristics and disturbance by buffalo in producing the barrens.

Gleason (1923) wrote that there were 2 episodes of prairie expansion. The fires came with the beginning of the Xerothermic Period about 7,000 years ago. The second came with the increased use of burning by the Indians to facilitate their hunting. He considered the barrens to be a stage of forest degeneration brought about by fires set by Indians, but did not seem to believe the barrens to be prairies.

Braun (1972) considered the barrens to be prairies but offered no explanation about their origin. She did not believe the barrens to be products of the Xerothermic Period, citing the presence of endemic species in the barrens of the Nashville Basin, and the presence of southeastern species in the Kentucky barrens. She also did not feel that prairie vegetation had been dominant for very long in these areas, citing the rapid reforestation of the barrens after settlement. Braun did point out that extensive "cedar barrens", a red cedar-prairie community type, occupy the escarpment above the Pennyroyal Plain. Hutchison (1980), in a recent survey of Harrison County barrens and glades for the Indiana Department of Natural Resources, found no barrens but did find a number of potentially significant glades with prairie plants and red cedars on the slopes of the Chester and Knobstone Escarpments. These sites have persisted despite the disappearance of the barrens from the Mitchell Plain.

Salts Cave, located 9 km northwest of the Pennyroyal Plain in Mammoth Cave National Park, Kentucky, has been the site of a number of archaeological studies. King (1974) states that slippers worn by prehistoric Indians living in or near Salts Cave were woven of *Eryngium yuccifolium* fiber. The heavy use of this fiber, 1 of many available to the Indians, suggests that this prairie plant was once common. Radiocarbon dates of other Salts Cave material range from A.D. 30 to 1540 B.C. (Watson 1974). The author uses 3 independent lines of evidence from dated Salts Cave excavations to suggest that there was a major shift from an oak-hickory climax forest to an open oak-hickory woodland during the second and first millenia B.C.:

1) Shifts in pollen spectra taken from a Salts Cave test pit which suggest a shift from an oak-hickory climax forest to a general opening of the forest canopy (Schoenwetter 1974).
2) Seeds from the same test pit show large increases in those from plants growing in open or disturbed ground (Yarnell 1974).
3) The ordering of vertebrate bones collected from cave sediments suggests a shift in abundance from woodland animals to those animals inhabiting more open ground (Duffield 1974).

Dr. Patrick Munson of the Glenn A. Black Laboratory for Archaeology at Indiana Univercity, Bloomington, Indiana, states that concentrations of Clovis Points (8,500-9,500 B.C.) occur widely north of the Wisconsin glacial boundary, especially on the western plains. The Clovis people were apparently hunters of plains and open land. Other concentrations of points occur in specific areas south of the glacial boundary. These areas include the Mitchell Plain, the Pennyroyal Plain, the Nashville Basin and Posey and Gibson Counties, Indiana. All of these areas were known to have had prairies, barrens, or otherwise open land. The pattern and ages of the point concentrations suggest that the barrens areas were open land 10-12,000 years ago.

The barrens areas of Kentucky and Indiana may have undergone more than 1 transition (forest-prairie-forest) over the past several thousand years. A transition from forest to prairie about 3-4,000 years ago is suggested by Watson's (1974) central Kentucky data. However, Munson's unpublished data suggest the barrens areas were open prior to that time. Others including Gleason (1923) believe the warm dry climate of the Xerothermic Period allowed the spread of prairie vegetation 7,000 years ago.

Barrens may have formed as a result of extended drought which, along with frequent fires, could have decimated the trees and prepared the way for the invasion of prairie plants from the many glades which persist in the nearby uplands today (Braun 1972, Bryant 1977, Hutchison 1980), and perhaps existed before the barrens were established (Baskin et al. 1978). Amelioration of the climate might later cause barrens areas, or barrens might disappear altogether. As long as the glades persisted on the dry rocky slopes of the uplands, a species pool of prairie plants would remain for later recolonization when conditions permit.

Acknowledgements

The author would like to thank Mr. John Bacone for his assistance in the preparation and presentation of this paper, Dr. Richard L. Powell for providing information on the geology of Harrison and Washington Counties and Dr. Patrick Munson for his assistance with archaeological data and information.

Literature Cited

Bacone, J.A., R.K. Campbell and G. Welhelm. 1980. Presettlement vegetation of the Indiana Dunes National Lakeshore (in press). Proc. Sec. Ann. Symp. on Scientific Research in National Parks. Nat. Park Service, Wash., D.C.

Basken, J.M. and C.C. Basken. 1978. Plant ecology of cedar glades in the Big Barren region of Kentucky (ms. in press). Rhodora.

Blewett, M.B. and J.L. Potzger. 1950. The forest primeval of Marion and Johnson Counties, Indiana, in 1819. Butler Univ. Pot. Stud. 10:40-52.

Braun, E. L. 1972. Deciduous Forests of North America. Hafner Publishing Company, New York. (facsimile of the 1950 Ed.).

Bryant, W.S. 1977. The Big Clifty Prairie, a remnant outlier of the prairie peninsula, Grayson County, Kentucky. Trans. Ky. Acad. Sci. 38:21-25.

Collett, J. 1879. Geological report on Harrison County, Indiana. Ind. Dept. Geol. and Nat. Res., Ann. Reports 8-10 and 292-423.

Crankshaw, W. B., S.A. Qadir and A.A. Lindsey. 1965. Edaphic controls of tree species in presettlement Indiana. Ecology 46:688-698.

Dicken, S. 1935. The Kentucky barrens. Bull. Geogr. Soc. Phila. 33:42-51.

Duffield, L. F. 1974. Nonhuman vertebrate remains from Salts Cave vestibule. In P.J. Watson, ed., pp. 123-124, Archaeology of the Mammoth Cave Area. Academic Press, New York.

Finley, D. and J.E. Potzger. 1952. Characteristics of the original vegetation in some prairie counties of Indiana. Butler Univ. Bot. Studies 10:114-118.

Garmon, H. 1925. The vegetation of the barrens. Trans. Ky. Acad. Sci. 2:107-111.

Gleason, H.A. 1923. Vegetational history of the Middle West. Ann. Assoc. Amer. Geogr. 12:39-85.

Gordon, R.B. 1936. A preliminary vegetation map of Indiana. Am. Midl. Nat. 17:866-877.

Hutchinson, M.C. 1980. A survey to locate and evaluate limestone glades in Harrison County, Indiana (unpublished). Indiana Dept. Nat. Res., Div. Nature Preserves, Indianapolis.

King, M.E. 1974. The Salts Cave textiles: a preliminary account. In P.J. Watson, ed., pp 31-40, Archaeology of the Mammoth Cave Area. Academic Press, New York.

Malott, C.A. 1922. The physiography of Indiana. In Handbook of Indiana Geology. Ind. Dept. Conservation Pub. 21, pt. 2:59-256.

McInteer, B.B. 1942. The barrens of Kentucky. Trans. Ky. Acad. Sci. 10:7-12.

__________. 1946. A change from grassland to forest vegetation in the "Big Barrens" of Kentucky. Am. Midl. Nat. 35:276-282.

Potzger, J.E. and M.E. Potzger. 1950. Composition of the forest primeval from Hendricks County southward to Lawrence County, Indiana. Proc. Indiana Acad. Sci. 60:109-113.

__________, M.E. Potzger and J. McCormick. 1956. The forest primeval of Indiana as recorded in the original U.S. land surveys and an evaluation of previous interpretations of Indiana vegetation. Butler Univ. Bot. Stud. 13:95-111.

Rohr, F.W. and J.E. Potzger. 1951. Forest and prairie in three northwestern Indiana counties. Butler Univ. Bot. Stud. 10:61-70.

Ross, M.I. 1950. *Pinus virginiana* in the forest primeval of five southern Indiana counties. Butler Univ. Bot. Stud. 10:80-89.

Soil Conservation Service. 1975. Soil survey of Harrison County, Indiana. U.S. Dept. Agri., Soil Conservation Serv., Wash. D.C. 78 pp.

Schoenwetter, J. 1975. Pollen analysis of sediments from Salts Cave vestibule. In P.J. Watson, ed., pp. 233-238, Archaeology of the Mammoth Cave Area. Academic Press, New York.

Transeau, E.N. 1935. The prairie peninsula. Ecology 16:423-437.

Watson, P.J. 1974. Prehistoric horticulturists. In P.J. Watson, ed., pp. 233-238, Archaeology of the Mammoth Cave Area. Academic Press, New York.

Yarnell, R.A. 1974. Plant food and cultivation of the Salts cavers. In P.J. Watson, ed., pp. 113-122, Archaeology of the Mammoth Cave Area. Academic Press, New York.

[illegible] years ago as suggested by Watson's (1974) central Kentucky data. However, [illegible] unpublished data suggest the barrens areas were open prior to that time. Others including Gleason (1923) believe the warm dry climate of the Xerothermic Period allowed the advance of prairie vegetation 7,000 years ago.

Barrens may have formed as a result of extended drought which, along with [illegible] could have decimated the [illegible] paved the way for the invasion of prairie plants from the many glades which persist in the nearby uplands today (Braun 1972, Bryant 1977, Hutchison 1980). [illegible] (Baskin and Baskin 1978) [illegible] areas, or barrens [illegible]. As long as the glades persisted on the dry rocky slopes of the uplands, a species pool of prairie plants would remain for later recolonization when conditions permit.

Acknowledgements

The author would like to thank Mr. John Bacone for his assistance in the preparation and presentation of this paper, Dr. Richard L. Powell for providing information on the geology of Harrison and Washington Counties and Dr. Patrick Munson for his assistance with archaeological data and information.

Literature Cited

Bacone, J.A., R.K. Campbell and G. Wilhelm. 1980. Presettlement vegetation of the Indiana Dunes National Lakeshore (in press). Proc. Sec. Ann. Symp. on Scientific Research in National Parks. Nat. Park Service, Wash., D.C.

Baskin, J.M. and C.C. Baskin. 1978. Plant ecology of cedar glades in the Big Barren region of Kentucky (ms. in press). Rhodora.

Blewett, M.B. and J.L. Potzger. 1950. The forest primeval of Marion and Johnson Counties, Indiana, in 1819. Butler Univ. Bot. Stud. 10:40-52.

Braun, E. L. 1972. Deciduous Forests of North America. Hafner Publishing Company, New York. (facsimile of the 1950 Ed.).

Bryant, W.S. 1977. The Big Clifty Prairie, a remnant outlier of the prairie peninsula, Grayson County, Kentucky. Trans. Ky. Acad. Sci. 38:21-25.

[illegible] Geol. Survey, Indiana [illegible] Res., Ann. Reports [illegible]

Cronkshaw, W. B., S.A. Qadir and A.A. Lindsey. 1965. [illegible]

Dicken, S. 1935. The Kentucky barrens. Bull. Geogr. Soc. Phila. 33:42-51.

Duffield, L. [illegible] Nonhuman vertebrate remains from Salts Cave vestibule. In P.J. Watson, ed., pp. 123-134, Archaeology of the Mammoth Cave Area. Academic Press, New York.

Finley, R. and J.E. Potzger. 1952. Characteristics of the original vegetation in some prairie counties of Indiana. Butler Univ. Bot. Studies 10:114-118.

Garman, H. 1925. The vegetation of the barrens. Trans. Ky. Acad. Sci. 2:107-111.

Gleason, H.A. 1923. Vegetational history of the Middle West. Ann. Assoc. Amer. Geogr. 12:39-85.

Gordon, R.B. 1936. A preliminary vegetation map of Indiana. Am. Midl. Nat. 17:866-877.

Hutchinson, M.C. 1980. A survey to locate and evaluate limestone glades in Harrison County, Indiana (unpublished). Indiana Dept. Nat. Res. Div. Nature Preserves, Indianapolis.

King, M.E. 1974. The Salts Cave textiles: a preliminary account. In P.J. Watson, ed., pp 31-40, Archaeology of the Mammoth Cave Area. Academic Press, New York.

Malott, C.A. 1922. The physiography of Indiana. In Handbook of Indiana Geology. Ind. Dept. Conservation Pub. 21, pt. 2:59-256.

McInteer, B.B. 1942. The barrens of Kentucky. Trans. Ky. Acad. Sci. 10:7-12.

__________. 1946. A change from grassland to forest vegetation in the "Big Barrens" of Kentucky. Am. Midl. Nat. 35:276-282.

Potzger, J.E. and M.E. Potzger. 1950. Composition of the forest primeval from Hendricks County southward to Lawrence County, Indiana. Proc. Indiana Acad. Sci. 60:109-113.

__________, M.E. Potzger and J. McCormick. 1956. The forest primeval of Indiana as record-

PRESETTLEMENT VEGETATION OF LAKE COUNTY, INDIANA

John A. Bacone
and
Ronald K. Campbell
Division of Nature Preserves
Indiana Department of Natural Resources
601 State Office Building
Indianapolis, Indiana 46204

Abstract. The original land survey records made during 1829-1834 were used to reconstruct the presettlement vegetation characteristics of Lake County, Indiana. From the survey records nine general community types have been recognized which are forest, savanna, prairie, wet prairie, marsh, swamp, dune complex, thicket and open water. The nature of the survey records not only permitted mapping of these general community types, but also enabled calculation of relative density, dominance and frequency in wooded communities, which provided a means to further characterize these areas. In addition extensive field studies throughout the county give further insight into the characteristics of those communities which were missed by the surveyors. A map showing the presettlement vegetation is presented. Prairie and savanna communities dominated the landscape. Less than 3% of Lake County was originally covered by forests.

Introduction

Lake County is located in extreme northwest Indiana. Bounded by Lake Michigan on the north and Illinois on the west, it is within the "Prairie Peninsula" of Transeau (1935). The complex of post-glacial processes, plant migration, climatic changes, soil and topography diversity, prevailing winds, periodic fires, and lake influences have resulted in a complex of plant communities in Lake County, especially near Lake Michigan.

In this paper, we will present the presettlement communities in floristic and geographic terms, as perceived by us and extrapolated from the original land surveys. Intensive field work, including floristic studies and natural areas inventories, allow for further refinement of some of the communities. The various communities will be discussed in terms of their natural integrity today, including the degree of change since presettlement times.

General Description

The diverse physiography of Lake County (Fig. 1) includes dune and swale topography in the north-central portion and the high dune country in the northeast. These are part of the Calumet Lacustrine Plain, or Lake Plain. The Valparaiso Moraine occupies the center of the county, and the Kankakee Basin in the southern part. Several large lakes occurred in the county, including Cedar Lake on the Valparaiso Moraine and Wolf Lake in the northwest.

The soils in Lake County are closely associated with its physiography. Sandy soils occur in the Kankakee Basin, to the south of the Valparaiso Moraine, and again to the north of the Moraine in the Lake Plain. Silt loam soils are found on the Valparaiso Moraine (Persinger 1972).

Methods

The original land survey notes and plat maps from the Government Land Office surveys are very useful in mapping the vegetation of an area prior to settlement. They may be used to identify major presettlement plant communities, to determine species composition and distribution within these communities, and to relate the occurrence and distribution of these communities to the environmental and edaphic factors which influenced their creation and maintenance. Such information is also valuable as base data when inventorying a region for natural areas. It also allows for the comparison of presettlement types with types present today, and to show the degree to which the landscape has been modified since settlement. Bourdo (1956) has discussed the methods used by the original surveyors, and the implications they have for vegetational analysis.

These surveys have been used to map presettlement vegetation in the Midwest (Anderson 1970, Kenoyer 1930, Kilburn 1955, Tans 1976). Such studies have also been undertaken in Indiana on a state-wide basis by Lindsey et al. (1965) and Potzger et. al. (1956), and in northwest Indiana by Findley and Potzger 1952, Meyer 1952, Rohr and Potzger 1951, Welch 1929. These Indiana studies mapped the vegetation at a relatively low resolution.

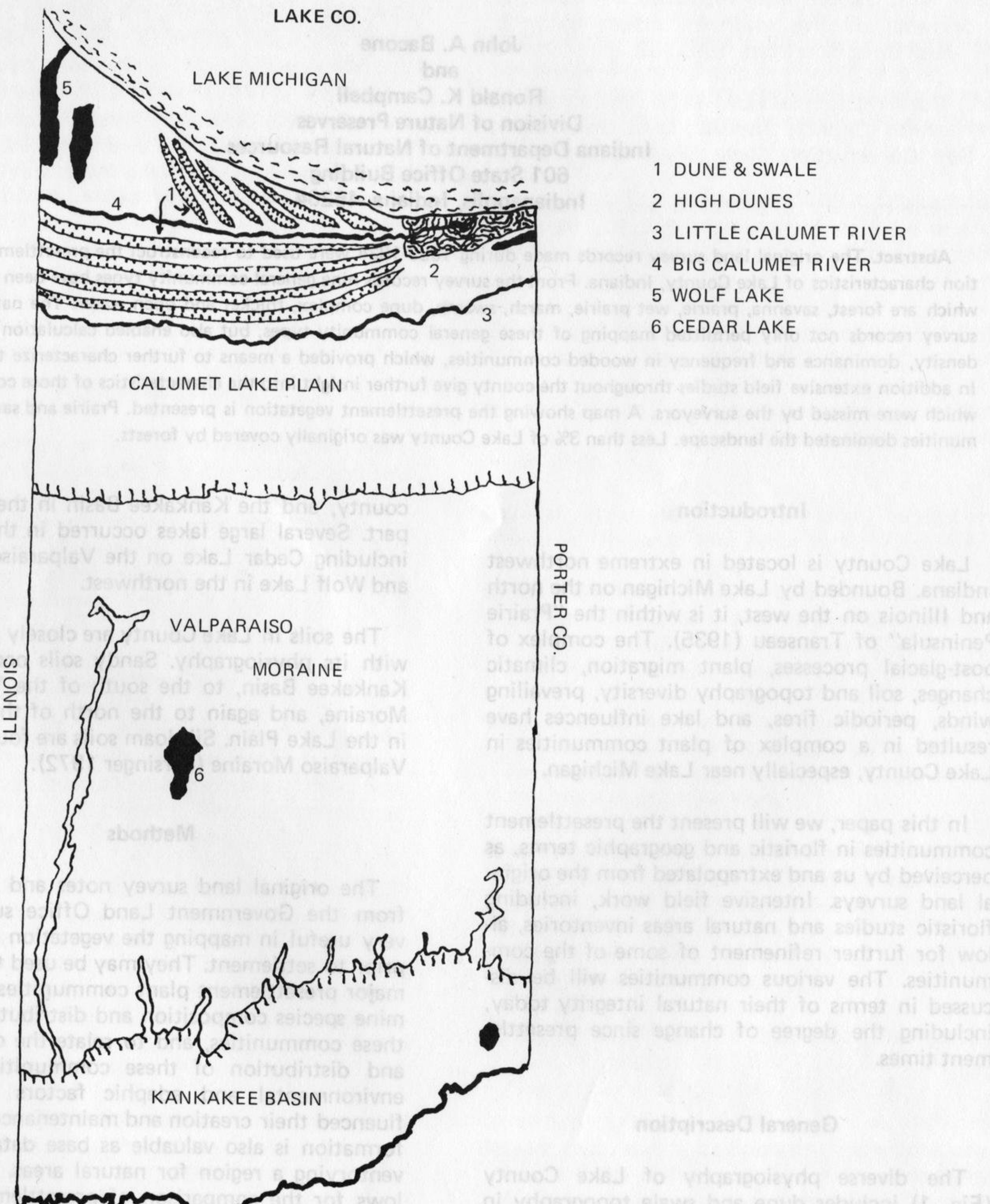


Fig. 1. General physiography of Lake County, Indiana.

The original land survey was conducted in Lake County from 1829 to 1835. The field notes, plat maps, and summary sheets were examined in the Archives Room of the State Library in Indianapolis. The information was transferred to a base map of the region. In consultation with soil maps and U.S.G.S. topographic maps, a general map of community types was drawn for the County (Fig. 2). Since more information was available on timbered tracts of land, these areas were examined in detail. Timbered land was classified into 3 main types: upland forest, savanna, and swamp. Floodplain, or bottomland forest, was only found along rivers in narrow bands, and was not mapped separately, but rather as a part of the community in which it was found. This was done by using 3 criteria: 1) the distance from the corner post to each witness tree, 2) the species of each witness tree, and 3) the surveyor's written description of the vegetation encountered on each section line. Savanna can theoretically be delineated from forest by considering the absolute density, calculated from the mean distance between the witness trees. This is discussed in detail by Cottam and Curtis (1956) and Tans (1976) among others. In practice, absolute density determined at each corner post cannot be used to determine if a given point is a savanna or not, but when considering all 3 criteria listed above, savannas were easily delineated in this region. Once these communities were mapped, the average absolute density corresponded well with the expected values as reported in the above studies. Wetland and upland forest types were determined and mapped based upon the types of tree species and the surveyor's comments.

The general community types mapped in Fig. 2 include dune complex, savanna, forest, wet prairie, marsh, swamp, thickets, open water and prairie. Savanna and forest community types were further characterized. Continuous areas were selected, and relative frequency, relative density, relative dominance and the importance value index were determined for several forest, savanna and dune complex tracts. This enabled not only a determination of dominant species, but allowed for examination of geographic trends as well.

Floristic studies, including Hill (1899), Peattie (1930), Pepoon (1927), Swink (1974) and Swink and Wilheim (1979) have contributed towards our understanding of presettlement communities as well. Documentation of associates, found on herbarium labels, aids in assessing habitat, and also provides insight into species composition of plant communities. The rare plant study of the Indiana Dunes National Lakeshore (Wilhelm 1980) resulted in information important in mapping presettlement communities for that region, which aided in assessing alteration from presettlement conditions, and compiling "typical species" lists for many of the plant communities located (Bacone et.al. 1980).

During the spring-fall of 1978, the Lake Michigan Watershed, including the north half of Lake County, was systematically inventoried to locate all remaining natural land (State Planning Services Agency 1978). Following this, Kurz (1979) inventoried the remainder of Lake County. During the studies, all remaining open land was systematically examined and evaluated, using current aerial photographs and U.S. Geological Survey topographic maps. The studies located 33 natural areas, and for these the plant communities were mapped and species lists compiled. Since the original surveyors listed mainly trees in forested communities and few species in the other communities, these recently located natural areas permit educated assumptions to be made as to the floristic composition of presettlement communities. Several communities not mentioned by the original surveyors were also located during these studies.

Results

Intensive natural habitat destruction and alteration, an advent of an aggressive and pre-emptory alien flora, and the suppression of fire during the postsettlement period, have combined to profoundly obfuscate the nature of local plant communities as manifest prior to European settlement. Recent attempts to locate and evaluate areas which preserve the presettlement vegetation have focused attention on the fact that most contemporary plant communities do not reflect presettlement conditions. Natural area surveys, interpretation of the original land survey notes, and years of field study, however, have provided insights into the floristic nature of presettlement communities.

Aside from the decidedly unique floristic complex of the immediate dune area, Lake County, Indiana apparently provided conditions for 2 principal, but intergrading floristic manifestations: land upon which tree species prevailed as conspicuous features, and land which, for one reason or another, remained hostile to the successful habitation by trees. The areas characterized by trees included such general community types as forest, swamp, thicket, and savanna - the latter intergrading into the treeless tracts. The treeless general community types included numberous communities, the most general of which were the marshes and wet to dry prairies.

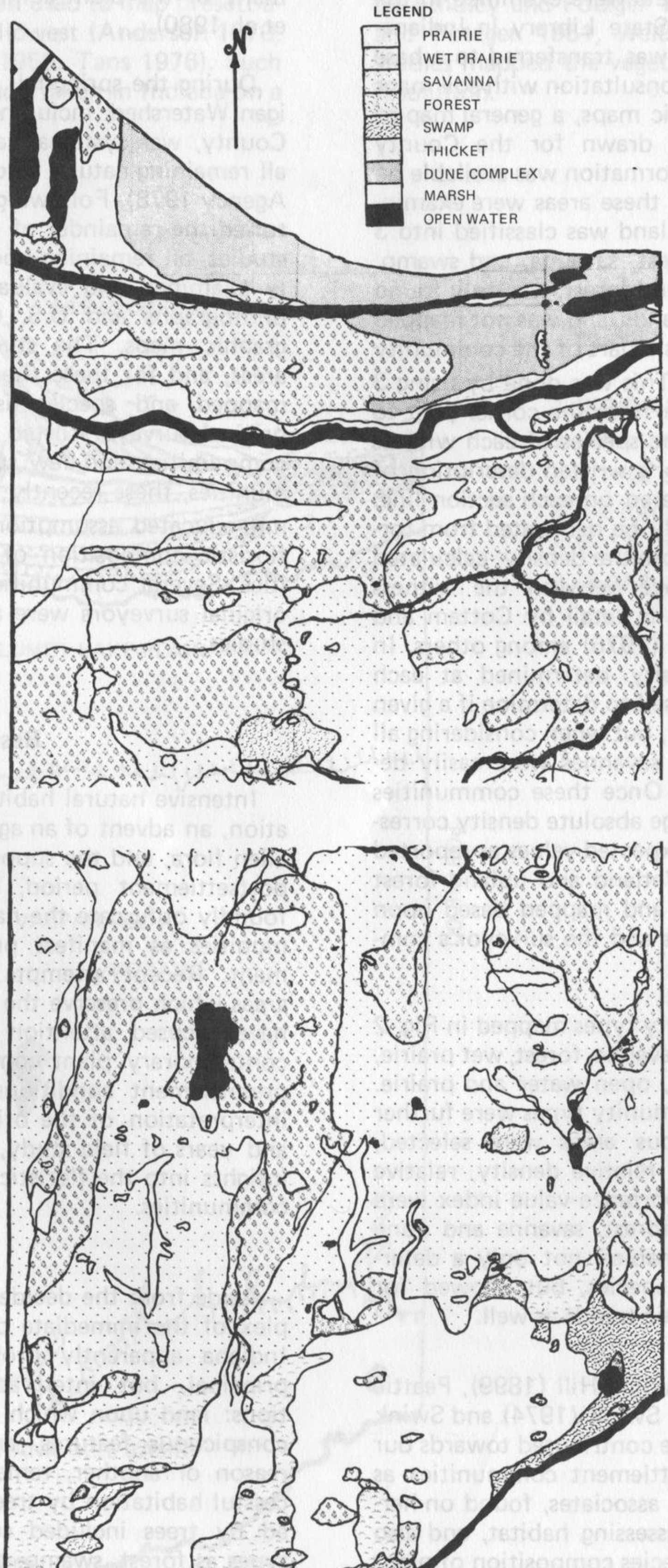


Fig. 2. The general community types of Lake County, Indiana.

Fig. 2 shows the distribution of the general community types as manifest at the time of original land surveys. These types are dune complex, savanna, forest, wet prairie, marsh, swamp, thicket, open water, and prairie. Within each general community type, several specific kinds of plant communities, are discussed below, and are classified according to the principal vegetation (treelless or wooded) to which each belongs (Table 1). With the exceptions of several types of savannas, the specific plant communities are still present today, although high quality examples of some of these communities no longer exist.

Dune Complex. The dune complex is a narrow band of communities including several open water habitats, marsh, shrub carr, wet prairie, sand prairie, savannas (black oak, black oak-pine), as well as the communities of the immediate dune area. Along with the "high dune country" in extreme northeastern Lake County, the dune complex also includes a unique topographic formation known as "ridge and swale" - a complex of linear and parallel east-to-west sand ridges interspersed with long ponds and marshes - found only in the extreme north-central part of the county. The most widespread community within the dune complex was the savanna.

Some of the descriptions used by the surveyors to describe the terrain of the dune complex include: "pine-swamp", "Oak and pine barrens", "Shrubby yellow and jack oak barrens", "dwarfish pine", and "Shrubby yellow and jack oak with pine and marshes". These plant communities, including small patches of dry sand prairie, are mapped together in the dune complex because a greater resolution would be required to map them individually. In general, the presence of conifers was used to delimit the southern boundary of the Dune Complex, thus separating it from several tracts of similar complexity immediately south of this area.

Pine is one of the most important trees in much of the complex, with black oak (*Quercus velutina* -noted by the surveyors as yellow oak) and aspen (*Populus tremuloides*) next in importance. It should be noted that for the most part the aspen was restricted to the immediate Lake Michigan vicinity, and was not important on the higher sand (hence not a component of the savanna). The pines throughout this complex are both white pine (*Pinus strobus*) and jack pine (*P. banksiana*), and both occur in wet situations as well as on dunes. White cedar (*Thuja occidentalis*) was important in the swamps, especially in the ridge and swale region. White cedar is not found in Lake County today. Sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), hickory (*Carya* spp.), and bur oak (*Quercus macrocarpa*) were not recorded here.

Immediate Dune Area. The immediate dune area is a narrow band along the windward face of the first line of dune's of the dune complex. Except for occasional tangential references, the communities of the immediate dune area were not mentioned by the surveyors. It includes:

1) The Beach community, restricted to a narrow, specialized strip adjacent to the littoral zone of the lakeshore. The beaches in presettlement times ran the entire length of Lake County's border with Lake Michigan, interrupted only occasionally by the mouths of creeks and streams. The species characteristic to this community include *Ammophila breviligulata, Cakile edentula lacustris, Corispermum hyssopifolium,* and *Euphorbia polygonifolia.*

2) The Foredune community occupies the windward exposure of the first line of dunes next to Lake Michigan. Its size and floristic development are a function, in part, of the degree to which the dune as a land form is developed. Dunes become generally larger as one moves from west to east. Characteristic species of the foredunes include *Andropogon scoparius, Arctostaphylos uva-ursi coactilis, Calamovilfa longifolia, Cirsium pitcheri, Pinus banksiana, Prunus pumila, Phus aromatica,* and *Solidago racemosa gilmani.*

3) The Panne typically is a moist, interdunal depression in calcareous sands on the leesides of dunes near Lake Michigan. A rather unique flora, fen-like in composition, is characteristic of this community. Currently, the pannes are restricted to the high dune county in northeastern Lake County, and a western variant of this community still exists in the ridge and swale region of northwest Lake County. Their usually small, superficially non-descript nature is such that no special reference to them was made by the original land surveyors; however, the fact that they contain a rich assortment of rare native species, as well as a few found in no other community in Indiana, testifies to their presettlement origin. Species characteristic of all the pannes include *Aster ptarmicoides, Cares aurea, C. garberi, C. viridula, Cladium mariscoides, Hypericum kalmianum, Lobelia kalmii, Sabatia angularis,* and *Triglochin maritima.* The eastern pannes are further characterized by *Rhynchospora capillacea* and *Utricularia cornuta;* the western pannes by *Bromus kalmii, Parnassia glauca, Satureja arkansasa,* and formerly by *Thuja occidentalis,* as evidenced by the survey notes and the stumps present today. Other communities of the Dune Complex are included under the appropriate general community type (Table 1).

Savanna. Savannas (the "barrens" of the surveyors) are open-wooded communities with a prairie ground cover. The openness of such communities was maintained at least in part by fire.

Savanna (excluding those of the dune complex) are found throughout Lake County. Almost all of the timbered land in Lake County was savanna during presettlement times.

The surveyors described these savannas with the following terms: "sandy barrens", "rolling, with oak", "white and yellow oak barrens", and "level, wet oak barrens" These "barrens" are generally very low in woody species diversity - primarily just black, white and bur oak, pine in the extreme north, and occasionally, hickory. They include:

1) Black oak savannas are found on sandy soil, chiefly in the northern part of Lake County, just south of the dune complex. White oak is the second-most important tree species, and the ground cover is composed primarily of dry sand prairie species. High quality examples of this community still are extant in the county.

2) The black oak-pine savannas are primarily restricted to the dune complex. Both jack and white pine are important associates, and white oak increases in importance to the south and east. The pines drop rapidly in importance as distance from Lake Michigan increases, until in the southern portion of the dune complex, the savanna is transitional to a pure black oak savanna.

3) Bur oak - black oak savannas were found only on the silt loam soils of the Valparaiso Moraine. White oak was the nex most important species, and hickory was important here as well. No other tree species were recorded for this savanna type. Due to a combination of factors including grazing, clearing for agriculture, and fire suppression, no intact examples remain today, although large groves of open-grown bur oaks (*Quercus macrocarpa*) can still be seen.

4) White oak - bur oak savannas also occurred on the silt loam soils of the Valparaiso Moraine. These are a variant of the bur oak - black oak savannas, occurring further to the south. Hickory is the next most important associate, followed by black oak. Red oak was occasionally noted here by the surveyors. No intact examples of this type are known today, for the same reasons noted for the bur oak - black oak savannas.

5) The oak - hickory savannas were found primarily in the southeastern portion of the County, on the south edge of the Valparaiso Moraine. The principal overstory species include black oak, bur oak and several species of hickory. They appear to have been a dry-mestic upland phase of the more mesophytic forests to the east, in Porter County. No known intact high quality examples can be found. This community occurred on both sandy and silty soils, and white oak was an important associate as well.

Several of these savanna communities, in which bur oak was very important, were delineated only from the original land survey data analysis. Since no examples can be found today, it is possible that they are variants of one general type.

Forest. Forests are upland or terrace communities which are heavily wooded. They normally have an understory with several woody strata underlain by an herbaceous ground cover. Fires played little or no role in their creation and maintenance.

The upland forests, primarily described by the surveyors as "thick timber", occurred only in a few relatively small patches in Lake County. In fact, except for the "forest" in central Lake County, true forest was found only in a few scattered areas. These areas of "thick timber" were, in some cases, composed of savanna species in which the trees were closer together than in other areas.

Floodplain forests are not mapped separately, because they usually were very narrow and did not separate out by using the surveyors' witness trees. In general, they were lumped with either upland forests or swamps.

Four forest communities have been recognized within Lake County:

1) Bottomland forests, characterized by annual deposition of silt during flooding, were found along some major water courses, including the Deep River. *Acer negundo, Acer saccharinum, Platanus occidentalis, Salix nigra, Ulmus american* and *U. rubra* are important canopy species. Small scattered examples still occur today, although most have been heavily disturbed.

2) Leeside dune forests are found on the leeside of foredunes, and on the leeside of higher dunes further south of Lake Michigan. It is possible that they hand closer affinities to savanna conditions in presettlement times, but they have taken on a more mesophytic character today. A few examples remain within Lake County, in the northeast. Characteristic overstory species include *Acer rubrum, Cornus florida, Hamamelis virginiana,* and *Quercus rubra.*

3) White oak forests occupied relatively small areas in extreme eastern Lake County. They were surrounded by and probably related to savanna and prairie community types. This community was delineated based upon surveyors' comments and species lists, and no high quality examples exist today. Important associates were black oak and sugar maple. This white oak forest is the western most location for both beech and sugar maple. Fire may have been the operative force limiting the westward distribution of both of these species.

4) Bur oak - white oak - black oak forest occurred in one spot in Lake County, on the north edge of the Valparaiso Moraine. This forest, referred to as "thick timbered" by the surveyors, is mapped as forest based on tree density (greater than 17.4 trees per acre) and the surveyor's comments. The species composition was exactly the same as the bur oak - black oak savanna immediately to the west. This tract may be more appropriately described as thick savanna.

Table 1. General vegetation types and specific plant communities of Lake County

General Community Type	Treeless Communities	Wooded Communities
Dune Complex[1]		
Immediate Dune Area	Beach Foredune Panne	Foredune Panne
Savanna		Black Oak (*)White oak-Bur oak (*)Bur oak-Black oak (*)Oak-Hickory Black Oak-Pine
Thicket		(*)Hazel (*)Aspen-Willow (*)Alder
Forest		(*)Bottomland Leeside Dune (*)White Oak (*)Bur oak-White oak-Black oak
Marsh	Aquatic Marsh Shrub Carr Wet Prairie	
Swamp		Alder White Cedar White and Jack Pine (*)Green Ash
Prairie	Sand Prairie (*)Silt Loam Prairie	

[1]/includes all communities except those prefixed by (*).

Wet Prairie. Wet prairie, as recognized by the surveyors, was found bordering the marshes along the Little Calumet River, in low areas and stream bottoms, and in the floodplain of the Kankakee River. It was referred to as "prairie bottoms or wet prairie", or "marsh or prairie". The only reference to specific taxa here was "marsh grass", "swamp grass", or "water grass". Because of the conceptual difficulties in distinguishing between wet prairie and marsh, we are lumping wet prairie under the marsh general community type.

Marsh. The marsh, as recognized by the surveyors, occurred along rivers, between dunes in and near the dune complex, in the Kankakee Basin, and in low spots on the Valparaiso Moraine. The surveyors described it as "marshy pond", "fine grass", "sand ridges and marshland", "marsh swamp", and "marsh or prairie". They noted the following species here: "wild rice", "cane", "bullrushes", "flag", "burgrass", "swamp grass", "watergrass", and "cranberry". Of interest is the fact that they never mentioned cattail, although it was noted during the original land survey in a nearby Illinois county (Moran 1978) and is obvious during much of the year, even winter.

"Shaky marsh" was occasionally mentioned by surveyors, but was not mapped due to its small size and the fact that no boundaries were discernable. These must have been floating sedge or peat mats, which today would translate into certain types of bogs or fens. The marsh community type includes all of the open (nonforested) wetland communities, including those on the drier end of the moisture gradient which were kept open by fires. The communities included here are:

1) Aquatic communities are open bodies of water (rivers, ponds, lakes) within which vascular plants, either submergent or emergent, occur. At its peripheries, it intergrades with marshland. These communities are found throughout Lake County, where suitable habitat occurs. They are best developed at Wolf Lake. Typical species include *Polygonum* spp., *Nuphar advena,* and *Nyphaea tuberosa.* Pollution, siltation, and drainage have resulted in a decrease in the abundance and quality of these communities.

2) Marshes are plant communites in which the substrate is inundated for all or nearly all of the growing season. It sometimes intergrades with the aquatic community on the wet end of the moisture gradient and with wet prairie on the drier end. It also intergrades with pannes in the ridge and swale region of northwest Lake County. Elsewhere the marsh can be more easily recognized, characterized by *Aster puniceus firmus, Bidens coronata tenuiloba, Carex aquatilis altior, Decodon verticillata, Polygonum punctatum,* and *Scirpus acutus.* Within Lake County today, most marshes have been heavily disturbed. Several extensive marshes still occur, especially near the Calumet Rivers and Cedar Lake, but these show signs of past disturbance.

3) A shrub carr is a wetland communith which manifests itself at the edges of swamps or marshes, or in wetlands which have suffered traumatic and long term altering of the water table or fire suppression. Hence, this community is more common today than during presettlement times. The important shrubs include alder and willows (*Salix* spp.). Aspen was rarely mentioned by the surveyors except near the shore of Lake Michigan and the thicket in the south. Today, shrub carrs dominated by aspen and alder are found in many places in the county. In general, except for the typical zones of shrubb carr found in undisturbed natural areas, this community has increased at the expense of other wetland communities, including marsh and wet prairie. The resumption of natural, frequent fires helps to restore the balance between these communities, providing they are not too degraded.

4) Wet prairie is defined here as the conceptual intergrade between the marsh and the prairie. It covers a wide range of floristic components and is very diverse in form. Since it intergrades, it is difficult to map. Examples of the wet prairie community are found in the swales in northern Lake County. A lowering watertable has decreased their original extent.

A typical list of species includes: *Aletris farinosa, Aster umbellatus, Calamagrostis canadensis, Carex lasiocarpa americana, Dryopteris thelypteris pubescens, Elecocharis melanocarpa, Osmunda cinamomea, O. regalis spectabilis, and Spartina pectinata.*

Swamps. Swamps are defined here as wooded wetlands where the water level is maintained near or at the surface of the substrate by ground water or rain, rather than by periodic flooding. Swamps were included within the dune complex in the north. Extensive swamps occurred along the Kankakee River in the south. The surveyors noted two types of swamp communities, coniferous swamps, and "timbered swamps". In the case of conifers, they specifically mentioned pine swamps, White cedar swamps also occurred, although not mentioned specifically. The several types include:

1) Coniferous swamps, both pine and white cedar, apparently only occurred in the dune complex. White cedar dominated in the dune and

swale region to the west, with jack pine as an associate. No native white cedars remain in Lake County today. Jack pine is still an important tree in swamps associated with the pannes of the dune complex in extreme northeast Lake County.

2) The timbered swamps noted by the surveyors are classified today as green ash (*Fraxinus pennsylvanica subintegerrima*) swamps. Important associates include cottonwood (*Populus deltoides*), sycamore, (*Platanus occidentalis*), black ash (*Fraxinus nigra*), silver maple (*Acer saccharinum*), and elm (*Ulmus* spp.). This type of swamp formerly covered large areas along the Kankakee River. Draining and logging have disturbed much of this community. The most extensive area remaining today is in the southwest.

3) Shrub swamps were sometimes noted, although except for alder (*Alnus rugosa americana*) and willow (*Salix* spp.), no other species were mentioned. These shrub swamps were relatively common but were not very extensive, usually occurring in a zone at the edge of a marsh or timbered swamp.

Thicket. Thickets are described as areas of small, shrubby timber which may be located on upland or lowland. Upland thickets were recorded in areas between prairie or wet prairie and other communities (usually marsh). The dominant species was hazel; cherry, crabapple and aspen were reported as associates. The surveyors used the terms "hazel brush" "hazel thicket" and "hazel ridge" to describe these areas. Lowland thickets were of two types. One area, dominated by alder, was a transitional zone between a lake and swamp forest, and another dominated by aspen and willow occurred as an island surrounded by wet prairie. All except one of the thickets recorded by the surveyors were in or at the edge of the Kankakee Lowlands. The remaining area was within 4 miles of this lowland.

Open Water. Open water was apparently more prominent on the landscape in presettlement times. At that time, the Grand Calumet and Little Calumet (referred to as the "River Styx") Rivers were one river, and were much wider and unchannelized. Several large lakes, including what are today called Cedar Lake and Wolf Lake, as well as smaller ponds and marshes, with their associated vegetation ("marshy ponds") were scattered throughout the County. Many of these are gone today or have been drastically altered. Aquatic communities associated with open water are treated under the marsh type in the section dealing with delineation of specific plant communities.

Prairie. Prairie is defined here as a treeless or nearly treeless tract of land, dominated by native grasses, sedges and forbs; land, whose synecological integrity is maintained by fire. "Dry prairie" as it was called by the surveyors, occurred on the silt loam soils of the Valparaiso Moraine. Sometimes it was referred to as "first-rate prairie", and the surveyors noted some forbs - "red root" (*Ceanothus ovatus*) and "rosin weed" (*Silphium terebinthinaceum*) along with the "prairie grasses". Dry sand prairie, usually a part of the sand savannas, could not be mapped separately based on the survey data. Prairie types include:

1) Sand prairies were for the most part not mappable because they intergrade with the savanna communities. Relatively large areas were known to have occurred because the surveyors sometimes walked several miles without mentioning a tree, but never delineated sand prairies from the "barrens". These prairies are basically the same as dry sand savannas without trees. Typical species include *Andropogon scoparius, Aster linariifolius, Koeleria cristata, Lithospermum croceum, Stipa spartea,* and *Tephrosia virginiana.* Sand prairies are well represented in northern Lake County, and periodic fires are necessary to keep them open.

2) Silt prairies were a common community in the center of Lake County. They occurred on the heavey silt loam soils on the Valparaiso Moraine. These soils have been converted to agriculture, and today, it is only possible to find silt prairies along railroad right-of-way and pioneer cemeteries. The only known high quality example is dominated by northern dropseed, *Sporobolus heterolepis.* Other typical species include: *Amorpha canescens, Andropogon gerardi, Dodecatheon meadia, Parthenium integrifolium, Silphium terebinthinaceum,* and *Solidago rigida.*

Discussion

Prairie and savanna dominated the landscape of presettlement Lake County. Savannas occupied approximately 31% of the land, and actually more, when combined with those of the dune complex which was chiefly savanna. The dune complex comprised 6% of the county. Dry prairie, like savanna, occupied 31% of Lake County, and marsh and wet prairie covered approximately 29%. The remaining 3% of land supported swamp forests, upland forests, thickets and open water. These statistics emphasize that Lake County was, in fact, a prairie county.

The communities that were once the most common are the rarest today. This is especially true in the case of the silt loam prairies, where only 1 acre has been located and preserved and in the case of those communities mentioned above (i.e., the bur oak savannas) where no outstanding examples exist today. The development of the land for agriculture, industry and other purposes, the suppression of fire which once played such an important role in the ecology of this region, and the drainage and filling of wetlands have left only a few small remnants of the original natural landscape. In light of these facts, it is hoped that the few remaining natural areas in the county may be spared and managed in such a manner as to preserve their presettlement characteristics.

Acknowledgements

The authors are grateful to Marlin Bowles, Donald Kurz, Donald McFall, and Thomas Post, natural area ecologists of the Natural Land Institute, and to Gerould S. Wilhelm of the Morton Arboretum, all of whom provided invaluable floristic and ecological information concerning Lake County. James Keith of the Indiana Division of Nature Preserves provided constant advice and encouragement. Special thanks are extended to Jerrie Leeds who typed the manuscript.

Literature Cited

Bacone, J. A., R. K. Campbell and G. Wilhelm. 1980. Presettlement vegetation of the Indiana Dunes National Lakeshore (in press). Proc. Second Ann. Symp. on Scientific Research in National Parks. Nat. Park Service, Wash., D.C.

Anderson, R. 1970. Prairies in the prairie state. Trans. Ill. State Acad. Sci. 63:214-21.

Bourdo, E. 1956. A review of the general land office survey and of its use in quantitative studies of former forests. Ecology 37:754-768.

Cottam, G., and J. Curtis. 1956. The use of distance measures in phytosociological sampling. Ecology 37:451-460.

Finley, D. and J. Potzger. 1952. Characteristics of the original vegetation in some prairie counties of Indiana. But. Univ. Bot. Stud. 10:114-118.

Hill, E. J. 1899. Notes on plants of the Chicago district. Bull. Torrey Bot. Club 26:303-311.

Kenoyer, L. A. 1930. Ecological notes on Kalamazoo County, Michigan, based on the original land survey. Mich. Acad. Sci. Arts and Letters 11:211-217.

Kilburn, P. 1959. The forest - prairie ecotone in northeastern Illinois. Am. Midl. Nat. 62:206-217.

Kurz, D. 1979. Inventory of natural areas in southern Lake County, Indiana. Natural Land Institute, Rockford, Illinois. 54pp.

Lindsey, A. A., W. B. Cranshaw, and S. A. Qadir. 1965. Soil relations and distribution map of the vegetation of presettlement Indiana. Bot. Gaz. 126:155-163.

Meyer, A. H. 1952. Fundamental vegetation of the Calumet Region, northwestern Indiana - northeastern Illinois. Papers Mich. Acad. Sci. Arts and Letters. 36:177-182.

Moran, R. C. 1978. Presettlement vegetation of Lake County, Illinois. Proc. Fifth Midwest Prairie Conf. pp. 12-19, D.C. Glenn-Lewin and R. Q. Landers, eds. Iowa State University, Ames.

Peattie, D. C. 1930. Flora of the Indiana Dunes. Field Mus. Natur. Hist., Chicago, Ill.

Persinger, I. D. 1972. Soil Survey of Lake -County, Indiana. Supt. Doc., U.S. Gov. Print. Off., Wash. D.C. 94p.

Pepoon, H. S. 1917. Flora of the Chicago region. Chicago Acad. Sci. Natur. Hist. Surv. Bull. 8:1-576.

Potzger, J., M. Potzger and J. McCormick. 1956. The forest primeval of Indiana as recorded in the original U.S. land surveys and an evaluation of previous interpretations of Indiana vegetation. But. Univ. Bot. Stud. 13:95-111.

Rohr, F. and J. Potzger. 1951. Forest and prairie in three northwestern Indiana counties. But. Univ. Bot. Stud. 10:61-70.

State Planning Services Agency. 1978. An inventory of natural areas in the Indiana coastal zone study area. Ind. State Plan. Serv. Agency Tech. Report 302. Indianapolis. 71pp.

Swink, F. 1974. Plants of the Chicago Region. 2nd Ed. The Morton Arboretum, Lisle, Ill.

Swink, F. and G. Wilhelm. 1979. Plants of the Chicago Region. 3rd Ed. The Morton Arboretum, Lisle, Ill.

Tans, W. 1976. The presettlement vegetation of Columbia County, Wisconsin in the 1830's. Wisc. Dept. Nat. Res. Tech. Bull. No. 90, Madison. 19pp.

Transeau, E. N. 1935. The prairie peninsula. Ecology 16:423-437.

Welch, W. 1929. Forest and prairie, Benton County, Indiana. Proc. Ind. Acad. Sci. 39:67-72.

Wilhelm, G. 1980. Special vegetation study of the Indiana Dunes National Lakeshore. Unpubl.

A SURVEY OF NATIVE PRAIRIE ON RAILROAD RIGHTS-OF-WAY IN MINNESOTA

John R. Borowske
Minnesota DNR
Scientific and Natural Areas
St. Paul, Minnesota 55155

and

Mark E. Heitlinger
The Nature Conservancy
328 E. Hennepin Ave.
Minneapolis, Minnesota 55414

Abstract. A survey was conducted from September 15 to November 3, 1978 to identify railroad right-of-way with native prairie vegetation. A total of 2,676 km (1,663 miles) of right-of-way was sampled at 1.6 km (1-mile intervals, and at each sampling point the right-of-way was characterized as Type A: high diversity native prairie, Type B: low diversity native prairie, or Type C: no native prairie present. The best-quality prairie, Type A, was observed at 360 sampling points, which is interpreted to mean that approximately 580 km (360 miles of Type A occurs on the surveyed right-of-way, 22% of the total surveyed. Sixteen prairie corridors with concentrations of high-quality prairie were identified. These range from 21 km to 174 km (13 to 108 miles) long, with a total length of 875 km (544 miles). It is recommended that steps be taken to avoid major destructive impacts, conduct additional biological surveys, and appropriately manage native prairie on railroad rights-of-way.

Introduction

Interest in Minnesota road and railroad rights-of-way has been stimulated by increased rail abandonment and the growing awareness that these are the only significant undeveloped areas in much of the prairie part of the state where cropland is most productive and costly (Figs. 1, 2, 3). The Minnesota State Planning Agency (1978) reported to the Legislature that railroad rights-of-way have high potential for recreation, wildlife management and other public uses. Roadsides as a natural resource in Minnesota was the subject of a recent symposium (Minnesota Departmnet of Transportation 1978) and a sizable body of literature is available on roadside-wildlife relationships (Federal Highway Administration 1975a, 1976b).

Among the midwestern states to recognize the value of native prairie on rights-of-way are Illinois, where the natural areas inventory project carefully searched for prairie remnants on rights-of-way (White 1978), and Michigan where Amtrak and the Nature Conservancy are cooperating to protect prairie areas on the rail line southwest of Kalamazoo. Papers on rights-of-way prairie research and preservation are cited by White (1978) and are the subject of a forthcoming review article by White.

Unlike most preserved natural areas which are isolated from each other, long stretches of nearly continuous native grassland on railroad rights-of-way allow for the natural processes of species and gene migration. Prairie preservation is best achieved where gene flow and vertebrate movements can occur along a prairie corridor (Reed and Schwarzmeier 1978). It might be possible to maintain transects of relatively natural vegetation across the entire east-west moisture gradients in the Great Plains, which would present an invaluable opportunity to study and monitor the dynamic relationship between tallgrass, midgrass, shortgrass, and western slope vegetation.

The purpose of this study was to locate and assess Minnesota railroad rights-of-way supporting native prairie vegetation. The survey was conducted on selected stretches of Burlington Northern rail lines and did not include many potentially interesting rights-of-way in southern Minnesota (Fig. 1). A detailed report including data collect-

[illegible] in the case of those communities mentioned above (i.e., the bur oak savanna) where no outstanding [illegible] [illegible] the suppression of fire which once played such an important role in the ecology of this region, and the drainage and filling of wetlands have left only a few small remnants of the original natural landscape. In light of these facts, it is hoped that the few remaining natural areas in the county may be spared and managed in such a manner as to preserve their presettlement characteristics.

Acknowledgements

The authors are grateful to Marlin Bowles, Donald Kurz, Donald McFall, and Thomas Post, natural area ecologists of the Natural Land Institute, and to Gerould S. Wilhelm of the Morton Arboretum, all of whom provided invaluable floristic and ecological information concerning Lake County. James Keith of the Indiana Division of Nature Preserves provided constant advice and encouragement. Special thanks are extended to Jerrie Leeds who typed the manuscript.

Literature Cited

Bacone, J. A., R. K. Campbell and G. Wilhelm. 1980. Presettlement vegetation of the Indiana Dunes National Lakeshore (in press). Proc. Second Ann. Symp. on Scientific Research in National Parks. Nat. Park Service, Wash., D.C.

Anderson, R. 1970. Prairies in the prairie state. Trans. Ill. State Acad. Sci. 63:214-21.

Bourdo, E. 1956. A review of the general land office survey and of its use in quantitative studies of former forests. Ecology 37:754-768.

Cottam, G., and J. Curtis. 1956. The use of distance measures in phytosociological sampling. Ecology 37:451-460.

Finley, D. and J. Potzger. 1952. Characteristics of the original vegetation in some prairie counties of Indiana. But. Univ. Bot. Stud. 10:114-118.

Hill, E. J. 1899. Notes on plants of the Chicago district. Bull. Torrey Bot. Club 26:303-311.

Kenoyer, L. A. 1930. Ecological notes on Kalamazoo County, Michigan, based on the original land survey. Mich. Acad. Sci. Arts and Letters 11:211-217.

Kilburn, P. 1959. The forest - prairie ecotone in [illegible] Illinois. Amer. Midl. Nat. 62:20[illegible]-217.

Kurz, D. 1979. Inventory of natural areas in [illegible] Natural Land Institute, Rockford, Illinois. 54pp.

Lindsey, A. A., W. B. Cranshaw, and S. A. Qadir. 1965. Soil relations and distribution map of the vegetation of presettlement Indiana. Bot. Gaz. 126:155-163.

Meyer, A. H. 1952. Fundamental vegetation of the Calumet Region, northwestern Indiana - northeastern Illinois. Papers Mich. Acad. Sci. Arts and Letters 36:177-182.

Moran, R. C. 1978. Presettlement vegetation of Lake County, Illinois. Proc. Fifth Midwest Prairie Conf. pp. 12-19, D.C. Glenn-Lewin and R. Q. Landers, eds. Iowa State University, Ames.

Peattie, D. C. 1930. Flora of the Indiana Dunes. Field Mus. Natur. Hist., Chicago, Ill.

Persinger, I. D. 1972. Soil Survey of Lake County, Indiana. Supt. Doc., U.S. Gov. Print. Off., Wash. D.C. 94p.

Pepoon, H. S. 1917. Flora of the Chicago region. Chicago Acad. Sci. Natur. Hist. Surv. Bull. 8:1-576.

Potzger, J., M. Potzger and J. McCormick. 1956. The forest primeval of Indiana as recorded in the original U.S. land surveys and an evaluation of previous interpretations of Indiana vegetation. But. Univ. Bot. Stud. 13:95-111.

Rohr, F. and J. Potzger. 1951. Forest and prairie in three northwestern Indiana counties. But. Univ. Bot. Stud. 10:61-70.

State Planning Services Agency. 1978. An inventory of natural areas in the Indiana coastal zone study area. Ind. State Plan. Serv. Agency Tech. Report 302. Indianapolis. 71pp.

Swink, F. 1974. Plants of the Chicago Region. 2nd Ed. The Morton Arboretum, Lisle, Ill.

Swink, F. and G. Wilhelm. 1979. Plants of the Chicago Region. 3rd Ed. The Morton Arboretum, Lisle, Ill.

Tans, W. 1976. The presettlement vegetation of Columbia County, Wisconsin in the 1830's. Wisc. Dept. Nat. Res. Tech. Bull. No. 90, Madison. 19pp.

A SURVEY OF NATIVE PRAIRIE ON RAILROAD RIGHTS-OF-WAY IN MINNESOTA

John R. Borowske
Minnesota DNR
Scientific and Natural Areas
St. Paul, Minnesota 55155

and

Mark E. Heitlinger
The Nature Conservancy
328 E. Hennepin Ave.
Minneapolis, Minnesota 55414

Abstract. A survey was conducted from September 15 to November 3, 1978 to identify railroad right-of-way with native prairie vegetation. A total of 2,676 km (1,663 miles) of right-of-way was sampled at 1.6 km (1-mile intervals, and at each sampling point the right-of-way was characterized as **Type A**: high diversity native prairie, **Type B**: low diversity native prairie, or **Type C**: no native prairie present. The best-quality prairie, Type A, was observed at 360 sampling points, which is interpreted to mean that approximately 580 km (360 miles of Type A occurs on the surveyed right-of-way, 22% of the total surveyed. Sixteen prairie corridors with concentrations of high-quality prairie were identified. These range from 21 km to 174 km (13 to 108 miles) long, with a total length of 875 km (544 miles). It is recommended that steps be taken to avoid major destructive impacts, conduct additional biological surveys, and appropriately manage native prairie on railroad rights-of-way.

Introduction

Interest in Minnesota road and railroad rights-of-way has been stimulated by increased rail abandonment and the growing awareness that these are the only significant undeveloped areas in much of the prairie part of the state where cropland is most productive and costly (Figs. 1, 2, 3). The Minnesota State Planning Agency (1978) reported to the Legislature that railroad rights-of-way have high potential for recreation, wildlife management and other public uses. Roadsides as a natural resource in Minnesota was the subject of a recent symposium (Minnesota Departmnet of Transportation 1978) and a sizable body of literature is available on roadside-wildlife relationships (Federal Highway Administration 1975a, 1975b).

Among the midwestern states to recognize the value of native prairie on rights-of-way are Illinois, where the natural areas inventory project carefully searched for prairie remnants on rights-of-way (White 1978), and Michigan where Amtrak and the Nature Conservancy are cooperating to protect prairie areas on the rail line southwest of Kalamazoo. Papers on rights-of-way prairie research and preservation are cited by White (1978) and are the subject of a forthcoming review article by White.

Unlike most preserved natural areas which are isolated from each other, long stretches of nearly continuous native grassland on railroad rights-of-way allow for the natural processes of species and gene migration. Prairie preservation is best achieved where gene flow and vertebrate movements can occur along a prairie corridor (Reed and Schwarzmeier 1978). It might be possible to maintain transects of relatively natural vegetation across the entire east-west mositure gradients in the Great Plains, which would present an invaluable opportunity to study and monitor the dynamic relationship between tallgrass, midgrass, shortgrass, and western slope vegetation.

The purpose of this study was to locate and assess Minnesota railroad rights-of-way supporting native prairie vegetation. The survey was conducted on selected stretches of Burlington Northern rail lines and did not include many potentially interesting rights-of-way in southern Minnesota (Fig. 1). A detailed report including data collected at each sampling point is on file with The Nature Conservancy.

It was not the purpose of this project to assess vegetation other than prairie. Significant prairie remnants may have been missed because of the use of a sampling technique. It should not be assumed, therefore, that all areas on the surveyed rights-of-way with biological or environmental significance have been discovered.

Methods

This survey was conducted in early fall when native prairie grasses cure to distinctive golden colors. Conducting the survey in the fall, however, meant that many native forbs were inconspicuous. If native grasses were observed at the sampling points, a careful search was made for native prairie forbs. A forb is defined here as a non-grasslike herbaceous plant. Native prairies are very diverse communities, usually with many more non-grass than grass species.

Field work was conducted between September 15 and November 3, 1978. The surveyor, John Borowske, drove on roads paralleling rights-of-way, stopping at 1-mile intervals for sampling. In long stretches of uniform disturbed grassland with no apparent prairie grasses, the interval between stops was extended to every second mile with the intermediate sampling point described as "no change."

At sampling points, the surveyor recorded data on the right-of-way vegetation either from the roadside or while walking a transect perpendicular to the tracks. The right-of-way was described from the roadside if no native prairie was observed and an accurate description could be made from that distance. Otherwise, the surveyor walked across the entire width of the right-of-way on a transect. Vegetation was sampled using a belt transect approximately 30 cm wide. If accurate description could be made from a distance, the observer simply visualized a strip 30 cm wide, traversing the right-of-way. If it was necessary to walk the transect, the observer walked down the center of the transect and recorded data in an estimated 30-cm wide belt.

In some cases fences, water, and private land made it difficult to reach the railroad right-of-way from the roadside. It the survey could accurately be made by binoculars, this was done. An attempt was made to use a trail motorcycle, but the rough surface of the rights-of-way prevented data collection for about 9% of the total number of miles that might have been included in this survey.

The percent cover of vegetation at sampling points was estimated for 4 categories: 1) native prairie, 2) disturbed grassland, 3) trees and shrubs, and 4) wetlands (Fig. 4). If the road and railroad rights-of-way were contiguous, the area examined was from the back slope of the road ditch to the far edge of the right-of-way as defined by a fence line or other obvious changes in land ownership or use. Data were recorded for only the railroad right-of-way if it was separate from the road right-of-way. The area taken up by unvegetated ballast was discounted in estimating percent cover. The following was recorded for each category:

1) **Native prairie**
- percent of the right-of-way covered by native prairie vegetation (grasses and forbs).
- the presence and relative abundance of the following prairie indicator grasses: big bluestem, little bluestem, Indian grass, prairie June grass, side-oats grama, and prairie cordgrass.
- the diversity of native prairie forbs along a transect (recorded as "high diversity" if 5 or more species, or "low diversity" if less than 5 species).

2) **Disturbed grassland**
- percent of the right-of-way covered by plants associated with disturbed soil conditions.
- the presence and relative abundance of the following common Eurasian species (characteristic of disturbed sites): smooth brome, quack grass, and bluegrass (*Poa* spp.).

3) **Trees and shrubs**
- percent of the right-of-way covered by trees and shrubs.
- whether the tree and shrub growth was sparse or dense.
- the presence of aspen, other hardwoods, coniferous trees, willow and other shrubs.

4) **Wetlands**
- percent of the right-of-way covered by wetlands.
- the presence of submerged vegetation, emergent vegetation (e.g., cattails), and wet meadows.

Information was also recorded on adjacent land use: crop or cultivated, pasture, wooded, highways or roads, and residential.

Each sampling point was also characterized, based on the presence and quality of native prairie vegetation, as Type A, B, or C:

1) **Type A (high diversity native plants)**

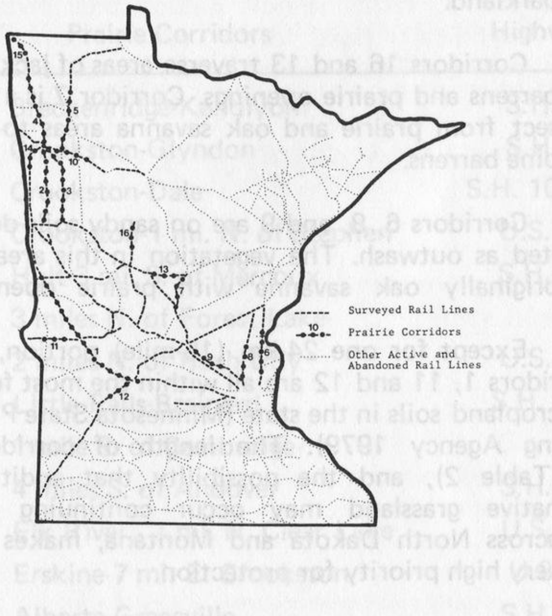


Fig. 1. Active and abandoned rail lines in Minnesota, excluding the Minneapolis-St. Paul area. Adapted from Minnesota State Planning Agency (1978) and Nielsen (1972). Also shown are rail lines surveyed in this study, and 16 prairie corridors recommended for protection.

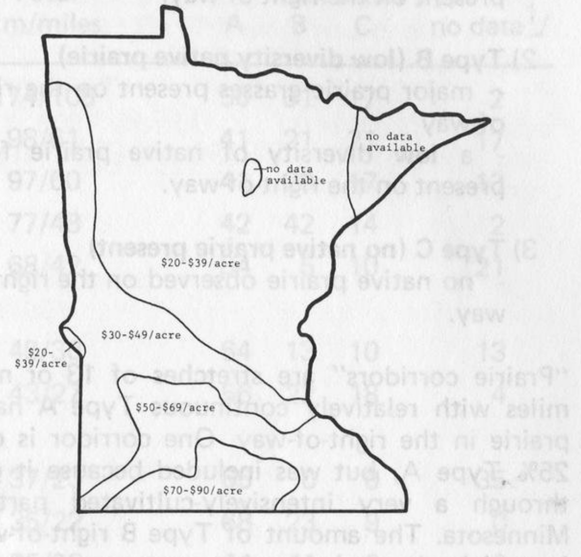


Fig. 2. Cash rent paid for tillable land as an indication of land value. Values are highest in the southern part of Minnesota, and higher in the prairie than forested areas. Adapted from Minnesota State Planning Agency (1979).

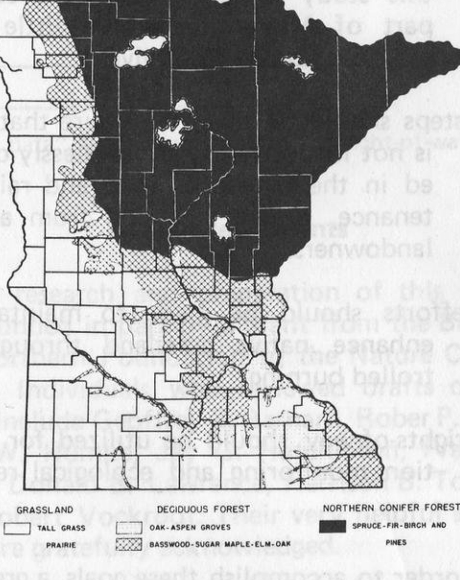


Fig. 3. Vegetation of Minnesota at the time of early white settlement. Adapted from Rosendahl and Butters (1928).

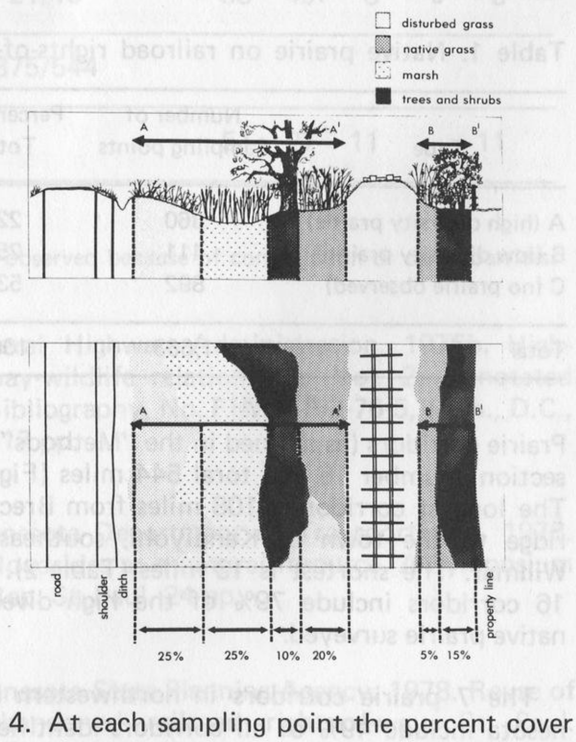


Fig. 4. At each sampling point the percent cover along a transect was estimated for disturbed grass, native grass, marsh, trees and shrubs. The road ditch and rail bed were excluded. The figure shows cross-sectional and aerial views. Vertical scale is exaggerated.

- major prairie grasses present on the right-of-way.
- a **high** diversity of native prairie forbs present on the right-of-way.

2) **Type B (low diversity native prairie)**
- major prairie grasses present on the right-of-way
- a **low** diversity of native prairie forbs present on the right-of-way.

3) **Type C (no native prairie present)**
- no native prairie observed on the right-of-way.

"Prairie corridors" are stretches of 13 or more miles with relatively continuous Type A native prairie in the right-of-way. One corridor is only 25% Type A, but was included because it goes through a very intensively-cultivated part of Minnesota. The amount of Type B right-of-way, in which the major prairie grasses were found but native forb diversity was low, was also considered in identifying prairie corridors.

Results and Discussion

The surveyor collected data at 1,663 sampling points spaced at 1.6-km (1-mile) intervals along railroad right-of-way (Table 1).

Table 1. Native prairie on railroad rights-of-way

Type	Number of Sampling points	Percent of Total
A (high diversity prairie)	360	22
B (low diversity prairie)	411	25
C (no prairie observed)	892	53
Total	1,663	100

Prairie corridors (as defined in the "Methods" section) number 16 and toral 544 miles (Fig. 1). The longest corridor is 108 miles from Breckenridge to the town of Kandiyohi, southeast of Willmar. The shortest is 13 miles (Table 2). The 16 corridors include 79% of the high diversity native prairie surveyed.

The 7 prairie corridors in northwestern Minnesota include 49% of all corridors identified in this survey. Corridors 2, 4, 14, and 15 are highly significant because they represent remnants of the level Lake Agassiz Lacustrine Plain (inside the beach ridges), an intensively farmed area in which there is only one known protected prairie preserve in Minnesota. The other corridors in this area are interesting transects including sections of lake plain, beach ridges, and till (Upham 1895). Corridor 10 spans a transect from prairie to aspen parkland.

Corridors 16 and 13 traverse areas of jack pine barrens and prairie openings. Corridor 7 is a transect from prairie and oak savanna areas to jack pine barrens.

Corridors 6, 8, and 9 are on sandy soils deposited as outwash. The vegetation in this area was originally oak savanna with prairie openings.

Except for one 24-km (15-mile) portion, corridors 1, 11 and 12 are all within the most fertile cropland soils in the state (Minnesota State Planning Agency 1979). The length of corridor 1 (Table 2), and the possibility that additional native grassland may occur continuing west across North Dakota and Montana, makes it a very high priority for protection.

The following are recommendations for additional study and management of railroad rights-of-way in Minnesota:

1) a preliminary prairie survey on all railroad rights-of-way should be completed. A shorter sampling interval than that used in this study is suggested in the southern part of Minnesota, where little native prairie is known to survive.

2) steps should be taken to insure that prairie is not inadvertently or needlessly destroyed in the course of road and rail maintenance, or by incursion from adjacent landowners.

3) efforts should be made to maintain and enhance native grassland through controlled burning.

4) rights-of-way should be utilized for vegetation monitoring and ecological research.

In order to accomplish these goals, a great deal of cooperation is needed, including the support of the Minnesota Department of Transportation, railroad corporations, private landowners, scientists, resource managers, and others. Prairie rghts-of-way are important biological resources and are worthy of additional study, protection, and management.

Table 2. Prairie corridors or stretches of relatively consistent good-quality prairie, with total length and percent of Types A, B, and C right-of-way

Prairie Corridors	Highway	Total km/miles	Percent of Type A	B	C	no data[1]/
1. Breckenridge-Kandiyohi	S.H. 9	174/108	50	31	17	2
2. Crookston-Glyndon	S.H. 9	98/61	41	21	21	17
3. Crookston-Dale	S.H. 102, 32	97/60	41	29	17	13
4. Crookston-1 mi. N. of Stephen	U.S. 75	77/48	42	42	14	2
5. Holt-3 mi. S. of Marcoux	S.H. 32	68/42	64	5	10	21
6. 3 miles N. of Forest Lake-2 miles N. of Rush City	U.S. 61	48/30	64	13	10	13
7. Little Falls-Brainerd	S.H. 371	43/27	56	22	18	4
8. 1 mile S. of Cambridge-4 miles S. of Andover	S.H. 65	37/23	65	0	0	35
9. Elk River - 1 mi. N. Clear Lake	U.S. 10	35/22	68	23	9	0
10. Erskine-7 mi. E. Crookston	U.S. 2	35/22	41	41	9	9
11. Alberta-Graceville	S.H. 28	32/20	25	40	5	30
12. Willmar-Clara City	S.H. 23	31/19	63	26	11	0
13. Staples-1 mi. E. of Pilliger	S.H.210	27/17	47	23	12	18
14. Nielsville - 4 mil. N. of Eldred	U.S. 75	26/16	50	44	6	0
15. St. Vincent - 2 mi. N. of Hallock	U.S. 75	26/16	63	25	6	6
16. 4 miles S. of Menahga-5 miles S. of Park Rapids	U.S. 71	21/13	38	46	8	8
Total		875/544				
Averages			51	27	11	11

[1]/"No data" figures are parts of the right-of-way that could not be observed because of construction or other barriers.

Acknowledgements

The research and preparation of this report were funded in part by a grant from the Burlington Northern Foundation to the Nature Conservancy. Individuals who reviewed drafts of this paper include Geoffrey S. Barnard, Rober P. Dana, John W. Humke, Jay G. Hutchinson, Frank D. Irving, Donald B. Lawrence, Harrison B. Tordoff, and Robert Vockrodt. Their very helpful suggestions are gratefully acknowledged.

Literature Cited

Federal Highway Administration. 1975a. Highway-wildlife relationships, Vol. 1, State of the art report, No. FHWA-RO-76-4, Wash., D.C., 183 pp.

Federal Highway Administration. 1975b. Highway-wildlife relationships, Vol. 2, Annotated Bibliography, No. FHWA-RO-76-5, Wash., D.C., 417 pp.

Minnesota Department of Transportation. 1978. Roadsides as a natural resource, A Symposium Rep. St. Paul. 24 pp.

Minnesota State Planning Agency. 1978. Reuse of abandoned railroad rights-of-way. St. Paul. 87 pp.

Nielsen, Waldo. 1972. Right-of-way; a guide to abandoned railroads in the United States. Old Bottle Magazine, Bend, Oregon. 124 pp.

Reed, D. M. and J. A. Schwarzmeier. 1978. The prairie corridor concept: possibilities for planning large-scale preservation and restoration. Proc. Fifth Midwest Prairie Conf., pp. 158-165., D. C. Glenn-Lewin and R. Q. Landers, Jr., eds. Iowa State University, Ames.

Rosendahl, C. O. and F. K. Butters. 1928. Trees and Shrubs of Minnesota. University of Minnesota Press, Minneapolis.

Upham, W. 1895. The Glacial Lake Agassiz. U.S. Surv. Monogr. No. 25. Wash., D.C.

White, J. 1978. Illinois natural area inventory technical report, Vol. 1, survey methods and results. Illinois Natural Area Inventory, Urbana.

FLORISTIC COMPOSITION OF PLANT COMMUNITIES IN A WESTERN MINNESOTA TALLGRASS PRAIRIE

Bohdan Dziadyk
Department of Biology, Augustana College
Rock Island, Illinois 61201

and

Gary K. Clambey
Department of Botany, North Dakota State University
Fargo, North Dakota 58105

Abstract. Floristic composition and importance of dominant species were studied at 6 study areas representing distinct plant communities in a western Minnesota prairie. Bluestem Prairie is a 490 ha remnant of native grassland in the Red River Valley. A total of 178 taxa in 43 plant families was recorded from the areas. The major families represented are the Compositae (24.2% of the total flora), the Gramineae (18.0%), the Cyperaceae (8.4%) and the Fabaceae (3.9%). Plant communities and numbers of species in different categories (graminoids, forbs and shrubs, respectively) included, on high prairie, (1) *Bouteloua gracilis-Stipa spartea* (15, 59, 6); on mid-prairie, (2) *Sporobolus heterolepis-Andropogon scoparius* (19,45, 2), and (3) *Andropogon scoparius-Sporobolus heterolepis* (16, 38, 2). Communities of greater moisture regime included, on low prairie, (4) *Andropogon gerardi-Calamagrostis inexpansa* (17, 35, 1); and on high meadow, (5) *Carex* spp. (29, 42, 2) with only 24 taxa characteristic of the swale zone. One disturbed high prairie community was (6) *Agropyron repens*-forb (9, 24, 0), floristically the most depauperate area. A similarity matrix based on coefficient of community shows a substantial floristic relationship between each community and several others, except for the *Agropyron*-forb type which has a very low relationship with nearly all other communities.

Introduction

The Red River Valley of Manitoba, North Dakota and Minnesota comprises the northern extent of the true or tallgrass prairie described by Weaver (1954). The native grasslands of the Valley occur on level, fertile land which was found to be ideally suited to the large-scale farming operations that began in the 1880's (Kazeck 1956) and have continued to the present. Although most of the native prairies of the Red River Valley have been destroyed through cultivation, many isolated remnants remain along railroad rights-of-way, in remote corners of some cultivated fields, in rural cemeteries and in some school sections (Ralston and Dix 1967).

Recently, the Nature Conservancy has given attention and high priority to acquiring tracts of native grasslands in good condition for scientific research and nondestructive public uses. The Conservancy has saved over 14,500 ha (36,000 acres) of midwestern grasslands to date. In Minnesota the Conservancy owns and manages more than 3600 ha (9000 acres) of grassland, much of it in and around the Red River Valley (Searle 1977). One of the larger preserves in the Valley is Bluestem Prairie located in west-central Minnesota. This natural laboratory provides the opportunity for biologists to study the structures and ecosystem functions of a sizable tract of native prairie. Resulting baseline information of such research may contribute to management of preserves and increase our understanding of a nearly vanished ecosystem. As part of an intensive ecological investigation beginning in May of 1978, we studied the species composition and the relative importance of dominants in each of 6 study areas representing distinct plant communities within the preserve.

Description of Area

Bluestem Prairie is a 490 ha (1200 acre) tract of native tallgrass prairie approximately 23 km east of Moorhead in central Clay County, Minnesota. The prairie is situated on the rolling topography of the Campbell Beach or strandline of Lake Agassiz, a glacial lake that existed in the Red River Valley from approximately 13,500 to 9,300 years ago (Bluemle 1977). The intermixed deposits of sand, gravel and silt in and around the prairie are the result of wave action of Lake Agassiz on the glacial till deposited by the several advances of Wisconsin glaciation. Topographic relief of the preserve is slight, ranging from 0 to less than 6% over most of the area. Drainage is through the nearby Buffalo River which flows west and empties into the Red River of the North.

On lowlands areas of the prairie, soils generally consist of deep, poorly and very poorly drained series formed in moderately coarse textured glaciolacustrine sediments over medium textured till or lacustrine sediments on glacial lake plains. On dry uplands and ridges soils characteristically consist of deep, well and moderately well drained series formed in sandy deposits on glacial lake and outwash plains (Soil Conservation Service 1975).

The area has a continental climate with a mean frost-free period of 130 days. The mean temperature for January, the coldes month, is $-14^{\circ}C$ ($7^{\circ}F$), and the mean temperature for July, the warmest month, is $22^{\circ}C$ ($72^{\circ}F$) (Jenson 1972). Mean annual percipitation is 480 mm (19 inches), of which about 75% occurs from April to September.

Methods

Six plant communities within Bluestem Prairie were selected for study during the growing seasons of 1978 and 1979. Communities were chosen on sites representing the major variations in drainage regime discussed by Dix and Smeins (1967) and modified by Ralston (1968) for the Red River Valley. These included 1 upland or high prairie site, 2 mid-prairie sites, 1 low prairie site and 1 swale or high meadow site. One upland over-grazed area only recently acquired was included as a comparison to the other sites.

Within each plant community a permanent study area 25 m x 25 m was delimited. During the course of other investigations a complete record was made of all vascular plant species encountered within the boundary of each study area during the two years. In late summer of each year the basal plant cover of each study area was estimated from a minimum of 100 readings of a systematically placed, 10-pin point frame.

To compare communites based on species presence, the coefficient of community (C) was determined for every combination of study areas (Cox 1980). It is calculated according to the formula:

$$C = \frac{2w}{a + b}$$

where w = number of species shared by the two communites, a - the total number of species in the first community and b = the total number of species in the second community.

Nomenclature follows Gleason and Cronquist (1963) except for *Helianthus nuttallii*, described in Stevens (1963), and *Aster ptarmicoides* X *Solidago ridellii* which appears to be a spontaneous hybrid at the prairie.

Results and Discussion

A total of 178 taxa of vascular plants was encountered in the 6 study areas, representing 112 general in 43 families (Table 1). The predominant families represented are the Compositae, with 24.2 percent of the total flora, the Gramineae (18.0%), the Cyperaceae (8.4%) and the Fabaceae (3.9%). Thus, more than half (54.5%) of all species encountered were members of only 4 families. These are all large, dominant families in most grasslands of North America. Eleven families were represented by 2 species in each family, and 18 families were represented by only 1 species in each.

Plant communites were named after the dominant species (usually those with highest basal cover) at each study area. This involved an element of subjectivity since the relative importance of the dominants changed in several study areas from 1978 to 1979. These changes may have been due to the effects of a wildfire that occurred at the prairie in October of 1978.

Site 1. *Bouteloua gracilis-Stipa spartea* community. This community was located on a sandy, level upland (T139N, R46W, E½, NW¼ 15). It exhibited a greater species richness (80 species) than any other community. Fifteen graminoids (grasses, sedges and rushes), 59 forbs and 6 shrubs were encountered. *B. gracilis*, the major species, had greater basal cover than *S. spartea* (4.1% and 1.4% respectively, in 1979). Both species are more important and widespread in the mixed prairie of the Great Plains (Coupland 1950, Weaver and Albertson 1956). Other important graminoids include *Calamovilfa longifolia, Koeleria cristata,* and *Carex heliophila.*

Important forbs in this community are *Artemisia campestris, Aster ericoides, Comandra pallida, Helianthus laetiflorus, Lithospermum canescens* and Solidago missouriensis. The shrubs *Amorpha canescens* and *Rosa suffulta* are common but species of *Salix* (*S. humilis* and *S. interior*) are rare. The only pteridophyte noted at Bluestem Prairie, *Botrychium multifidum*, was found infrequently in this community.

Table 1. Occurence (+) of vascular plants in the study areas examined during 1978 and 1979

Family and Species	Site 1	2	3	4	5	6
Equisetaceae						
Equisetum arvense L.					+1/	
Equisetum laevigatum A. Br.	+	+		+	+	
Ophioglossaceae						
Botrychium multifidum (Gmel.) Rupr.	+					
Juncaginaceae						
Triglochin maritima L.					+1/	
Gramineae						
Agropyron repens (L.) Beauv.						+
Agropyron trachycaulum (link) Malte.	+	+	+	+	+	
Agrostis stolonifera L.		+	+	+	+	
Andropogon gerardi Vitm.	+	+	+	+	+	
Andropogon scoparius Michx.	+	+	+	+	+	
Bouteloua curtipendula (Michx.) Torr.		+	+			
Bouteloua gracilis (HBK.) Lag.	+					
Bromus inermis Leyss.						+
Calamagrostis inexpansa Gray.		+	+	+	+1/	
Calamovilfa longifolia (Hook.) Scribn.	+					
Deschampsia cespitosa (L.) Beauv.			+		+	
Eragrostis spectabilis (Pursh) Steud.	+					+
Glycera striata (Lam.) Hitchc.					+1/	
Hierochloe odorata (L.) Beauv.				+		
Koeleria cristata (L.) Pers.	+	+				
Muhlenbergia asperifolia (Nees & Meyen) Parodi.				+		
Muhlenbergia racemosa (Michx.) BSP.					+	
Muhlenbergia richardsonis (Trin.) Rydb.		+	+	+	+	
Panicum capillare L.	+	+		+		+
Panicum lanuginoisum Ell.		+	+	+	+	
Panicum virgatum L.		+	+	+		
Panicum wilcoxianum Vasey.	+					
Phleum pratense L.		+				
Poa arida Vasey.				+		
Poa pratensis L.	+	+	+			+
Seteria viridis (L.) Beauv.						+
Sorghastrum nutans (L.) Nash.		+	+	+	+	
Spartina pectinata Link.		+			+1/	
Sporobolus cryptandrus (Torr.) Gray.						+
Sporobolus heterolepis Gray.	+	+	+	+	+	
Stipa comata Trin. & Rupr.	+					
Stipa spartea Trin.	+	+				+
Cyperaceae						
Carex brevior (Dewey) Mackenzie.					+	+
Carex buxbaumii Wahl					+	
Carex crawei Dewey.		+	+			
Carex haydenii Dewey.					+1/	
Carex heliophila Mackenzie.	+					
Carex interior Bailey.					+1/	
Carex lasiocarpa Ehrh.					+1/	
Carex meadii Dewey.					+	
Carex praegracilis W. Boott.	+			+	+	
Carex sartwellii Dewey.					+1/	
Carex scirpoidea Michx.			+			

Table 1. Continued

Family and Species	Site 1	2	3	4	5	6
Eleocharis compressa Sulliv.		+	+	+	+[1]	
Eleocharis tenuis (Willd.) Schult.					+[1]	
Eriophorum viridi-carinatum (Engelm.) Fern.					+[1]	
Scirpus americanus Pers.					+[1]	
Commelinaceae						
Tradescantia occidentalis (Britt.) Smyth.	+	+				
Juncaceae						
Juncus alpinus Vill.					+	
Juncus balticus Willd.				+	+[1]	
Juncus longistylis Torr.					+	
Juncus torreyi Cov.					+	
Liliaceae						
Alium stellatum Ker.	+	+	+	+		
Zygadenus elegans Pursh.		+	+	+		
Amaryllidaceae						
Hypoxis hirsuta (L.) Cov.		+	+	+	+	
Iridaceae						
Sisyrinchium montanum Greene.	+	+	+	+	+	
Orchidaceae						
Spriranthes cernua (L.) Rich.		+	+	+		
Salicaceae						
Salix humilis Marsh.	+					
Salix interior Rowlee.	+					
Salix petiolaris Sm.					+[1]	
Santalaceae						
Comandra pallida A. DC.	+	+	+			
Polygonaceae						
Polygonum convolulus L.						+
Polygonum ramosissimum Michx.						+
Chenopodiaceae						
Chenopodium album L.						+
Chenopodium leptophyllum Nutt.	+	+				
Salsola Kali L.						+
Nyctaginaceae						
Oxybaphus hirsutus (Pursh) Sweet.	+					+
Caryophyllaceae						
Cerastium arvense L.	+					
Lychnis alba Mill.						+
Ranunculaceae						
Anemone cylindrica Gray.	+					
Anemone patens L.	+					
Caltha palustris L.					+[1]	

Table 1. Continued

Family and Species	Site 1	2	3	4	5	6
Delphinium virescens Nutt.	+					
Ranunculus rhomboideus Goldie.	+					
Thalictrum dasycarpum Fisch. & Ave-Lall.		+	+	+	+	
Cruciferae						
Erysimum inconspicuum (Wats.) MacMill.	+					
Lepidium densiflorum Schrader.						+
Saxifragaceae						
Heuchera richardsonii R. Br.	+					
Parnassia palustris L.					+	
Rosaceae						
Geum triflorum Pursh.	+					
Potentilla arguta Pursh.	+					
Prunus pumila L.	+	+				
Rosa suffulta Greene.	+	+	+	+		
Fabaceae						
Amorpha canescens Pursh.	+	+				
Lathyrus palustris L.		+			+	
Melilotus alba Desr.	+	+	+			+
Melilotus officinalis (L.) Desr.						+
Petalostemum candidum (Willd.) Michx.	+	+	+			
Petalostemum purpureum (Vent.) Rydb.	+	+	+	+		
Psoralea argophylla Pursh.		+				
Linaceae						
Linum sulcatum Riddell.	+		+			
Polygalaceae						
Polygala senega L.			+			
Polygala verticillata L.	+	+	+	+		
Euphorbiaceae						
Euphorbia serpyllifolia Pers.	+					
Hypericaceae						
Hypericum majus (Gray) Britt.					+[1]	
Violaceae						
Viola papilionacea Pursh.		+	+	+	+	
Viola pedatifida G. Don.		+	+			
Onagraceae						
Epilobium palustre L.				+[1]		
Oenothera biennis L.	+					+
Oenothera serrulata Nutt.	+					
Umbelliferae						
Cictua maculata L.				+	+[1]	
Zizia aptera (Gray) Fern.	+	+	+	+		
Zizia aurea (L.) Koch.		+	+	+	+	
Cornacea						
Cornus stolonifera Michx.					+	

Table 1. Continued

Family and Species	Site 1	2	3	4	5	6
Primulaceae						
Lysimachia quadrifolia L.		+			+	
Gentianaceae						
Gentiana procera Holm.					+	
Apocynaceae						
Apocynum sibericum Jacq.		+	+	+		
Asclepiadaceae						
Asclepias incarnata L.					+	
Asclepias ovalifolia Decne.	+		+	+		
Asclepias syriaca L.		+		+		
Asclepias verticillata L.	+	+		+		
Asclepias viridiflora Raf.	+					
Boraginaceae						
Lithospermum canescens (Michx.) Lehm.	+		+			
Lithospermum incisum Lehm.	+					
Labiatae						
Lycopus americanus Muhl.					+[1]	
Lycopus uniflorus Michx.					+[1]	
Mentha arvensis L.					+[1]	
Prunella vulgris L.					+	
Pycnanthemum virginianum (L.) Durand & Jackson.		+		+	+	
Scutellaria parvula Michx.		+	+	+		
Solanaceae						
Physalis virginiana Mill.	+					
Scrophulariacea						
Pedicularis canadensis L.		+				
Pedicularis lanceolata Michx.					+	
Penstemon gracilis Nutt.	+					
Penstemon grandiflorus Nutt.	+					
Rubiaceae						
Galium boreale L.	+	+	+	+	+	
Caprifoliaceae						
Symphoricarpos occidentialis Hook.	+					
Campanulaceae						
Campanula aparinoides Pursh.					+[1]	
Campanula rotundifolia L.	+	+		+		
Lobeliaceae						
Lobelia Kalmii L.					+	
Lobelia spicata Lam.		+	+	+		
Compositae						
Achillea millefolium L.	+	+	+			
Agoseris glauca (Pursh) D. Dietr.			+			
Ambrosia artemisiifolia L.						+
Ambrosia psilostachya DC.	+			+		

Table 1. Continued

Family and Species	Site 1	2	3	4	5	6
Antennaria plantaginifolia (L.) Richards.	+	+	+			
Artemisia campestris L.	+					+
Artemisia dracunculus L.	+					+
Artemisia frigida Willd.	+					+
Artemisia ludoviciana Nutt.	+					
Aster ericoides L.	+	+	+	+		+
Aster junciformis Rydg.					+1/	
Aster laevis L.		+	+	+		
Aster ptarmicoides (Nees) T. & G.		+	+	+	+	
ASter sericeus Vent.	+					
Aster Umbellatus Mill.					+	
Aster ptarmicoides (Nees) T. & G. X *Solidago ridellii* Frank.					+	
Chrysopsis villosa (Pursh) Nutt.	+					+
Cirsium flodmanii (Rydb.) Arthur.	+					+
Conyza canadensis (L.) Cronq.	+					+
Crepis runcinata (James) T & G.		+	+	+	+	
Echinacea purpurea (L.) Moench.	+					
Erigeron strigosus Muhl.	+					+
Eupatorium maculatum L.					+	
Helenium autumnale L.					+	
Helianthus laetiflorus Pers.	+					
Helianthus maximiliani Schrader.		+	+	+		
Helianthus nuttallii T. & G.				+	+	
Hieracium canadense Michx.					+	
Iva xanthifolia Nutt.						+
Liatris aspera Michx.	+	+	+	+		
Liatris punctata Hook	+					
Liatris pycnostachya Michx.		+	+	+	+	
Ratibida columnifera (Nutt.) Woot. & Standl.	+					
Rudbeckia hirta L.		+	+	+		
Senecio pseudaureus Rydb.	+	+	+	+	+	
Solidago canadensis L.		+	+	+	+	
Solidago graminifolia (L.) Salisb.					+	
Solidago missouriensis Nutt.	+					+
Solidago nemoralis Ait.	+					+
Solidago riddellii Frank.		+			+	
Solidago ridida L.	+	+	+	+	+	+
Sonchus arvensis L.		+			+	
Tragopogon dubius Scop.	+					+
Total Species	80	60	56	53	73	33

1/ Species characteristic of the swale zone.

Site 2. *Sporobolus heterolepis-Andropogon scoparius* community. This site was found on a relatively well drained, gentle slope (3%) (T 139N, R46W, N½, SW¼ 15). Both dominants had the same basal cover (about 10.6%) in 1978, but in 1979, following the fall burn of the previous year, the cover of *A. scoparius* decreased to 2% while cover of *S. heterolepsis* remained high (9.3%). Both grasses are important in upland true prairie with *A. scoparius* usually occupying by far the larger area (Weaver 1954). *Muhlenbergia richardsonis, Eleocharis compressa* and *Carex crawei* were important associates of the dominant grasses.

Sixty-six species were noted in this community, 19 of which were graminoids and 45 were forbs. Forbs are far less prominent in this community than in the preceding one and among the more important are *Galium boreale, Scutellaria parvula, Solidago canadensis* and *Zygadenus elegans.* Only 2 infrequent shrubs were encountered, *Amorpha canescens* and *Rosa suffulta.*

Table 2. Similarity matrix for plant communities of Bluestem Prairie

Site No.	1	2	3	4	5	6
1	....					
2	0.40	....				
3	0.37	0.79	....			
4	0.33	0.75	0.74	....		
5	0.13	0.42	0.37	0.44	....	
6	0.34	0.12	0.09	0.07	0.04	....

Site 3. *Andropogon scoparius-Sporobolus heterolepis* community. This community was found on a level area with moderately good drainage (T139N, R46W, N½, NE¼ 22). This site is intermediate in moisture regime to the *Bouteloua-Stipa* and the *Andropogon-Calamagrostis* communities. However, it is somewhat more mesic than the *Sporobolus-Andropogon* Type. A very significant shift in the relative importance of dominant species occurred in this site during the 2 years of study. In 1978 the basal cover of *A. scoparius* and *S. heterolepsis* was 7.4% and 3.4% respectively. The cover of the tall, mesic grass, *Sorghastrum nutans,* was 4.3%. In 1979 the cover values for the same grasses were 2.8%, 4.4% and 1.0% respectively. In both this and the preceding community *Sporobolus heterolepis* maintained its basal cover while *Andropogon scoparius* decreased in cover. The decrease in cover of the latter species is probably due to fire damage in the crowns of the plants.

In a list of 56 species, 16 were graminoids, 38 were forbs and only 2 were shrubs. Prominent forbs include *Hypoxis hirsuta, Liatris pycnostachya, Polygala senega,* and *Viola pedatifida.* The relatively infrequent prairie orchid *Spiranthes cernua* was found in this community as well as in the preceeding and following sites.

Site 4. *Andropogon gerardi-Calamagrostis inexpansa* community. This community was characteristic of low prairie with level, poorly drained soils (T139N, R46W, W½, NW¼ 15). Of the 17 graminoids present *A. gerardi* and *C. inexpansa* were the most important (7.2% and 3.8% basal cover, respectively in 1979). Several studies have shown the importance of *A. gerardi* in lowland prairies in the Red River Valley (Ralston and Dix 1967, Smeins and Olsen 1970, Wali et al. 1973). *C. inexpansa* may be locally abundant, but it is much less important than *A. gerardi* in the native prairies. As in the mid-prairie communities, the grass *Muhlenbergia richardsonis* is an important component. Species of *Carex* were much less important in this community than in the high meadow type.

Among 35 forbs found in the *Andropogon-Calamagrostis* community the more common were *Apocynum sibiricum, Hypoxis hirsuta, Senecio pseudaureus, Sisyrinchium montanum* and *Solidago canadensis.* The only woody species present, *Rosa suffulta,* was rarely observed.

Site 5. *Carex* spp. community. In shallow prairie swale areas that are inundated in the spring the high meadow community is common. This site (T139N, R46W, E½, NE¼ 22) is characterized by a narrow swale zone 10 – 20 m in width dominated by species of *Carex.* The most important of these is *Carex sartwellii* which had a basal cover of 5.0% in 1979. All other species of *Carex* contributed an additional 6.7% to the cover in 1979. Other important graminoid components of the *Carex* community are *Calamagrostis inexpansa, Juncus balticus* and*Spartina pectinata.* Mid-prairie species found infrequently at the edges of this community are *Andropogon scoparius* and Sporobolus heterolepsis and several forbs.

With a total of 73 species this site is almost as rich floristically as the *Bouteloua-Stipa* community and much richer than some other moist communities in the Red River Valley (Hadley and Buccos 1967, Smeins and Olsen 1970). However, only 24 species were characteristic of the narrow swale zone of this site (Table 1). Many of the forbs in the *Carex* community are found in none of the other sites. These include *Aster junciformis, Aster umbellatus, Caltha palustris, Campanula aparinoides, Eupatorium maculatum, Lycopus americanus, Mentha arvensis* and *Solidato graminifolia.* The shrubs *Cornus stolonifera* and *Salix petiolaris* also were found in no other study area.

Site 6. *Agropyron repens*-forb community. This community occurred on a level, well drained upland (T139N, R46W, N½, SE¼ 22) comparable to the *Bouteloua-Stipa* site. However, this site had been overgrazed by domestic livestock prior to acquisition of the area by the Nature Conservancy. The *Agropyron*-forb community was floristically the most depauperate area of this study. Only 33 total species were encountered (9 graminoids, 24 forbs and no shrubs). Nevertheless, this site contains more species than a similar *Poa-Melilotus* community (20 species) examined by Hadley and Buccos (1967) in eastern North Dakota.

The basal cover of the dominant species *A. repens* (8.8%) was the same in both 1978 and 1979. This may be attributable to the fact that this site was the only one not burned in the 1978 fire. The dominant forb in 1978 was *Melilotus alba.* However, since this species is a biennal it was a very minor component in 1979. The disturbed nature of this community is emphasized by the prevalence of *Poa pratensis, Ambrosia artemisiifolia, Chenopodium album, Lepidium densiflorum, Polygonum convolvulus* and *Salsola kali.*

The similarity matrix based on coefficient of community for total species is presented in Table 2. As might be expected the greatest similarity is between the *Sporobolus-Andropogon* and *Andropogon-Sporobolus* communities (C = 0.79). Both occur on relatively well drained sites with the same dominant species present. The *Andropogon-Calamagrostis* community is very similar floristically to both of the above communities (C = 0.75 and C = 0.75), but it is much less similar to the *Carex* community (C = 0.44). The latter relationship is largely explained by the many graminoid species that occur in the *Carex* community but not in the low prairie site.

The relationship of the *Bouteloua-Stipa* community to the *Andropogon-Calamagrostis* type (C = 0.33) is similar to that of the former community with the disturbed *Agropyron*-forb site (C = 0.34). However, the floristic relationship between the *Bouteloua-Stipa* community and the *Carex* community is very low (C = 0.13), as would be expected with the very different moisture regimes found at these two sites. The lowest relationships between one site and nearly all others are noted for the *Agropyron-forb community (C = 0.12, 0.09, 0.07 and 0.04 for sites 2-5, respectively).* These comparisons show very strikingly the large changes that may occur in species composition of the prairie after prolonged disturbance such as overgrazing.

Acknowledgments

The assistance of Dr. Richard Williams in identifying several species of plants is gratefully acknowledged. Appreciation is extended to the Minnesota Chapter of the Nature Conservancy for permission to conduct research at the Bluestem Prairie Preserve. Financial assistance during the study was provided by the Department of Botany, North Dakota State University.

Literature Cited

Bluemle, J.P. 1977. The face of North Dakota, the geological story. North Dakota Geol. Surv., Educational Series 11. Washburn Printing Center, North Dakota. 73pp.

Coupland, R. T. 1950. Ecology of mixed prairie in Canada. Ecol. Monogr. 20:271-315.

Cox, G. W. 1980. Laboratory manual of general ecology. William C. Brown Company, Dubuque, Iowa.

Dix, R. L. and F. E. Smeins. 1967. The prairie, meadow, and marsh vegetation of Nelson County, North Dakota. Can. J. Bot. 45:21-58.

Gleason, H. A. and A. Cronquist. 1963. Manual of vascular plants of northeastern United States and adjacent Canada. D. Van Nostrand Company. Princeton, New Jersey.

Hadley, E. B. and R. P. Buccos. 1967. Plant community composition and net primary production within a native eastern North Dakota prairie. Am. Midl. Nat. 77:116-127.

Jensen, R. E. 1972. Climate of North Dakota. National Weather Serv. North Dakota State University, Fargo.

Kazeck, M. E. 1956. North Dakota, a Human and Economic Geography. North Dakota Institute for Regional Studies, Fargo.

Ralston, R. D. 1968. The grasslands of the Red River Valley. University of Saskatchewan, Saskatoon. Ph.D. Thesis.

Ralston, R. D. and R. L. Dix. 1967. Green herbage production of native grasslands in the Red River Valley - 1965. Ann. Proc. North Dakota Acad. Sci. 20:57-66.

Searle, R. N. 1977. Saving pieces of prairie. The Nature Conservancy News 27:14-21.

Smeins, F. E. and D. E. Olsen. 1970. Species composition and production of a native northwestern Minnesota tall grass prairie. Am. Midl. Nat. 84:398-410.

Soil Conservation Service. 1975. Soil survey interpretations. U. S. Dept. of Agri., Soil Conservation Service, Lincoln, Nebraska.

Stevens, O. A. 1963. Handbook of North Dakota Plants. North Dakota Institute for Regional Studies, Fargo.

Wali, M. K., G. W. Dewald and S. M. Jalal. 1973. Ecological aspects of some bluestem communities in the Red River Valley. Bull. Torrey Bot. Club 100:339-348.

Weaver, J. E. 1954. North American Prairie. Johnsen Publishing Company, Lincoln, Nebraska.

COLONY LONGEVITY OF A PRAIRIE ANT, FORMICA CINEREA

Russel O. Wagner
Department of Biology
University of Wisconsin-Platteville
Platteville, Wisconsin 53818

Abstract. Between 1956 and 1979 a total of 241 colonies of the mound-building ant *Formica cinerea* were checked for mound size in 4 transects of 150 X 1m. The site is a prairie remnant on 1 side of a southwestern Wisconsin railroad track. The colonies were classed as a) temporary, surviving only 1 season, b) colonies recorded as present when the transects were originally established in 1956, c) those appearing as new, young colonies after 1956, and d) colonies that enlarged along the borders. Of 58 mounds (colonies) recorded in 1956, 28 remained active after 24 growing seasons. From the large size of several measured in 1957 it is obvious that colonies are capable of "living" for more than 25 years. Of 21 new mounds appearing in 1947 3 were still active after 23 growing seasons. Three of 17 enlarged mounds appearing in 1957 were active in 1979. The transects were examined only 5 times between 1966 and 1979, so it is possible only to estimate average ages and maximum longevity. At the second prairie conference in 1970 in a first report on these ants based on 11 seasons data, the idea was proposed that each colony appears to have a growth pattern resembling that of many individual organisms: a rapid growth during youth, a mature period of relative stability, and a period of senescence preceding its demise. Thirteen additional years of data support this idea although there are periods of decrease and enlargement during the "mature" period. The absence of annual burning by railroad personnel in recent years resulted in partial invasion by woody species. This affected the ant population as well. In one area 76% of the colonies died out since 1966 compared with 39% in a relatively little affected portion.

SESSION II. Classification and Structure of Missouri Glade Communities.
Wallace R. Weber, Presiding

Nelson's paper provides a detailed description of the several glade types based on a wide variety of geological materials. Common factors are thin soils and harsh, fluctuation moisture regimes. This study becomes the basis of future analyses and an important aid in preservation of these unique environments. The paper by Redfearn relates the bryophytic communities of cedar glades in Missouri with their ecological equivalents in more moist regimes in Tennessee and hotter, drier regimes in Texas. Successional studies of cedar glades using gradient analysis are summarized by Hicks. The flora and fauna of the Ozark glades are described by Hendrickson and Davis based on an audiovisual program presented at the conference.

PRELIMINARY REPORT ON THE IDENTIFICATION, DISTRIBUTION AND CLASSIFICATION OF MISSOURI GLADES

Paul Nelson
and
Douglas Ladd
Missouri Department of Natural Resources
P.O. Box 176
Jefferson City, Missouri 65102

Abstract. The initial results of a long-term research project that will culminate in a comprehensive study of the glade communities of Missouri are presented. For the purposes of this study, the term "glade" refers to essentially treeless rocky barrens generally occurring on south- and west-facing slopes of otherwise forested ridges. Glades occur on a wide variety of substrate types, including limestones, cherts, basic intrusives, volcanic rocks, dolomites, sandstones, and shales. Glades are characterized by a very thin soil cover and harsh, often widely fluctuating environmental conditions. Preliminary identification of glades through remote sensing techniques is discussed and evaluated. Glade occurrence on different substrates is correlated with various geological and topographic factors, and patterns of glade distribution are compiled and discussed. A brief enumeration of unique floristic elements is presented, with a discussion of autecological patterns of selected taxa including fidelity, endemism, isolation, and adaptation. A geologically/floristically based classification system is developed. Future research goals and preservation for a complete system of glades are discussed.

Introduction

Glades are essentially treeless xeric rocky barrens dominated by a predominantly herbaceous flora, generally occurring on south-and west-facing slopes of otherwise forested sites. The term glade has been employed in a variety of different contexts, and in fact a precise definition is difficult because of the wide variety of glade types, and the continuum existing between glade, prairie, and savanna communities. Although sharp distinction cannot be made between glades and xeric prairies, this paper will primarily be concerned with a discussion of glades in non-prairie areas. Certainly rock escarpments or thin-bedded rocky soils on prairies have a high degree of floristic affinity to glades on similar substrates. Such areas are subject to the same environmental parameters as glades except that prairie sites have been postulated to be more dependent upon periodic fires to maintain their vegetational integrity than the more xeric glade communities. Glade-like sites in prairie areas would be classified as Dry Prairie following the revision of the terrestrial classification scheme for the Missouri Natural Areas System (Nelson 1980).

For the purposes of this study, the following conditions are assumed to be generally characteristic of glades:

1) bedrock at or near the land surface as a result of major erosional activity and resistance to weathering,

2) topographically located on moderate to steep slopes in deeply dissected drainages or hilly to mountainous terrain. Glades usually have a southern or western exposure because of increased solar desiccation on sites with these aspects,

3) soil cover, when present, is extremely thin, ranging from less than 1 cm to 50 cm thick, and interspersed with copious rock fragments. These shallow soils are frequently disrupted by frost upheavals,

4) extremely xeric conditions prevailing throughout much of the growing season, although soils may be seasonally saturated in spring, winter, and fall. Glades may have seasonal or permanent spring seeps and locally dry-mesic soil conditions,

5) the periphery and sometimes large expanses of the glades themselves are characterized by a variable mosaic of stunted, often gnarled trees and shrubs.

Glades occur in several regions of eastern and central North America. States with significant glade areas include Arkansas, Indiana, Kentucky, Tennessee, and Missouri. Perhaps no other state exhibits the same extent and diversity of glade communities as Missouri. This plethora of glades can be attributed to a variety of factors including substrate diversity, previous geologic disturbances and uplifts, past climatic changes, and numerous fluctuating environmental parameters. Most previous studies involving Missouri glades have concentrated on descriptions of well-known glade regions (Erickson, Brenner, and Wraight 1942, Kucera and Martin 1957, Palmer 1910). One of the first attempts to describe Missouri glades was Henry Rowe Schoolcraft's *Scenes and Adventures in the Semi-Alpine Regions of the Ozark Mountains of Missouri and Arkansas* (1853). Determination of glade sites through the use of aerial photographs was accomplished as early as 1942 (Erickson, Brenner, and Wraight 1942).

The physiographic provinces discussed here refer to the Natural Divisions of Missouri (Thom and Wilson paper, this volume). Major glade regions of Missouri primarily encompass the unglaciated portions of the state (generally south of the Missouri River but including the Lincoln Hills Section and extended over much of northern Missouri, covering the bedrock with a mantle of loess deposits and glacial till. This relatively thick accumulation of soil material excludes the formation of glades over most of the glaciated portions of the state. Glades have been documented in glaciated regions where major rivers and streams have downcut into bedrock, such as along the Salt and Missouri Rivers. Within Missouri, glades are known to occur on 6 major substrates: dolomite, limestone, sandstone, igneous rock, chert and shale.

One of the most striking aspects of Missouri glades is their unique and characteristic flora. Glade plants possess many adaptations enabling them to survive in a harsh environment often subject to widely fluctuating extremes of temperature and moisture. Because of their extremely xeric nature during much of the growing season, glades are primarily occupied by herbaceous vascular plants. Floristic composition of glades is influenced by a variety of parameters, especially substrate type, and is an integral element of any viable glade classification scheme. Species concepts and nomenclature for all vascular taxa in this study follow Steyermark (1963).

The primary objectives of this study are to develop a detailed geologically and floristically based classification and inventory system for all glade community types in Missouri, as well as to foster understanding and appreciation for this unique ecosystem through the publication of both a popular-level illustrated flora of Missouri glade communities and a technical assessment of Missouri glades. It is hoped this will stimulate the establishment and preservation of a complete system of glade community types. As the initial phases of the project, this paper discusses general patterns of glade distribution and abundance by substrate type throughout the state. Explanations are formulated for patterns of glade occurrence based on the results of this study. A complete listing of the vascular flora of Missouri glades with substrate affinities is included as an appendix at the conclusion of the paper.

Materials and Methods

Several remote sensing techniques were employed to conduct an accurate statewide survey of glade extent, location, and substrate type. Criteria employed in selection of remote sensing methods included speed, accuracy, consistency over all glade types, and cost effectiveness. Initial recognition of glade sites was accomplished through study of aerial photographs. Photgraphs utilized included the Agricultural Stabilization and Conservation Service (ASCS) central file photos, taken in the 1930's and 1940's; photographs flown in the 1970's for the Army Corps of Engineers Dam Survey; and various photographs housed at county ASCS offices taken from 1965 to 1977. The county office photographs proved to be the most accurate in evaluating potential glade areas. The most accurate determinations of glade sites were accomplished through the use of a magnifying stereoscope and zoom reducing scope, but time limitations precluded the use of these techniques for the entire study. Scale of photographs utilized varied from 1.5-8.0 inches per mile.

Glade sites were determined through detailed evaluation of photographs and correlation with USGS topographic maps. Initial photograph evaluations were made of areas with which the investigators had a thorough field familiarity in order to become proficient at recognition of glade areas. Several criteria proved helpful in distinguishing glade areas from aerial photographs. Glades usually appear on photographs as sharply contrasting zones with irregular boundaries, often bordered by an easily discernable fringe of *Juniperus virginiana.* Glades formed on sedimentary rocks often have a series of exposed ledges, giving an appearance of contour lines on the photograph. When compared with USGS topographic maps, glade boundaries include "U" shaped curves, "S" curves, circles, and scorpioid curves (Fig. 1). Such irregular figures occuring consistently across a broad spectrum of habitats

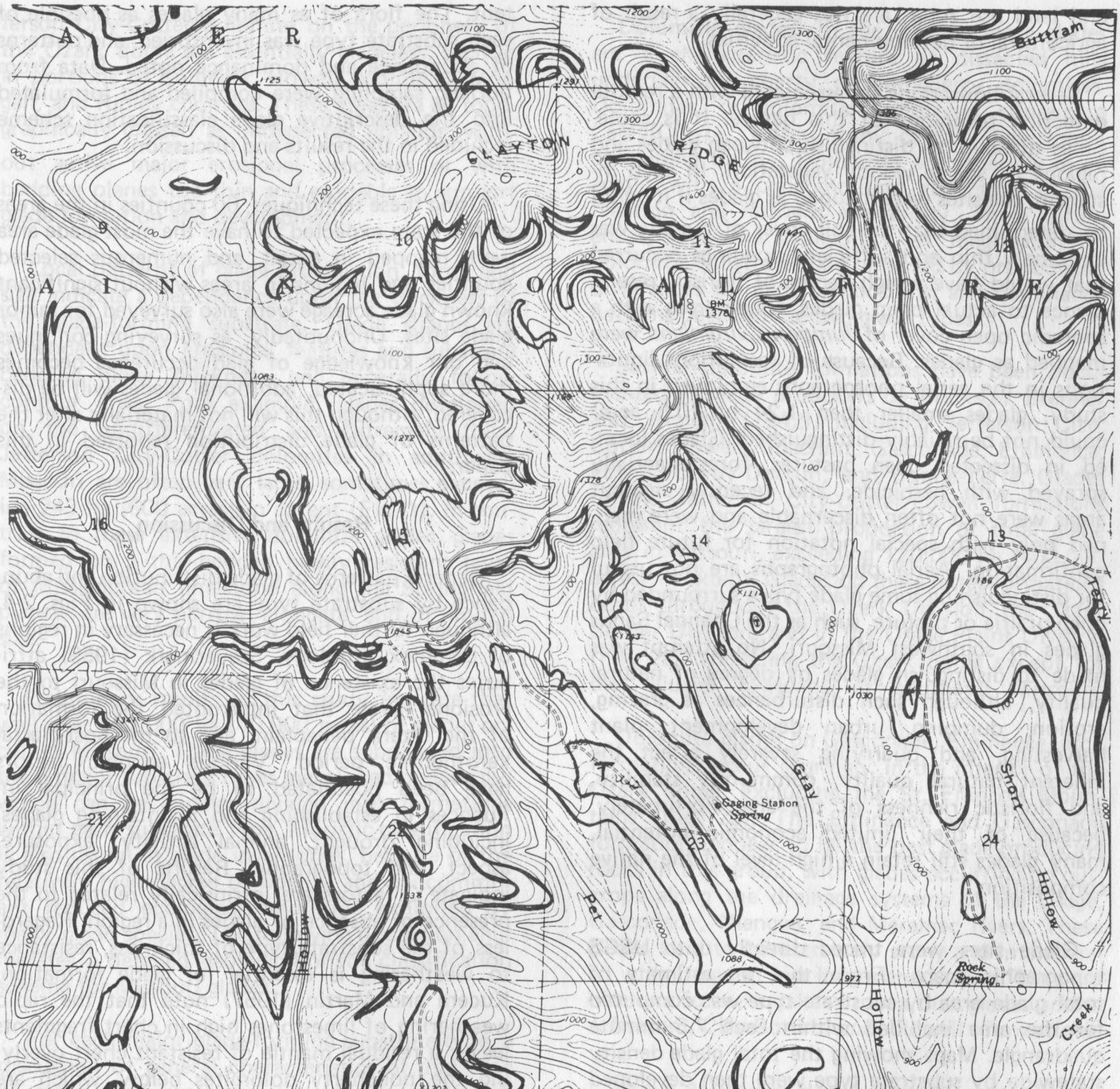


Fig. 1. Sample USGS topographic map section with glade tracings as determined by remote sensing techniques (Protem NE 7.5 minute quadrangle, 1968).

and land use zones are not generally a result of agricultural or developmental activities.

Several limitations are associated with a remote detection technique of this nature. It is sometimes difficult to distinguish between glades and regions of sparse woody vegetation. In such instances, the sites were mapped as glades if it could be determined that the soil cover of the site was extremely thin and sufficient openings occurred that would have a high degree of floristic resemblance to actual open glades. Glade areas with a sporadic open cover of *Juniperus virginiana* were mapped as glades. Because of resolutions limitations in the aerial photographs employed in this study, glades smaller than 1.24 ha (0.5 acre) could not be reliably distinguished. Glades located in dissected open pastures, forests aerially sprayed with herbicide, and recently clearcut areas were not often discernable and were mapped only with special notation for future field confirmation. Aerial photographs are not useful for distinguishing some glade types surrounded by open prairie or pasture, such as the Channel Sands glades in southwest Missouri. No attempt was made to distinguish glades by degree of natural quality, although such disturbances as grazing, erosion, dumping, urban development, plant harvesting, and quarrying severely affect the inherent natural quality, community stability, and floristic richness of the site. Fortunately, because of their limited economic potential, many glades still retain a high level of the native composition.

Glade sites were traced directly onto USGS topographic maps. From this, an estimate of total glade area by substrate type was computed for the area included within each 7.5 minute quadrangle. Maps showing the total glade density statewide by substrate type were then developed to provide an overview of glade distribution patterns within the state, and for future correlation with plant distributions. Glade substrate determinations were made by reference to published geological surveys, county soil surveys, Tollman and Robertson (1969), Anderson (1979), personal communications with ASCS agents, and field observations.

Glade distributions were randomly checked for accuracy, and an intensive field check was conducted for a representative quadrangle (Rolla 7.5). Sporadic spot checks were also conducted in glade regions throughout the state. In all instances, there was essentially complete correlation between field observations and patterns of glade occurrence determined by remote sensing techniques. Field checking was more intensive in regions of glades of potentially questionable status or extent. The flora of as many glades as possible of each substrate type was inventoried, and patterns of abundance and dominance noted. Data from floristic sampling were compiled and formulated into the descriptive glade classification scheme included in the results and discussion.

Using these techniques, 60 counties in the areas of the state expected to have the most glade area were mapped in detail, and numerous selected counties and regions in areas without significant known glade acreage were also surveyed for minor glade sites. Undoubtedly, as surveying continues and our knowledge of glad occurence becomes more sophisticated, additional glades will be discovered, although this will not materially alter the patterns of glade distribution reported in this paper.

Results and Discussion

General patterns of glade distribution and abundance by substrate type are shown in Figs. 2-4, although further field work is necessary in regions of complex lithology. Steyermark (1959) attributes the existence of glades in Missouri to the erosional cycle that interrupted the formation of the Ozark peneplain, and to the post-glacial xerothermic period. Various edaphic factors have been postulated to be the principal influences in establishing and maintaining glades, including drought, animal activity, exposure, aspect, and topography. Results of this study indicate 2 factors are intrinsically related to the presence or absence of glades in a region. Regardless of the substrate type of thickness, resistance to weathering is essential for glade formation. Kucera and Martin (1957) note that the rapid weathering of limestones high in chert fragments leaves a residual mantle of resistant chert overlying the noncherty dolomites below, which are more resistant to weathering than chert bearing limestones. Thus, the weathered chert residuum is suitable for forest growth, while the resistant dolomites lower on the slope result in glade formation. Another factor necessary for glade formation, given a substrate sufficiently resistant to weathering, is an active erosional cycle on moderate to steep slopes. As an example of the importance of topography in glade formation, the outer periphery of the Ozark dome is encircled by lower Ordovician age dolomites of the Jefferson City-Cotter formation. This formation is noted for its high frequency of glades, such as the White River glades (Kucera and Martin 1957), and the Jefferson County glades (Erickson, Brenner, and Wraight 1942). Field work during this study also revealed significant glade areas in the same formation near Lake of the Ozarks and in the Gasconade River drainage. However, several large expanses of Jefferson City-Cotter dolomite on the periphery of the Ozark dome are essentially gladeless, such as in portions of Bollinger, Howell, Moniteau, Morgan, and Ripley counties. These areas are all topographically classed as undissected uplands, without active major erosional processes or with bedding planes too thin and erodable to support glade formation and development.

Local patterns of glade distribution, form, and size indicate a dependence upon the thickness of the glade-forming substrate. Glade shapes are dependent upon erosional features and substrate bedding plane thickness, and generally follow contour lines. Fore example, glades developed on the undifferentiated and extremely thick Jefferson City-Cotter dolomites in southwest Missouri are often very large, sometimes exceeding 243 ha (600 acres) in extent (Fig. 1). In contrast to these extensive dolomite glades, glades formed on a thin-bedded highly resistant layer of Mississippian limestone along the Springfield plateau are very narrow, elongate, and of limited size.

Preliminary results of this study indicate that well over 162,000 ha (40,000 acres) of glades occur in Missouri. These glades are subdivided into the 6 major substrate types mentioned previously, which can be further divided into formations within each substrate type. Floristic classification is also useful in glade inventories, because of the relatively high degree of fidelity and concommitant reduced ecological amplitude exhibited by many glade species. The following discussion enumerates a detailed geologic-floristic classification scheme for Missouri glades.

For each major glade-forming substrate type, a discussion of general characteristics of that type of glade, and vegetational profile is presented. Dominant plants are those species consistently occurring as major components of the vegetation of that glade type. It should be emphasized that plants classed as dominant do not dominate every glade of that substrate, nor are they necessarily restricted to glades; many attain their maximum development in prairie or savanna habitats. Plants listed as characteristic for a given glade type are those plants which regularly occur on a glade of that substrate, the presence of which in conjunction with other characteristic species provides a reliable indicator of the glade type. Characteristic species are not necessarily or even usually confined to glade habitats, and the discussion pertains only to their occurrence in glade situations. Some taxa occur on a particular glade type only within a limited range or are totally endemic to that glade type. These species are classed as restricted in this discussion.

Dolomitic glades. In the Ozarks, these glades are a characteristic feature of dissected hills underlain by cherty or non-cherty dolomites. Dolomites, or dolomitic limestones, containing $CaMg(CO_3)_2$, differ from calcitic limestones, containing $CaCo_3$. Dolomites are generally more acidic with a concommitant reduction in soil reaction and nutrient availability. These differences, plus the availability of magnesium on dolomitic substrates, are reflected by pronounced differences in plant composition and dominance patterns between the two glade types.

Several dolomite formations have been documented as glade producers by Erickson, Brenner and Wraight (1942), including Jefferson City, Cotter, Powell, Joachim, Gasconade, Eminence, Potosi, Derby-Doerun, and Bonne-Terre. Glades of the Jefferson City-Cotter/Powell formations represent the largest proportion of total glade area in Missouri, exceeding 120,000 ha (400,000 acres) in extent. Glades on these latter formations occur throughout the Ozark Division, the Ozark Border Division, and in the Osage Plains Division (Fig. 2a), encircling the Ozark dome except for the alluvial lowlands of southeast Missouri.

Dolomite glades on Gasconade, Eminence, etc., formations occur sparingly in the interior of the Ozark dome, excluding the St. Francois Mountains (Fig. 2b). The Eminence and Gasconade formations appear to be the best glade-producing rocks in this group, with glades occurring on outcrops along the drainage systems of the Osage, Gasconade, Niangua, and Meramec rivers. These glades tend to be extremely stony and interspersed with frequent low ledges and shelves. They are often xeric and smaller in area than glades on the Jefferson City-Cotter and Powell formations.

Some dolomitic glades have been studied by Erickson, Brenner, and Wraight (1942), Kucera and Martin (1957), and Steyermark (1940, 1963). Several regions have unique or restricted plants including *Centaurea americana* and *Valerianella ozarkana* on glades in the Elk River Section of the Ozark Division, *Crataegus danielsii* and *Erysimum capitatum* on glades on glades in the Missouri River Section of the Ozark Border Division, and *Clematis fremontii* var *richlii* on glades in the Mississippi River Section or the Ozark Border Division. Dolomitic glades in the White River Section of the Ozark Division harbor a diverse assemblage of restricted species, including *Acacia angustissima, Baptisia australis, Centaurium texense, Cotinus obovatus, Eriogonum Lingifolium, Juniperus ashei, Liatris mucronata, Marshallia caespitosa* var. *signata, Palafoxia callosa, Penstemon cobaea* var. *purpureus, Phyllanthus polygonoides, Scleria oligantha, Scutellaria bushii, Stenosiphon*

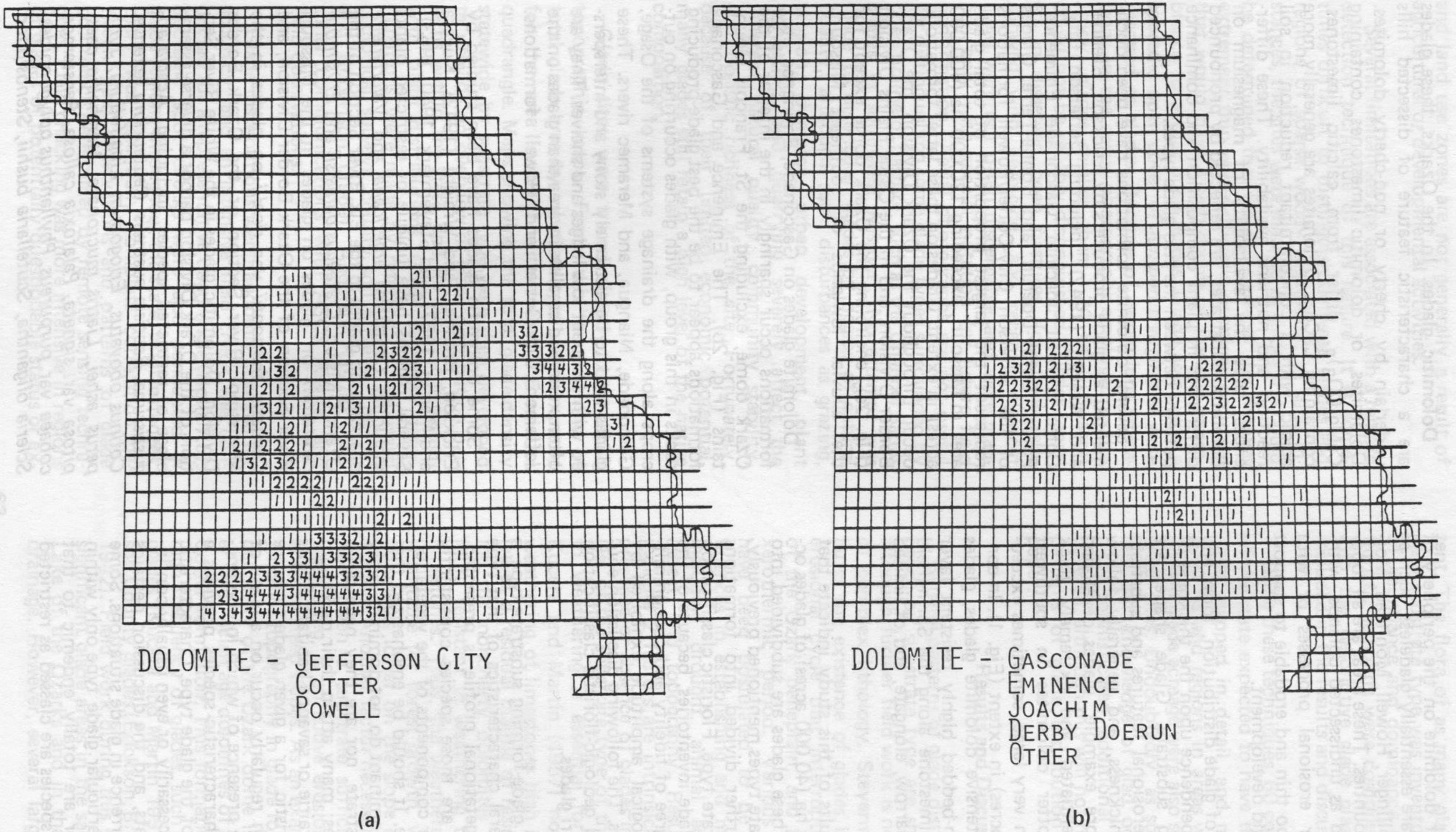


Fig. 2. Density profiles for dolomite glades. a. Jefferson City-Cotter and Powell formations. b. Joachim, Gasconade, Eminence, Potosi, Derby-Doerun, and Bonne-Terre formations. 1, < 4 ha; 2, 4-40; 3, 40-202; 4, greater than 202.

linifolius, Thelesperma trifidum, and *Yucca glauca* var. *mollis.*

Grasses frequently observed on dolomite glades include *Andropogon scoparius, Bouteloua curtipendula, Sorghastrum nutans,* and *Sporobolus heterolepis.* Other characteristic plants include *Arenaria patula, Aster sericeus, Buchnera americana, Carex meadii, Castilleja coccinea, Comandra richardsiana, Dodecatheon meadii, Echinacea pallida, Echinacea paradoxa, Fimbristylis caroliniana, Heliotropium tenellum, Houstonia nigricans, Hypoxis hirsuta, Liatris squarrosa, Lithospermum canescens, Oenothera missouriensis, Panicum lanuginosum, Panicum virgatum, Petalostemum purpureum, Quercus stellata, Rhus aromatica, Rudbeckia missouriensis, Satureja arkansana, Silphium terebinthinaceum, Sporobolus neglectus,* and *Viola pedata.*

Sandstone glades. Sandstone glades occur in relatively limited extent on a number of formations in several different natural divisions in the state (Fig. 3a). Glades are found on the St. Peter, Lamotte, Channel Sands, Roubidoux, Gasconade, Gunter, and Pennsylvanian Formations. On St. Peter sandstone these occur in a broad arc extending outward north and east of the Ozark Dome, in the Ozark Border Division, and the Lincoln Hills Section of the Galciated Plains Division. These glades generally occur on outcrops with a southern or western exposure along narrow ridges and bluff escarpments, usually bordering major streams and rivers. The largest glades discovered on this formation are linear areas up to 6 ha (14.8 acres). Lamotte sandstone glades occur in the Mississippi River Section of the Ozark Border Division, primarily in St. Genevieve County along River Aux Vases, Jonca Creek, Pickle Creek, Hickory Creek, Fourche Creek, and their tributaries. These glades, averaging less than 0.5 ha (1.23 acres) in area, occur on escarpments along narrow canyons, exposed in open raviness, above bluffs, and on broad conical knobs.

The largest expanses of sandstone glades occur on Channel Sands deposits on the Springfield Plateau Section of the Ozark Division. These glades, ranging up to 20 ha (50 acres) in area, occur where expanses of sandstone are exposed on gently rolling uplands amidst forest or prairie, and along south-facing slopes of narrow tributary valleys to large streams. Several restricted taxa occur on this substrate, including *Geocarpon minimum, Portulaca mundula, Sedum nattallianum,* and *Valerianella stenocarpa.*

Numerous small glades exist on Gasconade, Gunter, and Roubidoux sandstones in the Upper Ozark Section of the Ozark Division. These glades usually occur along bluff escarpments of the larger Ozark waterways, including the Big Piney, Niangua, Jack's Fork, and Eleven Point rivers. Many dolomite glades in this region contain a residuum of sandstone, and determination of the exact nature of the substrate at a given point can be problematical in areas of complex lithology. Glades on Pennsylvania sandstone are known from the Osage Plains Division and Springfield Plateau Section of the Ozark Division in southwest Missouri. These glades often appear as outcrops on hilly prairies.

Typically, soils on sandstone glades are thin or absent, resulting in a stunted or nonexistent arborescent flora and carpets of mosses and lichens covering bare rock expanses. Dominant plants on sandstone glades include *Andropogon scoparius, Crotonopsis elliptica, Juniperus virginiana, Quercus stellata,* and *Vaccinium arboreum.* Characteristic species on sandstone glades of all types include *Cheilanthes lanosa, Cladina* spp., *Diodia teres, Eragrostis spectabilis, Festuca octoflora, Hypericum gentianoides, Isoetes melanopoda, Lechea villosa, Plantago pusilla, Selaginella rupestris,* and *Talinum parviflorum.* Additional characteristic species on glades in the Springfield Plateau Section include *Cyperus filiculmis, Juncus secundus, Krigia occidentalis, Saxifraga texana,* and *Selenia aurea. Chaetopappa asteroides, Corydalis crystallina,* and *Linaria canadensis* are characteristic on glades in the Osage Plains Division. Estimated acreage of this type in the state is approximately 810 ha (200 acres).

Limestone glades. Limestone formations designated as Burlington, Keokuk, and Plattin-Kimmswick occur in the Lincoln Hills and Eastern River sections of the Ozark Border Division, in the Springfield Plateau, Lower Ozark, and Elk River sections of the Ozark Division, and to a limited extent in the Osage Plains Division (Fig. 3b). These glades typically appear as elongate narrow areas on steep slopes along major drainages. Because of substrate stratigraphy, they are seldom massive in extent. The largest concentration of limestone glades occurs on the Burlington-Keokuk formation north of Springfield.

Dominant grasses on limestone include *Andropogon scoparius* and *Bouteloua curtipendula.* Other plants include *Androsace occidentalis, Arabis hirsuta, Astragalus distortus, Draba reptans, Erysimum capitatum, Gutierrezia drancunculoides, Heliotropium tenellum, Lespedeza capitata, Lithospermum anescens, Mentzelia oliogosperma, Ophioglossum engelmannii, Onosmodium occidentale, Psoralea tenuiflora, Schrankia uncinata, Sedum pulchellum, Sporobolus asper, Sporobolus neglectus, Tradescantia ohiensis, Verbena canadensis.* Restricted species on limestone glades in

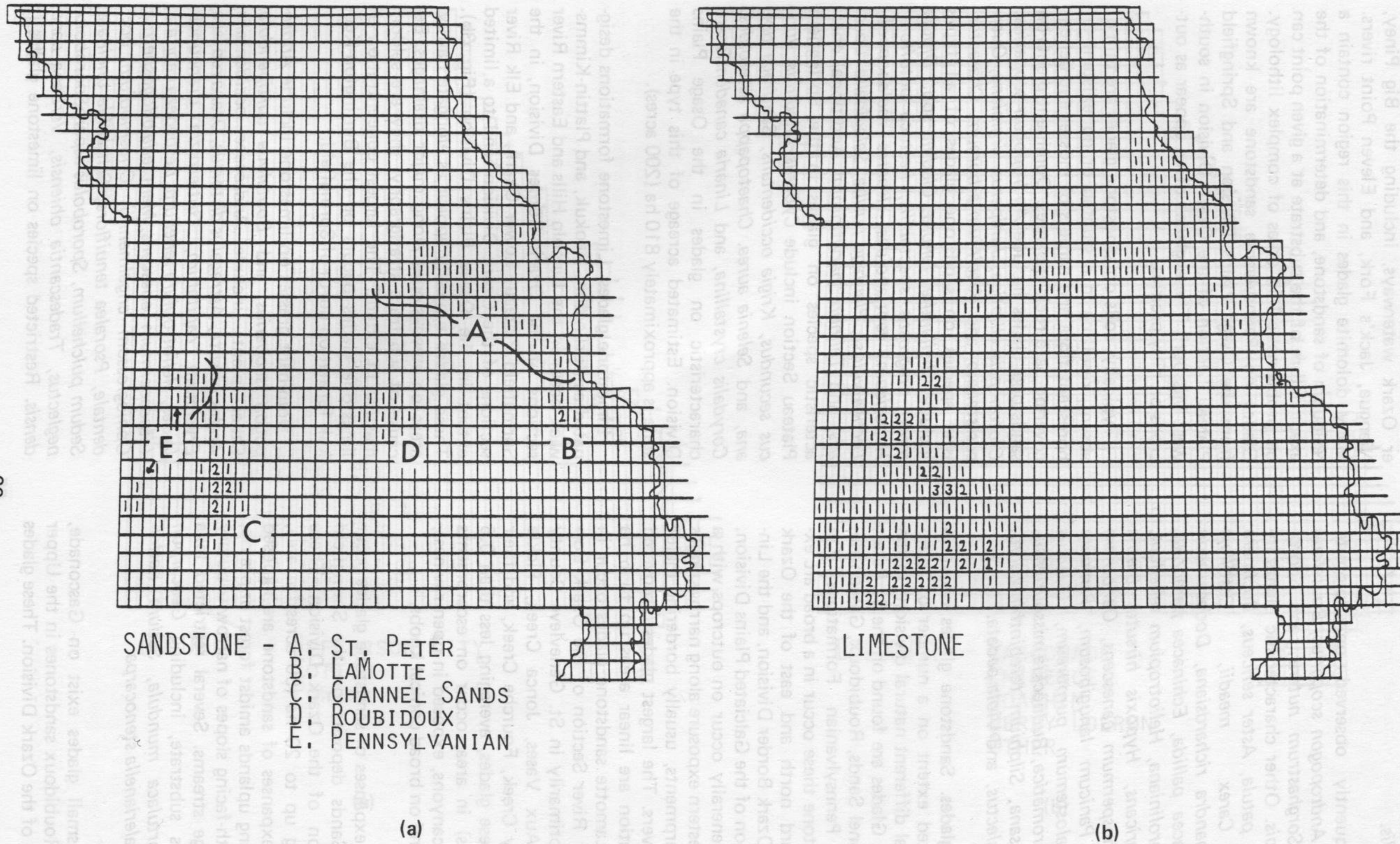


Fig. 3. Density profiles for glades on (a) sandstone and (b) limestone substrates. Explanation of glade size given in Fig. 2.

the Springfield Plateau Section of the Ozark Division include *Castilleja purpurea* and *Lesquerella filiformis*. *Acacia angustissima* is restricted to glades in the White River Section of the Ozark Division. Total area in the state is estimated to be 1214 ha (3,000 acres); it is likely that more limestone glades will be included in sections yet to be inventoried.

Igneous glades. Southeatern Missouri is one of few regions in the central United States where precambrian igneous rocks are exposed and available for plant colonization. Glade-forming outcrops occur over an area of nearly 12,800 km^2 (5,000 mi^2) in and around the St. Francois Mountain Section of the Ozark Division (Fig. 4a). Igneous glades also occur locally east of Eminence in the Lower Ozark Section of the Ozark Division, and on a few igneous outcrops in the Mississippi River Section of the Ozark Border Division. Igneous glades occur most commonly on broad domes, as well as on narrow ridges and along drainages and shut-ins. Sterile igneous exposures at low levels along drainages often give rise to glades in close association with aquatic communities. Distribution of glades correlated with specific igneous rock types indicates a greater glade frequency and area on the prebatholithic rock (felsite, rhyolite, dillenite) occuring on the south and west flanks of the St. Francois Mountains. Glades are less numerous on granites, probably because they are less resistant to weathering. This theory is further supported by the lower relief and less severe topography of the igneous area underlain by batholithic rocks.

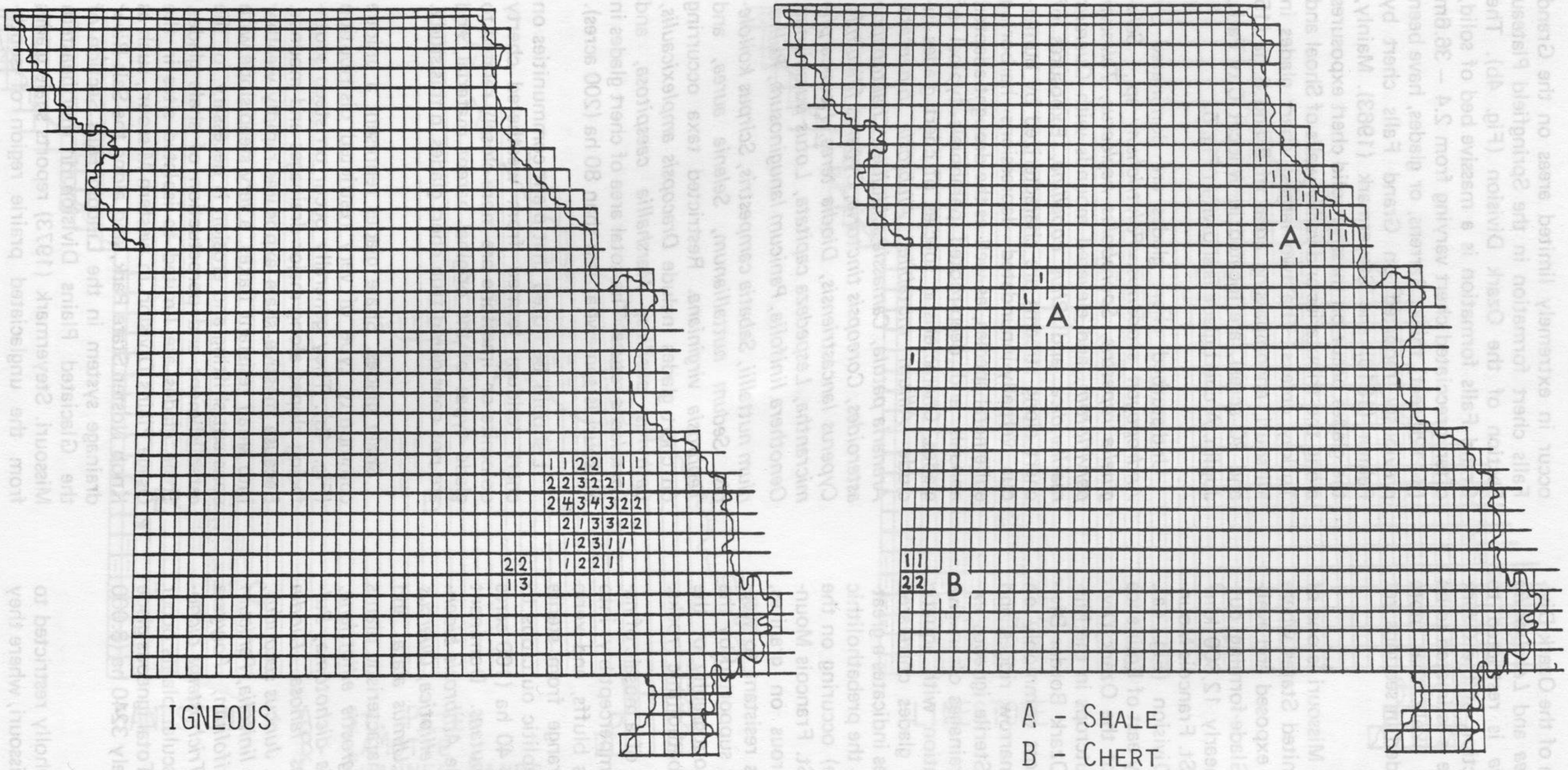
Igneous glades occur as part of a mosaic of natural communities, merging imperceptibly into savanna, igneous talus, igneous bluffs, and xeric upland forest. These glades range from sterile moss and lichen-encrusted ehyolitic outcrops to prairie-like expanses exceeding 40 ha (100 acres dominated by *Sorghastrum nutans*. Dominant plants on igneous glades include *Ambrosia bidentata, Cladina* spp., *Crotonopsis elliptica, Quercus stellata, Sorghastrum nutans, Ulmus alata,* and *Vaccinium arboreum*. Other characteristic plants on igneous glades include *Agrostis elliottiana, Andropogon scoparius, Aristida dichotoma, Bulbostylis capillaris, Cheilanthes lanosa, Diodia teres, Hypericum gentianoides, Juncus secundus, Lespedeza capitata, Oenothera linifolia, Panicum lanuginosum, Panicum linearifolium, Polygala senega, Polygonum tenue,* and *Trichostema dichotomum*. No truly restricted vascular plants occur on igneous glades in Missouri. Total igneous glade area in the state is approximately 3240 ha (8.000 acres).

Chert glades. This type is wholly restricted to the southwestern portion of Missouri, where they occur in extremely limited areas on the Grand Falls chert formation in the Springfield Plateau Section of the Ozark Division (Fig. 4b). The Grand Falls formation is a massive bed of solid, often brecciated chert varying from 2.4 – 36.6m (8–120 feet) thick. Barrens, or glades, have been previously reported on Grand Falls chert by Palmer (1910) and Steyermark (1963). Mainly, the glades occur on massive solid chert exposures along the tributaries and valley walls of Shoal and Turkey creeks. The two largest chert glades in Missouri, encompassing areas of 6 and 8 ha (15 and 20 acres), are located in Wildcat City Park, Joplin. A chert glade is shown in Fig. 5.

Undisturbed chert glades are dominated by *Andropogon scoparius, Polytrichum* sp., *Selaginella rupestris, Sporobolus neglectus, Talinum parviflorum,* and elevated mounds with *Quercus marilandica* and *Rhus copallina*. Exposures of chert along streams are characterized by numerous vernally-innundated depressions harboring ephemeral species, as well as the drought-adapted annuals and deep-rooted perennials typical of glades. Characteristic species of chert glades include *Allium mutabile, Ambrosia bidentata, Arenaria patula, Camassia scilloides, Chaetopappa asteroides, Coreopsis tinctoria, Cyperus filiculmis, Cyperus lancastriensis, Diodia teres, Hemicarpha micrantha, Lespedeza capitata, Lotus purshianus, Oenothera linifolia, Panicum lanuginosum, Ptilimnium nuttallii, Sabatia campestris, Scirpus koilolepis, Sedum nuttallianum, Selenia aurea,* and *Tephrosia virginiana*. Restricted taxa occurring on chert glades include *Dracopsis amplexicaulis, Lathyrus pusillus, Marshallia caespitosa,* and *Portulacca retusa*. The total area of chert glades in Missouri is somewhat less than 80 ha (200 acres).

It should be noted that plant communities on chert residum formed from weathered cherty dolomite or limestone are more closely related to glade types of the original parent material, and are not considered true chert glades in this study.

Shale glades. Shale glades represent a unique community type of very restricted distribution (Fig. 4b). They generally occur on steep south-facing slopes along major drainages and mounds. Because massive shale exposures rapidly weather into small resistant flakes, a very steep slope with constant shifting and erosion is necessary for the establishment and perpetuation of shale glades. Shale glades are limited to isolated sites in the Osage Plains Division in western Missouri, such as Knob Noster State Park, and along the Salt River drainage system in the Lincoln Hills Section of the Glaciated Plains Division in northeastern Missouri. Steyermark (1973) reports shale glades from the unglaciated prairie region of south-



(a)

(b)

Fig. 4. Density profiles for glades on (a) igneous and (b) chert and shale substrates. Explanation of glade size given in Fig. 2.

Fig. 5. View of representative glade habitat.

western Missouri. Because of their inherent instability, the diversity of shale glade flora is limited to species tolerant of a constantly eroding habitat. *Andropogon scoparius* is the only dominant plant, while *Gillenia stipulacea* and *Astragalus distortus* are characteristic taxa. Interestingly, while Missouri shale glades display little floristic affinity to the geologically similar shale barrens of the Appalachians, *Astragalus distortus* is a characteristic species of both communities (Keener 1970). The only species of restricted occurrence in Missouri shale glades is *Penstemon cobaea* var. *cobaea.* Steep shaley slopes of upland prairies resemble shale glades but are considered dry shale prairie (Nelson 1980). The acreage of total shale glade in Missouri is less than 200 ha (500 acres).

Acknowledgements

Special thanks are extended to Janet Hicks, Dave Hoffman, Deborah Ladd, Robert Mohlenbrock, Bruce Schuette, Jerry Vineyard, and Betty Williams for their assistance during the course of this research.

Literature Cited

Anderson, K. A. et al. 1979. Geological map of Missouri. Missouri Department of Natural Resources, Division of Geology and Land Survey.

Erickson, R. O., L. G. Brenner, and J. Wraight. 1942. Dolomitic glades of east-central Missouri. Ann. Mo. Bot. Garden 29:89-101.

Keener, C. S. 1970. The natural history of the mid Appalachian shale barren flora. In P. E. Holt (ed). The Distributional History of the Biota of the Southern Appalachians. Part II: Flora. Virginia Polytechnic Institute and State University Research Monogr. 2:215-248.

Kucera, C. L. and S. C. Martin. 1957. Vegetation and soil relationships in the glade region of the southwestern Missouri ozarks. Ecology 38: 285-291.

Nelson, P. W. 1980. Classification of terrestrial natural communities in Missouri. Unpubl. ms. 72 pp.

Palmer, E. J. 1910. Flora of the Grand Falls chert barrens. Trans. Acad. Sci. St. Louis 19:97-112.

Schoolcraft, H. R. 1853. Scenes and Adventures in the Semi-alpine Regions of the Ozark Mountains of Missouri and Arkansas. Lippencott, Grambo, Philadelphia.

Steyermark, J. A. 1940. Studies of the vegetation of Missouri I. Natural plant associations and succession in the Ozarks of Missouri. Field Museum Nat. History Bot. Series. 9:349-475.

Steyermark, J. A. 1959. Vegetational history of the Ozark forest. University of Missouri Studies XXXI, Columbia. 138 pp.

Steyermark, J. A. 1963. Flora of Missouri. Iowa State University Press, Ames.

Thom, R. H. and J. H. Wilson. 1980. The Natural Divisions of Missouri. Unpubl. ms. 22 pp.

Tolman, C. F. and F. Robertson. 1969. Exposed Precambrian rocks in southeast Missouri. Missouri Geol. Surv. and Water Resources Rep. No. 44. 68 pp.

APPENDIX I. Vascular plants found in Missouri glades arranged according to substrate occurrence, with taxa that are endemic or restricted to a given glade type indicated by asterisk (*).

Species	Glade Substrate[1/]				
* *Acacia angustissima*	D				
Acalypha gracilens	D		S	I	C
Acer saccharum	D	L			
A. rubrum	D		S		
Agave virginica	D			I	
Agrostis elliottiana			S	I	

Species	Glade Substrate					
Allium mutabile			S	I	C	
A. stellatum	D	L				
Ambrosia artemisiifolia			S	I	C	Sh
A. bidentata			S	I	C	
Amelanchier arborea	D		S	I		
Amorpha canescens	D	L				
Ampelopsis cordata	D					
Amsonia ciliata filifolia	D					
A. tabernaemontana	D					
* *Andrachne phyllanthoides*	D	L	(White River Section)			
Andropogon gerardii	D	L		I		
A. saccharoides			S			
A. scoparius	D	L	S	I	C	Sh
A. ternarius			S		C	
Androsace occidentalis	D	L				
Anemone virginiana	D	L				
Apocynum cannabinum	D	L				
Arabis candensis	D	L				
A. hirsuta		L				
A. missouriensis				I	C	
Arenaria patula	D	L			C	
A. stricta	D					
Aristida dichotoma				I		
A. intermedia	D					
A. longespica	D	L				
A. oligantha			S		C	Sh
A. purpurascens			S	I	C	
Artemisia caudata			S	(Roubidoux, St. Peter)		
A. ludoviciana			S			
Asclepias quadrifolia	D	L				
A. purpurascens	D	L				
A. stenophylla	D	(Gunter, Gasconade)				
A. tuberosa	D	L				Sh
A. verticillata	D	L				
A. viridiflora	D	L				
A. virdis	D					
Aspelenium platyneuron	D	L	S	I	C	
Aster azureus	D					
A. Laevis	D					
A. linearifolius	D	(Chert residuum)				
A. oblongifolius	D	L	S	I	C	Sh
A. patens	D		S			
A. ptarmicoides	D	L				
A. sericeus	D	L				
A. turbinellus			S	I	C	
Astragalus distortus		L				Sh
A. mexicanus trichocalyx	D					
Baptisia australis minor	D					
B. leucantha	D					
B. leucophaea	D	(chert residuum)				
Berberis canadensis			S	(Roubidoux)		
Berchemia scandesn	D					
Berlandiera texana	D					
Blephilia ciliata	D	L				
Bouteloua curtipendula	D	L				
Bulbostylis capillaris			S	I	C	
Bumelia lanuginosa	D	L				
Cacalia tuberosa	D					

Species	Glade Substrate					
Callirhoe digitata	D					
C. papaver	D					
Camassia angusta		L				
C. scilloides	D	L	S	I	C	
Carex artitecta				I		
C. bushii			S	I		
C. complanata hirsuta			S	I		
C. crawei	D					
C. eburnea	D	L				
C. leavenworthii			S	I		
C. meadii	D	L				
C. microdonta		L				
C. tetanica	D					
Cardamine parviflora			S	I		
Carya texana			S	I		
Cassia fasciculata			S	I		
Castilleja coccinea	D	L				
C. purpurea		L				
Ceanothus americanus	D					
Celtis laevigata texana	D	L				
C. tenuifolia	D	L				
Centaurea americana	D	L				
Centaurium texense	D					
* *Centunculus minimus*	D		S			
Cercis canadensis	D	L				
Chaerophyllum tainturieri	D	L				
C. texanum	D		S			
Chaetopappa asteroides			S			
Cheilanthes feei	D					
C. lanosa			S	I	C	
* *Chionanthus virginica*	D	(White River Section)				
Chrysopsis villosa			S	(Channel Sands)		
Clematis fremontii riehlii	D	(Mississippi River Section)				
Collinsia violacea			S		C	
Comandra richarsiana	D	L				
Coreopsis lanceolata	D		S	I	C	
C. palmata	D			I	C	
C. tinctoria					C	
Cornus drummondii	D	L				
C. florida	D	L				
Corydalis crystallina			S			
* *Citunus obovatus*	D	(White River Section)				
Crataegus spp.	D	L	S	I	C	
Crotalaria sagittalis				I		
Croton capitatus	D	L				
C. monanthogynus	D	L	S	I	C	
Crotonopsis elliptica			S	I	C	
Cyperus aristatus			S	I	C	
C. filiculmis			S	I	C	
C. flavescens				I		
C. lancastriensis			S			
C. ovularis			S	I	C	
Danthonia spicata			S	I		Sh
Daucus pusillus	D					
Delphinium carolinianum	D	L				
D. treleasii	D	L				
Desmodium illinoense	D					

Species	Glade Substrate				
D. nuttallii			S	I	
D. sessilifolium	D				
Diodia teres			S	I	C
Dioscorea quaternata	D	L			
Diospyros virginiana	D	L	S	I	C
Dirca palustris	D				
Dodecatheon meadia	D	L			
* Draba aprica			S	I	
D. brachycarpa			S	I	
D. cuneifolia	D	L			
D. reptans		L			
* Dracopsis amplexicaulis					C
Echinacea pallida	D	L			
E. paradoxa	D				
Eleocharis compressa	D		S	I	
E. lanceolata	D	L			
E. tenuis				I	
Eragrostis capillaris	D	L			
Eriogonum longifolium	D	(White River Section)			
Eryngium yuccifolium	D				
Erysimum capitatum		L			
Eupatorium altissimum	D	L			
Euphorbia corollata	D	L			
E. missurica	D	L			
E. supina				I	
Evolvulus nutallianus	D				
Festuca octoflora			S	I	C
Fimbristylis autumnalis			S	I	C
F. caroliniana	D		S		C
F. dichotoma	D		S		C
Fraxinus americana				I	
F. quadrangulata	D	L			
Galium arkansanum	D		S	I	(chert residuum)
G. virgatum	D	L			
Gaura biennis	D	L			
Gentiana quinquefolia	D				
G. puberula	D				
* Geocarpon minimum			S	(Channel Sands)	
Geranium maculatum	D				
Gerardia aspera		L			
G. flava	D	(Chert residuum)			
G. gattingeri			S	I	
G. tenuifolia			S	I	
Gillenia stipulacea					Sh
Gratiola neglecta				I	
Grindelia lanceolata	D				
Gutierrezia dracunculoides	D	L			
Haplopappus ciliatus	D				
Hedoma hispida			S	I	
H. pulegioides	D	L			
Helianthus hirsutus		L		I	
H. maximilianii	D				
H. mollis	D	L			
H. occidentalis	D				
Hemicarpha drummondii	D				
H. micrantha			S	I	C
Heuchera richardsonii	D		S		
Hexalectris spicata	D				

Species	Glade Substrate				
Houstonia caerulea				I	
H. longifolia	D		S		
H. nigricans	D	L			
H. minima			S	I	C
H. pusilla			S	I	
Hybanthus concolor	D				
Hymenopappus scabiosaeus	D	(White River Section)			
Hypericum drummondii			S	I	
H. gentianoides			S	I	
H. mutilum			S		
H. punctatum			S		C
H. sphaerocarpum	D	L			
H. spathulatum				I	
Hypoxis hirsuta	D	L	S	I	C
Ilex decidua	D				
Isanthus brachiatus	D	L			
Isoetes butleri	D	L	S		C
I. melanopoda			S	I	
Juncus biflorus			S		
J. interior	D		S		C
J. marginatus	D	L	S		
J. secundus			S	I	
* *Juniperus ashei*	D	(White River Section)			
J. virginiana	D	L	S	I	
Krigia dandelion					
K. virginica			S	I	
Kuhnia eupatorioides	D	L			
* *Lathyrus pusillus*					C
Leavenworthia uniflora	D				
Lechea tenuifolia			S	I	C
L. villosa			S	(St. Peter)	
Lespedeza capitata			S	I	C
L. virginica	D	L	S		C
* *Lesquerella filiformis*		L			
Liatris aspera	D	L			
L. cylindracea	D			I	
* *L. mucronata*	D	(White River Section)			
L. scabra	D			I	
L. squarrosa	D	L		I	C
Linaria canadensis			S	I	C
Linum medium			S	I	C
L. sulcatum	D		S		
Lithospermum canescens	D	L			
L. incisum	D	(Gunter dolomite)			
Lobelia spicata	D	L			
Lotus purshianus			S		C
Marshallia caespitosa					C
M. caespitosa signata	D				
Matelea decipiens	D	L			
Melica nitens	D			I	
Mentzelia oligosperma		L			
Mertensia virginica		L			
Mirabilis albida	D			/	
M. linearis		L			
Monarda fistulosa	D				
M. russelliana	D				
Muhlenbergia cuspidata	D				
Myosotis virginica	D		S	I	

Species	Glade Substrate						
Nemastylis geminiflora	D						
N. nuttallii	D						(White River Section)
Nothoscordum bivalve	D	L	S	I	C	Sh	
Oenothera linifolia			S	I	C		
O. missouriensis	D	L					
O. speciosa	D	L					
O. triloba	D						
Onosmodium hispidissimum	D	L					
O. occidentale	D	L					
O. subsetosum	D	L					
Ophioglossum engelmannii	D	L					
Opuntia compressa	D	L	S	I	C		
O. macrorhiza	D	L					
Orobanche uniflora	D						(chert residuum)
Oxalis violacea	D			I			
Palafoxia callosa	D	L					
Panicum capillare	D	L	S	I			
P. gattingeri			S	I	C		
P. lanuginosum	D	L	S		C	Sh	
P. linearifolium				I			
P. perlongum			S	I			
P. sphaerocarpon			S	I	C		
P. virgatum	D	L					
Parthenium hispidum	D	L					
P. integrifolium	D	L					
Pedicularis canadensis	D						
Pellaea atropurpurea	D	L					
* *Penstemon arkansanus*	D						(White River Section)
P. cobaea						Sh	(Shaley limestone)
P. cobaea purpureus	D						(White River Section)
P. digitalis	D	L					
P. pallidus	D	L	S	I	C		
P. tubaeflorus	D	L					
Perideridia americana	D	L					
Petalostemum candidum	D	L					
P. purpureum	D	L		I			
Phacelia gilioides				I			
P. hirsuta	D						
Phlox bifida				I			
P. pilosa	D						
* *Phyllanthus polygonoides*	D						(White River Section)
Physalis pumila		L					
Physostegia virginiana	D	L					
Pinus echinata	D		S	I			
Plantago pusilla			S	I	C		
P. virginica			S	I			
Poa chapmaniana			S	I	C		
Polygala incarnata				I			
P. sanguinea			S	I	C		
P. verticillata	D			I			
Polygonum tenue			S	I	C		
Polytaenia nuttallii	D	L					
Portulaca mundula		L	S		C		
P. neglecta		L					
* *P. retusa*					C		
Potentilla simplex	D		S				
Prenanthes aspera	D						
Psoralea esculenta	D	L					

Species	Glade Substrate					
P. psoralioides		L	S	I	C	
P. tenuiflora	D	L				
Ptelea trifoliata	D	L				
Ptilimnium nuttallii	D	L			C	
Pycnanthemum tenuifolium	D	L	S	I		
Quercus marilandica			S	I	C	
Q. prinoides	D	L				
Q. rubra			S	I		
Q. stellata	D	L	S	I	C	
Q. velutina			S	I		
Ranunculus facicularis	D	(chert residuum)				
Ratibida pinnata	D	L				
Rhamnus caroliniana	D					
Rhus aromatica	D	L	S	I		
R. copallina	D	L	S	I	C	
R. glabra			S	I	C	
R. toxicodendron	D	(White River Section)				
Rhynchospora harveyi			S			
Rosa caroliniana	D	L				
Rudbeckia missouriensis	D	L				
Ruellia humilis	D	L				
Sabatia angularis	D	L				
S. campestre	D		S		C	
Salvia azurea grandiflora		L				
* *Sapindus drummondii*	D	(White River Section)				
Satureja arkansasa	D	L				
Saxifraga texana			S		C	
S. virginiensis			S	I		
Schrankia uncinata	D					
Scirpus koilolepis			S		C	
S. lineatus	D		S	I		
Scleria ciliata			S			
S. oligantha	D	(chert residuum)				
S. pauciflora			S	I	C	
* *Scutellaria bushii*	D	(White River Section)				
S. parvula	D		S	I		
* *Sedum nuttallianum*			S		C	
S. pulchellum	D	L				
Selaginella rupestres			S		C	
* *Selenia aurea*			S		C	
Senecio plattensis	D					
Setaria geniculata		L				
Silene caroliniana			S	(Roubidoux)		
S. virginica	D					
Silphium intergrifolium	D	L				
S. laciniatum	D	L				
S. terebinthinaceum	D	L				
Sisyrinchium campestre	D	L				
Similax bona-nox	D	L	S	I		
Solanum carolinense	D					
Solidago drummondii	D	L				
S. gattingeri	D					
S. hispida				I		
S. nemoralis	D					
S. radula	D		S	I		
S. rigida			S	(St. Peter)		
Sorghastrum nutans	D	L	S	I	C	Sh
Specularia biflora	D		S	I		

Species	Glade Substrate				
S. leptocarpa		L	S		
S. perfoliata	D		S	I	C
Spermolepis inermis	D		S		C
S. echinata			S		
Sphaeralcea angusta		L	S		
Spriranthes cernua	D	L	S	I	
S. gracilis			S	I	
S. tuberosa		L	S		
Sporobolus asper		L			
S. clandestinus			S	I	
S. heterolepis	D				
S. neglectus neglectus	D	L			
S. neglectus ozarkanus	D	L			
Stenosiphon linifolius	D	(White River Section)			
Strophostyles leiosperma			S	I	C
S. umbellata				I	
Stylosanthes biflora	D			I	
Swertia caroliniensis	D		S		
Symphoricarpos orbiculatus	D	L	S	I	
Taenidia integerrima	D	L			
Talinum calycinum	D	L	S	I	C
T. parviflorum			S	I	C
Tephrosia virginiana	D		S		C
Thalictrum revolutum	D				
Tradescantia longipes				I	
T. ohiensis			S	I	C
T. tharpii		L	S		C
Tragia cordata	D	L			
T. urticifolia	D				
Trichostema dichotomum			S	I	
Trifolium reflexum	D	L	S		
Trillium viride	D				
Triosteum perfoliatum	D	L			
Tripsacum dactyloides	D	(Gunter dolomite)			
Ulmus alata			S	I	
Uniola latifolia				I	C
Vaccinium arboreum			S	I	
V. stamineum			S		
V. vaccilans	D	(chert residuum)			
* *Valerianella bushii*	D	(White River Section)			
* *V. ozarkana*	D	(White River Section)			
V. radiata	D	L			
Verbena canadensis	D	L		I	
V. simplex	D	L			
Verbesina helianthoides			S	I	
Vernonia crinita	D	L			
Viburnum rufidulum	D	L			
Viola pedata	D	L	S	I	
V. sagittata				I	
Woodsia obtusa				I	C
Yucca glauca mollis	D				
Zanthoxylum americanum	D	L			
Zizia aptera	D	L		I	

Total 410 species.

1/D, dolomite; L, limestone; S, sandstone; I, igneous; C, chert; Sh, shale

BRYOPHYTES OF CEDAR GLADES

Paul L. Redfearn, Jr.
Department of Life Sciences
Southwest Missouri State University
Springfield, Missouri 65804

Abstract. Calcareous cedar glades are common in southwest Missouri. Seventy-four taxa are reported and listed as to their occurrence on soil, exposed rock surfaces, cedar trees, hardwood trees, or logs. A comparison is made of the bryofloras of calcareous glades of southwest Missouri with similar cedar glade habitats in Tennessee and the Edward's Plateau of Texas. The cedar glades of southwest Missouri and Tennessee are similar in floristic composition but dissimilar to the cedar glades of the Edward's Plateau. It is suggested that this difference is due to drier conditions in the latter.

Introduction

Cedar glades are common throughout much of southwest Missouri. They develop from open areas where the bedrock is close to the surface and has extensive horizontal outcroppings. Consequently, soils are usually thin and have little water retaining capacity. Though cedar glades may develop from sandstone, granitic, and rhyolitic rocks, this paper deals only with calcareous glades occurring on limestones or dolomitic limestones. Such glades may be characterized as alkaline habitats with irregular outcroppings of rock that produce horizontal and vertical bare exposures. Small rock fragments are also common. By any measure, vegetation of the cedar glades must be considered xerophytic. Yet, a remarkable diversity of bryophytes occur on the exposed rocks, thin soils, trees, and logs and it is the purpose of this paper to report on this diversity in the bryoflora and to compare the brylfloras of calcareous glades of southwest Missouri with similar cedar glade habitats in Tennessee and the Edward's Plateau of Texas.

In the discussion that follows it is important to recognize that the description of the bryoflora is based upon non-quantitative collection data and observations over a 20-yr period. Based on this experience, estimates of presence of a taxon in a particular cedar glade habitat have been made and range from rare (probably present in a particular habitat in less than 25% of the glades), to uncommon (probably present in a particular habitat in 25-60% of the glades), to common (probably present in a particular habitat in 60-100% of the glades). the nomenclature of the taxa follows Conard and Redfearn (1979).

The distribution of a bryophyte in an areas is largely governed by microhabitats such as the degree of shading and the type of substrate upon which it is growing. For the purpose of this survey the habitats of bryophytes in cedar glades have been divided into the following categories:

1) Epilithic habitats. - rock surfaces with negligible accumulation of soil beneath the bryophyte colony.
2) Soil habitats. - soil may be relatively thin, only about 2-5 cm deep, or deeper soils often with numerous fragments.
3) Corticolous and epixylic habitats. - at the base of or on the trunk or limbs of cedars and hardwoods, or on logs.

Epilithic Habitats

On rocks that are essentially unshaded and horizontal, the common species are *Grimmia alpicola, G. apocarpa, Orthotrichum strangulatum, Ptychomitrium incurvum, Hedwigia ciliata,* and *Desmatodon plinthobius.* All of these species may be locally frequent and have extensive coverage. This is particularly true for *Hedwigia ciliata,* the species of *Grimmia,* and *Orthotrichum strangulatum.* Species that are uncommon on unshaded rocks include *Entodon seductrix, Grimmia pilifera, G. laevigata,* and *Bryum pseudotriquetrum.* The latter species may form extensive mats on open rock surfaces where there is sufficient seasonal seepage. Species that may be considered rare in open rocky habitats are *Brachythecium acuminatum, Ptychomitrium leibergii, Tortula ruralis, Mannia gragrans,* and *Reboulia hemisphaerica. Tortula ruralis* may be locally abundant. *Ptychomitrium leibergii* is the rarest of the species occuring in cedar glades, being known from a single glade in Ozark County. On open vertical surfaces of large rocks *Anomodon rostratus* and *Bryum pseudotriquetrum* are uncommon.

On shaded horizontal rocks the common species are *Homomallium adnatum, Weissa controversa,* and *Anomodon rostratus.* Uncommon species are *Brachythecium oxycladon, Rhynchostegium serrulatum, Bryoandersonia illecebra,* and *Campylium chrysophyllum.* Along small drainage pathways *Amblystegium varium* is rare.

On vertical rocks surfaces that are shaded the common species are *Anomodon rostratus* and *Clasmatodon parvulus.* The latter species is particularly characteristic of vertical exposures of fissures. Uncommon species are *Anomodon attenuatus, Fissidens viridulus, Weissia controversa,* and *Frullania riparia. Drummondia prorepens, Fissidens subbasilaris,* and *Porella platyphylla* are rare.

Soil Habitats

Pleurochaete squarrosa may be considered a characteristic species of cedar glades. It grows on thin and deep soils in both the open and beneath cedar trees. It is certainly common, probably found in over 90% of the cedar glades in southwest Missouri. Its coverage is frequently extensive, forming large mats growing loosely on the soil. Other species that are common on soils in both the open and shade are *Bryum argenteum, Weissia controversa,* and *Bryum pseudotriquetrum.* Another common species is *Tortella humilis* though it is usually restricted to shaded soils at the bases of trees and rocks. Other species common on shaded soil are *Campylium chrysophyllum, Leucodon julaceus, Mnium cuspidatum, Fissidens cristatus, Brachythecium oxycladon, Thuidium recognitum, Fabronia ciliaris,* and *Taxiphyllum taxirameum.* The latter 2 species characteristically grow on soil beneath rock overhangs.

A number of species occur sporadically on soil in both the open and shade and may be considered uncommon. These are:

Anomodon attenuatus
Astomum muhlenbergianum
Atrichum angustatum
Barbula unguiculata
Bryoandersonia illecebra
Bryum bicolor
Bryum capillare
Dicranella heteromalla
Dicranum Scoparium
Eurhynchium hians
Eurhynchium pulchellum
Haplocladium virginianum
Leucobryum glaucum
Mnium affine var. *cilaire*
Rhynchostegium serrulatum
Thelia asprella
Lophocolea heterophylla
Mannia fragrans
Reboulia hemisphaerica

Many of these species such as *Dicranum scoparium, Leucobryum glaucum, Bryoandersonia illecebra* and *Lophocolea heterophylla* become common in adjacent hardwood forests.

Two species, *Physcomitrium pyriforme* and *Funaria flavicans,* characteristically appear on open soils during the spring. They are common.

Corticolous and Epixylic Habitats

The corticolous and epixylic flora of cedar glades is diverse. Species such as *Pylaisiella selwynii, Drummondia prorepens,* and *Leucodon julaceus* often cover extensive areas at the base or on the truck and limbs of trees. Other species such as *Tortula pagorum, T. papillosa, Orthotrichum* spp. and *Homalotheciella subcapillata* tend to be scattered and relatively small in coverage. Some species are abundant on the bases of trees or on logs. This is particularly true for *Thelia asprella* on bases of trees and *Leucodon julaceous* on logs. The most typical species growing on both cedars and hardwoods are *Tortula pagorum, Drummondia prorepens, Leucodon julaceus, Orthotrichum* spp. and *Pylaisiella selwynii.* The characteristic species growing on logs are *Entodon seductrix* and *Platygyrium repens.* The distribution of corticolous and epixylic species is shown in Table 1.

Comparison of the Bryofloras of Southwest Missouri with Tennessee and the Edward's Plateau of Texas

Geographers and ecologists are always interested in the floristic composition of areas with similar physiognomy. This is no less true for bryologists though comparisons may be more difficult. This is because bryophytes present in an area are easily overlooked or misidentified by even experienced collectors. Thus a comparison of floras may be spurious. This is certainly the case when the species lists being compared are compiled from reports prepared by different collectors. Some authors, particularly Grieg-Smith (1964) consider such comparisons naive when made between areas of different sizes. With these disclaimers in mind, it is still possible, using presence or absence data, to make an approximation of similarity between 2 floras using a Coefficient of Community (Whittaker 1975, Peilou 1979) calculated by the

Table 1. Corticolous and epixylic bryophytes of calcareous cedar glades of Southwest Missouri. c = common; u = uncommon; r = rare

Taxa	Cedars Base	Cedars Trunk	Hardwoods Base	Hardwoods Trunk	Logs
A. *Mosses*					
Amblystegium varium					r
Anomodon minor			c	c	
Brachythecium acuminatum			r		
Bryum pseudotriquetrum			r		
Campylium chrysophyllum					r
Campylium hisidulum	r		r		
Clasmatodon parvulus	r				
Drummondia prorepens		c	c	c	r
Entodon seductrix	r		c		c
Fabronia ciliaris		c		u	
Fissidens cristatus					r
Fissidens subbasilaris			c		
Haplohymenium triste		c		c	
Homalotheciella subcapillata		r		r	
Leskea gracilescens	u	u	c	c	
Leucodon julaceus		c		c	c
Lindbergia brachyptera		u		c	
Orthotrichum ohioense				u	
Orthotrichum pussilum		c		c	
Orthotrichum stellatum				r	
Platygyrium repens					c
Pylaisiella selwynii		c		c	u
Rhynchostegium serrulatum			u		
Sematophyllum adnatum					r
Thelia asprella	c		c		r
Thelia hirtella		c		c	
Tortella humilis	c		c		u
Tortula pagorum		c		c	
Tortula papillosa		r			
B. *Liverworts*					
Frullania brittoniae		r			
Frullania eboracensis		c		c	
Frullania riparia	u	u			
Frullania squarrosa				u	
Porella platyphylla		r			
Porella platyphylloidea		u		u	

following equation:

$$\text{Coefficient of Community (CC)} = \frac{2c}{a + b}$$

Where a is the total taxa in 1 community,

b is the total taxa in the comparison community, and

c is the taxa common to both communities.

Two communities that have all taxa in common will have a CC = 1. If 2 communities share no taxa in common, CC =0).

A comparison of the bryofloras of calcareous cedar glades of Tennessee, southwest Missouri, and the Edward's Plateau of Texas is shown in Table 2. The taxa listed for southwest Missouri and the Edward's Plateau are based upon my own collections. The taxa listed for Tennessee are based on reports by Quarterman (1947, 1949). From Table 2 the following comparisons are possible:

Table 2. Bryophytes present in the calcareous cedar glades of southwest Missouri, Tennessee, and the Edward's Plateau of Texas

Taxa	Southwest Missouri	Tennessee	Edward's Plateau
Mosses			
Amblystegium serpens (Hedw.)B.S.G.		x	
Amblystegium varium (Hedw.) Lindb.	x	x	
*Anomodon attenuatus (Hedw.) Hue*b.	x	x	
Anomodon minor (Hedw.) Fuernr.	x	x	
Anomodon rostratus (Hedw.) Schimp.	x	x	
Astomum muhlenbergianum (Sw.) Grout	x		
Atrichum angustatum (Brid.)B.S.G.	x		
Barbula acuta (Brid.)Brid. var. *bescherellii* (Sauerb. *ex* Jaeg. & Sauerb) Crum			x
Barbula unguiculata Hedw.	x		
Brachythecium acuminatum (Hedw.)Aust.	x		
Brachythecium oxycladon(Brid.)Jaeg. & Sauerb.	x		
Brachythecium salebrosum(Web. & Mohr.)B.S.G.		x	
Bryoandersonia illecebra (Hedw.) Robins.	x	x	
Bryum argenteum Hedw.	x		
Bryum bicolor Dicks.	x		
Bryum calillare Hedw.	x	x	
Bryum pseudotriquetrum (Hedw.) Gaertn., Meyer & Schreb.	x		x
Bryum billardieri Schwaegr			x
Bryum caespiticium Hedw.			x
Campylium chrysophyllum (Brid.) J. Lange	x	x	
Campylium hispidulum (Brid.) Mitt.	x	x	
Ceratodon purpureus (Hedw.) Brid.			x
Clasmatodon parvulus (Hampe) Hook. & Wils.	x	x	
Climacium americanum Brid.		x	
Cryphaea glomerata B.S.G. *ex* Sull.		x	
Desmatodon plinthobius Sull. & Lesq. *ex* Sull.	x		
Discranella heteromalla (Hedw.) Schimp.	x		
Dicranum scoparium Hedw.	x	x	
Drummonida prorepens (Hedw.) Britt.	x		
Entodon seductrix (Hedw.) C. Muell.	x	x	
Eurhynchium hians (Hedw.) Sande Lac.	x	x	
Eurhynchium pulchellum (Hedw.) Jenn.	x		
Fabronia cilaris (Brid.) Brid.	x		x
Fissidens cristatus Wils. *ex* Mitt.	x	x	
Fissidens osmumdoides Hedw.		x	
Fissidens subbasilaris Hedw.	x		
Fissidens taxifolius Hedw.	x	x	
Fissidens viridulus (Sw.) Wahlenb.	x	x	x
Funaria flavicans Michx.	x		
Grimmia alpicola-apocarpa complex	x	x	x
Grimmia laevigata (Brid.) Brid.	x		
Grimmia pilifera P. - Beauv.	x		
Grimmia rauii			x
Grimmia wrightii (Sull.) Aust.			x
Haplocladium virginianum (Brid.) Broth.	x		
Haplohymenium triste (Ces. *ex* De Not.) Kindb.	x	x	
Hedwigia ciliata (Hedw.) P. -Beauv.	x		
Homalotheciella subcapillata (Hedw.) Broth.	x	x	
Leskea gracilescens Hedw.	x	x	
Leskea obscura Hedw.		x	
Leskeela nervosa (Brid.) Loeske		x	

Table 2. continued

Taxa	Southwest Missouri	Tennessee	Edward's Plateau
Leucobryum glaucum (Hedw.) Angstr. ex Fr.	x	x	
Leucodon brachypus Brid.		x	
Leucodon julaceus (Hedw.) Sull.	x	x	x
Lindbergia brachyptera (Mitt.) Kindb.	x	x	
Mnium affine Bland. *ex* Funck, var. *ciliare* C. M.	x		
Mnium cuspidatum Hedw.	x	x	
Orthotrichum diaphanum Brid.			x
Orthotrichum ohioense Sull. & Lesq. *ex* Aust.	x	x	
Orthotrichum pusillum Mitt.	x	x	
Orthotrichum stellatum Brid.	x	x	
Orthotrichum strangulatum P. -Beauv.	x	x	
Physcomitrium pyriforme (Hedw.) Hampe	x	x	
Platygyrium repens (Brid.) B.S.G.	x	x	
Pleurochaete squarrosa (Brid.) Lindb.	x	x	x
Pylaisiella selwynii (Kindb.) Crum, Steere & Anderson	x	x	
Ptychomitrium incurvum (Schwaegr.) Spruce	x		
Ptychomitrium leibergii Best	x		x
Rhynchosetegium serrulatum (Hedw.) Jaeg. & Sauerb.	x	x	
Sematophyllum adnatum (Michx.) Britt.	x	x	
Sterophyllum radiculosum (Hook.) Mitt.			x
Taxiphyllum deplanatum (Bruch & Schimp. *ex* Sull.) Fleisch.		x	
Taxiphyllum taxirameum (Mitt.) Fleisch.	x	x	
Thelia asprella Sull.	x		x
Thelia hirtella (Hedw.) Sull.	x	x	
Thuidium recognitum (Hedw.) Lindb.	x	x	
Tortella humilis (Hedw.) Jenn.	x	x	x
Tortula pagorum (Milde) De Not.	x	x	x
Tortula papillosa Wils. *ex* Spruce	x		
Tortula ruralis (Hedw.) Gaertn. Meyer & Scherb. var. *ruralis*	x		
Trichostomum jamaicense (Mitt.) Jaegr. & Sauerb.			x
Weissia controversa Hedw.	x	x	x
Weissia ligulifolia (Bartr.) Grout	x	x	x
Liverworts			
Asterella tenella (L.) P. Beauv.		x	
Cephaloziella sp.		x	
Fossombronia brasiliensis Steph.		x	
Frullania brittoniae Evans	x	x	
Frullania ebolacensis Gott.	x	x	x
Frullania inflata Gott.	x	x	
Frullania riparia Hampe *ex* Lehm	x	x	
Frullania squarrosa (Reinw. et al.) Dum.	x	x	x
Lophocolea heterophylla (Schrad.) Dum.	x	x	
Mannia fragrans (Balbis) Frye & Clark		x	
Porella platyphylla (L.) Pfeiff.	x	x	
Porella platyphylloidea (Schwein.) Lindb.	x	x	

Table 2. continued

Taxa	Southwest Missouri	Tennessee	Edward's Plateau
Radula complanta (L.) Dum.		x	
Reboulia hemisphaerica (L.) Raddi	x		x
Riccia macallisteri M. A. Howe		x	

Total taxa in cedar glades of Tennessee	61
Total taxa in cedar glades of southwest Missouri	74
Total taxa in cedar glades of the Edward's Plateau	25
Taxa common to cedar glades of Tennessee and southwest Missouri	46
Taxa common to cedar glades of Tennessee and the Edward's Plateau of Texas	9
Coefficients of Community (CC)	
Southwest Missouri - Tennessee	0.68
Southwest Missouri - Edward's Plateau	0.30
Tennessee - Edward's Plateau	0.21

These relationships can be visualized in the form of a plexus (Fig. 1.) where the distance between the cedar glade floras is proportional to their dissimilarity (1 - CC), the width between the connecting lines is proportional to the CC, and the diameter of the circles is proportional to the total number taxa present. It is obvious that the bryofloras of the calcareous cedar glades of southwest Missouri and Tennessee are much more similar to each other than they are to the bryoflora of the Edward's Plateau of Texas.

The cause for the difference between the bryofloras of Tennessee and southwest Missouri with the bryoflora of the Edward's Plateau appears to be in the difference in the moisture relations of these areas (Table 3). The Edward's Plateau has significantly less precipitation, a much higher mean lake evaporation and over twice as many days when the temperature exceeds 32°C than does southwest Missouri and Tennessee. However, the moisture conditions between Tennessee and southwest Missouri are not that different and probably will not explain the difference between their bryofloras. Furthermore, nearly all the taxa reported in the cedar glades of Tennessee but not from the cedar glades of southwest Missouri do occur in other habitats in southwest Missouri. The same may be said for the taxa reported from the cedar glades of southwest Missouri but not in the cedar glades of Tennessee. In fact, only 1 species, *Ptychomitrium leibergii*, a

Table 3. Climatic data for southwest Missouri, middle Tennessee, and the Edward's Plateau of Texas. Estimates based on the Climatic Atlas of the United States

Study Location	Mean Lake Evaporation -cm/year	Mean No. Days Temp above 32°C	Avg Ppt - cm May-Sept	Avg Ppt - cm Total	Avg Temp °C Jan	Avg Temp °C July
Middle Tennessee	96.5	40	45.7	122.0	4.5	25.6
Southwest Missouri	101.2-106.7	40	53.3	101.6	1.1-2.2	24.4-25.6
Edward's Plateau of Texas	172.7-188.0	90-110	33.0	63.5	4.5-10.0	27.8-28.9

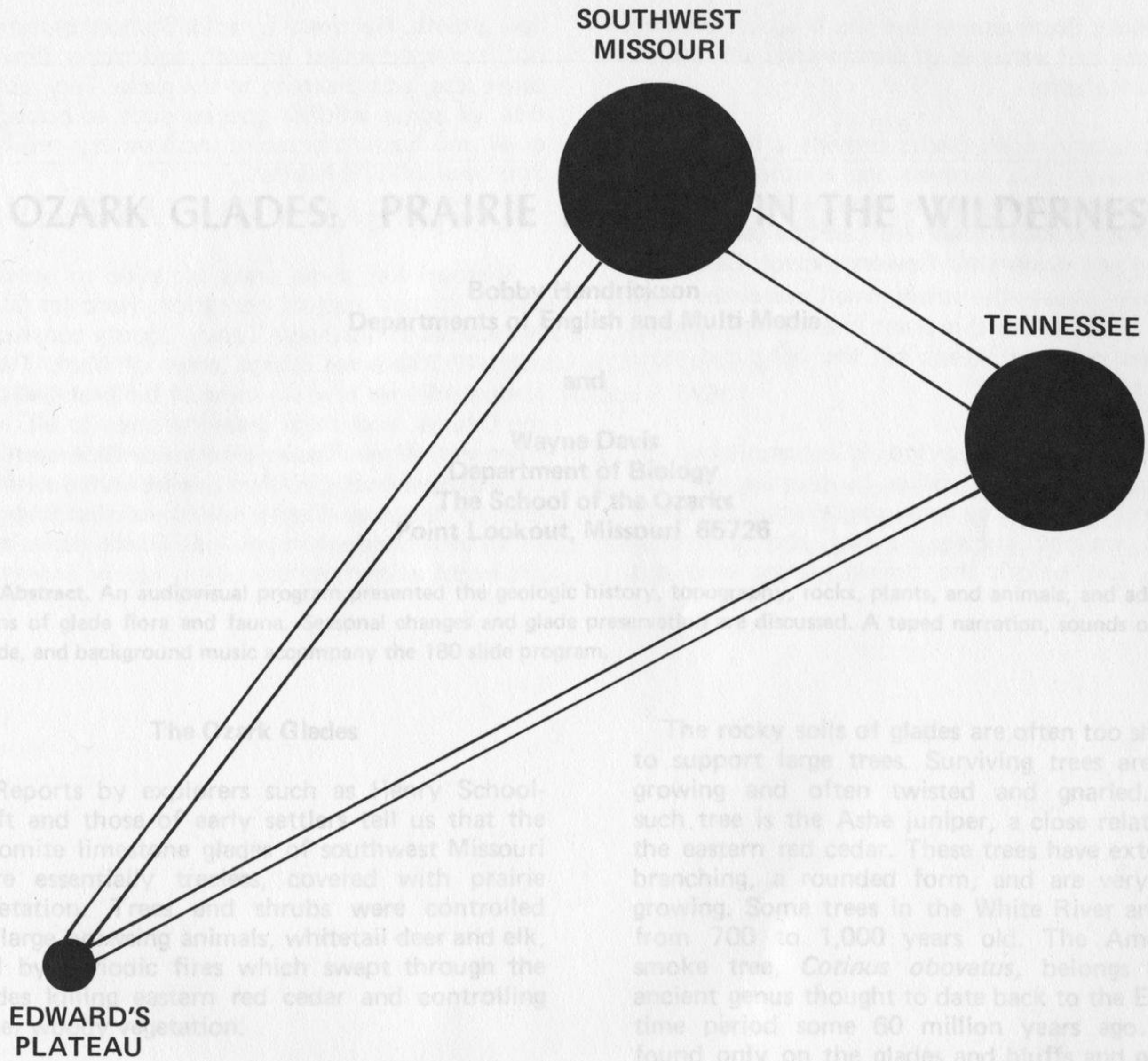


Fig. 1. Plexus diagram of bryophytic floras of calcareous glades of southwest Missouri, Tennessee, and the Edward's Plateau of Texas.

species with a decidedly western distribution, is missing from the bryoflora of Tennessee. It may be that the difference between southwest Missouri and Tennessee cedar glade floras are not significant and are due to the random dispersion of taxa or to insufficient collections. On the other hand, the differences may be significant and due to subtle, yet undetected ecological or geographical factors.

Acknowledgements

This paper is based upon research funded by the National Science Foundation grants GN 9059, GB 67, GB 4095, and the Research Committee of Southwest Missouri State University.

Literature Cited

Conard, H. S. and P. L. Redfearn, Jr. 1979. How to Know the Mosses and Liverworts. 2nd ed. Wm. C. Brown Co. Pub., Dubuque.

Greig-Smith, P. 1964. Quantitative Plant Ecology. 2nd ed. Butterworth & Co., Washington.

Quarterman, Elsie. 1947. A preliminary survey of the bryophytes of two cedar glades. Bryologist 50:377-380.

____________. 1949. Ecology of cedar glades. III. Corticolous bryophytes. Bryologist 52: 153-165.

U. S. Government Printing Office. 1969. Climatic Atlas of the United States. U. S. Dept. of Commerce. Wash., D.C. 80 pp.

Whittaker, R. H. 1975. Communites and Ecosystems. 2nd ed. Macmillan Publishing Co., Inc., New York.

Table 2, continued

Taxa	Southwest Missouri	Tennessee	Edward's Plateau
Radula complanata (L.) Dum.		x	
Reboulia hemisphaerica (L.) Raddi	x		x
Riccia macallisteri M. A. Howe		x	

Total taxa in cedar glades of Tennessee	61
Total taxa in cedar glades of southwest Missouri	74
Total taxa in cedar glades of the Edward's Plateau	25
Taxa common to cedar glades of Tennessee and southwest Missouri	46
Taxa common to cedar glades of Tennessee and the Edward's Plateau of Texas	9
Coefficients of Community (CC)	
Southwest Missouri - Tennessee	0.68
Southwest Missouri - Edward's Plateau	0.30
Tennessee - [illegible]	[illegible]

These relationships can be visualized in the form of a plexus (Fig. 1) where the distance between the cedar glade floras is proportional to their dissimilarity (1 - CC), the width between the connecting lines is proportional to the CC, and the diameter of the circles is proportional to the total number taxa present. It is obvious that the bryofloras of the calcareous cedar glades of southwest Missouri and Tennessee are much more similar to each other than they are to the bryoflora of the Edward's Plateau of Texas.

The cause for the difference between the bryofloras of Tennessee and southwest Missouri with the bryoflora of the Edward's Plateau appears to be in the difference in the moisture relations of these areas (Table 3). The Edward's Plateau has significantly less precipitation, a much higher mean lake evaporation and over twice as many days when the temperature exceeds 32°C than does southwest Missouri and Tennessee. However, the moisture conditions between Tennessee and southwest Missouri are not that different and probably will not explain the difference between their bryofloras. Furthermore, nearly all the taxa reported in the cedar glades of Tennessee but not from the cedar glades of southwest Missouri do occur in other habitats in southwest Missouri. The same may be said for the taxa reported from the cedar glades of southwest Missouri but not in the cedar glades of Tennessee. In fact, only one taxa, [illegible]

Table 3. Climatic data for southwest Missouri, middle Tennessee, and the Edward's Plateau of Texas. (Estimates based on the Climatic Atlas of the United States.)

Location	Precipitation cm/year	[illegible]	Mean lake evaporation May-Sept	Total	Mean temp. Jan	[illegible] °C
Middle Tennessee	96.5	40	[illegible]	[illegible]	[illegible]	[illegible]
Southwest Missouri	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Edward's Plateau	172.7-	90-	33.0	63.5	4.5-	27.8-
	[illegible]	[illegible]		[illegible]	4.0	28.9

OZARK GLADES: PRAIRIE ISLANDS IN THE WILDERNESS

Bobby Hendrickson
Departments of English and Multi-Media
and
Wayne Davis
Department of Biology
The School of the Ozarks
Point Lookout, Missouri 65726

Abstract. An audiovisual program presented the geologic history, topography, rocks, plants, and animals, and adaptations of glade flora and fauna. Seasonal changes and glade preservation are discussed. A taped narration, sounds of the glade, and background music accompany the 180 slide program.

The Ozark Glades

Reports by explorers such as Henry Schoolcraft and those of early settlers tell us that the dolomite limestone glades of southwest Missouri were essentially treeless, covered with prairie vegetation. Trees and shrubs were controlled by large browsing animals, whitetail deer and elk, and by periodic fires which swept through the glades killing eastern red cedar and controlling other woody vegetation.

These open glades furnished grazing for the cattle and horses of early Ozark settlers. The dried prairie grasses were nutritious enough to sustain livestock through the winter, but overgrazing occurred and a slow deterioration of the glades began. Preferred plants such as big bluestem and prairie clover decreased in abundance. Soil erosion was accelerated. Forest fires stopped at the glade edge because there was insufficient fuel to burn. The elk population was greatly reduced in numbers and so cedars, winged elm, and Carolina buckthorn became more plentiful.

Today, it is primarily on the southern and western slopes of Ozark mountains that we still find the fascinating open areas known as glades. The glades are characterized by the Gasconade soil type occasionally a few inches deep, rocky outcroppings, and vegetation that reflect the rigors and challenges of survival on the glades. The tenacity for life on Ozark glades is dramatically exhibited by plants that literally split the rocks. Lichens add color to the limestone and slowly wear away the rocks adding year by year to the sparse soils.

The rocky soils of glades are often too shallow to support large trees. Surviving trees are slow growing and often twisted and gnarled. One such tree is the Ashe juniper, a close relative of the eastern red cedar. These trees have extensive branching, a rounded form, and are very slow growing. Some trees in the White River area are from 700 to 1,000 years old. The American smoke tree, *Cotinus obovatus,* belongs to an ancient genus thought to date back to the Eocene time period some 60 million years ago. It is found only on the glades and bluffs and gets its name from the bluish-gray smokelike appearance of its fruiting sprays. Eastern red cedars usually grow in rows at the base of the slablike outcroppings of dolomitic limestone called benches. Here the soil is deeper and crevices in the bedrock offer the cedar roots more growing room. Since the eastern red cedar is the dominant tree species on the glades, natives often refer to the glades as "cedar glades".

A glade may cover an entire mountainside, but more commonly it will be long and narrow, occupying the relatively flat space between parallel benches. A chief characteristic of glades is their extreme dryness. Rainwater quickly runs off, and even the summer dew is burned away by early morning, leaving glades similar to the arid southwest, providing habitat for desert-like plants and animals. Roadrunners, scorpions, collared lizards, prickly pear, brush or Texas mice, as well as American aloe and stonecrop reinforce impressions of an arid climate. The Ozark flavor of the glades is reflected in local plant names such as the goat's beard. The blossom and seed head of this plant are sometimes mistaken for a gigantic dandelion. Some plants like the Missouri evening primrose and varieties of penetemons are unique to Ozark glades.

The sunny, open glades provide a habitat for wild flowers that succeed one another in short, highly specialized growing seasons. But many of these blossoms are small and can't be seen from a passing car. Such tiny flowers include *Calamint.* This mint causes the strong smell associated with glades. Natives say this plant, mashed and spread on ones clothing, keeps off the ticks and mosquitoes.

Today glade restoration is accomplished by control of trees and shrubs by burning and cutting and may involve some seed planting. Usually cedars are cut, allowed to dry, and burned in spring just before the prairie grasses send out new growth. Recovery is rapid. Stunted bluestems put out spectacular growth, and many flowers, some rare, add diversity to the glade. The population of some wildlife species such as bobwhite quail and Eastern bluebird increase as a result of improved wildlife habitat.

Missouri has some areas set aside to preserve glades in their natural condition. Hercules Glade Wilderness in northeast Taney County consists of over 12,300 acres. Large areas of Mark Twain National Forest contain some of the best glades in the Ozarks, and these areas are open to all. Hercules and Mark Twain glades are best seen up close and on foot, and they can be visited without fear of trespass. Come see these dazzling life forms first-hand when you visit Ozark glades-prairies in the wilderness.

A VEGETATIVE ANALYSIS OF HERCULES GLADES WILDERNESS

Janet L. Hicks
Department of Life Sciences
Southwest Missouri State University
Springfield, Missouri 65804

Abstract. Sites in the tallgrass prairie-like glade region of southwest Missouri were studied quantitatively. Bray-Curtis ordination techniques of indirect gradient analysis were applied to the data in an attempt to reveal distinct successional stages in the glade development. Only sites with highly obvious varying exposures, aspects, soil depth, slopes, and position on the slope were discernable by this manner. Floristic composition, special vegetative adaptations to the glade environment, geologic and cultural history, and glade management problems are also discussed.

A VEGETATIVE ANALYSIS OF HERCULES GLADES, WILDERNESS

Janet L. Hicks
Department of Life Sciences
Southwest Missouri State University
Springfield, Missouri 65804

Abstract: Sites in the tallgrass prairie-like glade region of southwest Missouri were studied quantitatively. Bray-Curtis ordination techniques and indirect gradient analysis were applied to the data in an attempt to reveal distinct successional stages in the glade development. Only sites with highly obvious varying exposures, aspects, soil depth, slopes, and position on the slope were discernable by this manner. Floristic composition, special vegetative adaptations to the glade environment, geologic and cultural history, and glade management problems are also discussed.

SESSION III. Ecological Studies in Tallgrass Prairie.
Clair L. Kucera, Presiding

A wide range of subjects dealing with structure and function of the grassland ecosystem is discussed in the following papers. Phytosociological analyses and taxonomic surveys are requisites for evaluating successional changes, and for validating our understanding of the physiological process. Kaul provides a comprehensive description of prairie flora in the canyon region of Nebraska. Species diversity and similarity indices are employed. Comparable data are presented by Lura for South Dakota prairie. Floristic surveys are provided by Iffrig for Missouri loess-hill prairies, by Schwarzmeier and Bielefeldt for Wisconsin prairie, and by Thompson for a prairie tract in Ontario. An island biogeographical approach to the study of Wisconsin prairie is employed by Nepstad and Hoffines. Successional evaluations of small mammal populations over a 30-year span are discussed by Kettle and Fitch for Kansas prairie undergoing vegetational change. In a second paper these authors discuss prairie recovery following disturbance, emphasizing its retardation. Destruction of grassland habitat and its effects on the lesser prairie chicken in Kansas are analyzed by Sexson. Cattle-prairie dog interactions are discussed by Uresk and Bjugstad. The seasonal dynamics of sand prairie in Wisconsin in relation to resource availability are analyzed by Plumb-Mentjes. Studies from Oklahoma and Ohio prairies by Kapustaka provide valuable insights on nitrogen economies in prairie, and are compared with agricultural systems. Seasonal variations in C_3 and C_4 grass biomass are shown by Bultsma and Tieszen for South Dakota prairies; related selectivity and utilization by cattle and bison are also discussed.

PRAIRIE DOGS AS ECOSYSTEM REGULATORS ON THE NORTHERN HIGH PLAINS

Daniel W. Uresk
and
Ardell J. Bjugstad
USDA-Forest Service
Rapid City, South Dakota 57701

Abstract. The increase in prairie dog populations on the northern High Plains has emphasized the need for additional information on cattle-prairie dog forage relationships. To obtain information on cattle-prairie dog forage relationships, 4 treatments were evaluated over 4 growing seasons. These treatments were: 1) no grazing (prairie dogs eliminated and cattle excluded), 2) grazing by prairie dogs, 3) grazing by cattle and 4) grazing by cattle and prairie dogs. In addition, forage utilized by cattle and prairie dogs was assessed. Standing crop values were obtained on all treatments by plant species under cages, and forage utilization was assessed by harvesting under cages and outside cages. Results indicate major differences among treatments. Peak standing crop values on the prairie dog treatment was 24% higher when compared to the cattle only grazing treatment. Cattle plus prairie dogs was 13% higher than the cattle treatment followed by no grazing, which was about equal with a 2% increase. Grasses showed an increase on both the no grazing, cattle plus prairie dog treatments (4%) followed by a decrease on the prairie dog treatement (-6%) when compared to the cattle treatment only. Forbs increased on the prairie dog treatment (+165%) followed by no grazing (+91%), and the cattle plus prairie dog treatment (+76%) when compared to the cattle treatment. Utilization by cattle and prairie dogs was 37% in June and 56% in August. After 4 years active prairie dog burrows were highest on the prairie dog plus cattle treatment with 95/acre, while on the praire dog treatment 43/acre were present. Data on standing crop values are presented for prairie dog-cattle relationships by treatments and forage utilization.

Introduction

Much time, money and effort have been spent on attempts to reduce prairie dog populations in the western United States. In the past, justifications for these efforts centered on reducing reservoirs of contagious diseases spread by prairie dogs. More recently, control of the black-tailed prairie dog (*Cynomys ludovicianus*) has been deemed necessary to improve the forage and livestock production on rangelands.

The degree of competition between cattle and prairie dogs has not been fully assessed. Hansen and Gold (1977) showed that the proportions of different plant species consumed by prairie dogs and cattle were similar having a r_s value of 0.8 and a similarity index of 0.65. Taylor and Loftfield (1924) concluded that Zuni prairie dogs (*Cynomys gunnisoni zuniensis*) destroy 80% of the total annual production of forage and may come into direct competition for forage with cattle. Summers and Linder (1977) determined that the 5 important forage species for black-tailed prairie dog were buffalograss, scarlet globemallow, threadleaf sedge, blue grama, and western wheatgrass. Bonham and Lerwick (1976) found that plant species diversity and livestock use of plant species was greater on than off prairie dog towns.

A study was initiated to examine prairie dog-cattle-vegetation interactions and to clarify the role of prairie dogs in rangeland ecosystems. The objective of this study was to compare differences in total plant production in response to 4 treatments. These treatments were 1) poisoning of prairie dogs followed by no grazing by either prairie dogs or cattle, 2) grazing by prairie dogs only, 3) grazing by cattle only, and 4) grazing by both cattle and prairie dogs.

Study Area

This study was conducted on prairie dog towns in the lower Sage Creek and Conanta West grazing allotments of the Buffalo Gap National Grasslands near Wall, South Dakota over a 5-year period. The dominant vegetation on this site consisted primarily of blue grama and buffalograss.

Results and Discussion

Peak plant production of above ground herbage over a 5 year period where only prairie dogs grazed, was higher during the last 4 years than under the other 3 treatments (Fig. 1). Production values where the cattle plus prairie dogs grazed were generally higher than those for areas only by cattle and the ungrazed area. Variation in values across years was a reflection of yearly precipitation differences. The second year (1976) was one of drought while the fourth year (1978) was considered a wet year. Only 3 years of data were presented for the cattle only grazing treatment, since the area was invaded by prairie dogs during the fourth season (1978).

One of the main points of this study was to compare the response of the vegetation under cattle grazing to responses under the other treatments. Treatment effects on the total vegetation relative to the cattle grazing treatment are shown in Fig. 2. The results clearly show that when all years are averaged, plant production where prairie dogs only grazed was approximately 24% higher than under the cattle only grazing. Plant production on sites grazed by cattle and prairie dogs together was 13% higher than under cattle grazing alone. Under no grazing the average production was about the same as the cattle treatment. During the dry year (1976), the total herbage production on sites grazed by cattle and prairie dog together was approximately 15% less than the cattle only grazing treatment. However, during wetter years production was much higher than that found on the cattle only grazing treatment.

Grass production was the lowest when grazed only by prairie dogs during the first 4 years, when compared to the other 3 treatments. Production of grasses on the ungrazed and cattle plus prairie dog treatments was about equal until the fourth yr., when the ungrazed treatment produced approximately 1200 lbs. of grass per acre (1365 kg/ha) compared to about 800 lbs./acre (906) kg/ha) under the other 2 treatments. During the fifth year (1979) grass production was 1349, 1188, and 987 lbs./acre on the prairie dog, cattle plus prairie dog, and ungrazed treatments, respectively. This increase in grass production may be the result of decreased population densities of prairie dogs on the areas grazed by prairie dogs only.

Forbs production was higher when grazed only by prairie dogs during the last 4 years of the study, and lowest for the ungrazed treatment. Forb production was higher throughout the 3 years under the prairie dog grazing, when compared to the cattle only grazing. All treatments were higher in forb production during the first year of harvest, but steadily decreased when compared to the cattle only grazing. Forbs were generally produced more on the cattle plus prairie dog treatment, except during a dry year when the forb production was approximately equal to the cattle grazing treatment.

When averaging the percentage values by treatment over the first 3 year period, forb production

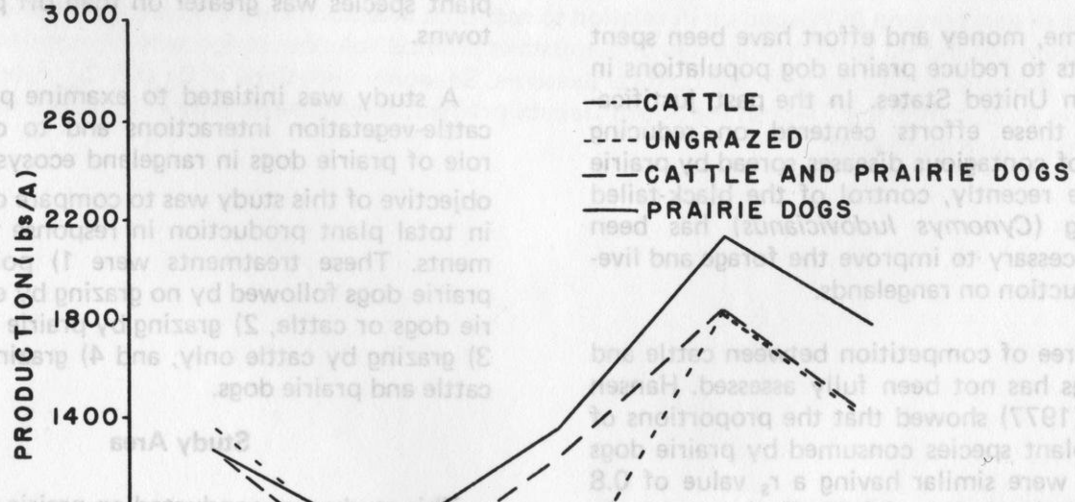


Fig. 1. Peak plant production under 4 treatments, cattle, ungrazed, cattle plus prairie dogs, and prairie dogs, and prairie dogs over a 5-year period, with peak plant production equal to the sum of the peaks for the forb and grass categories.

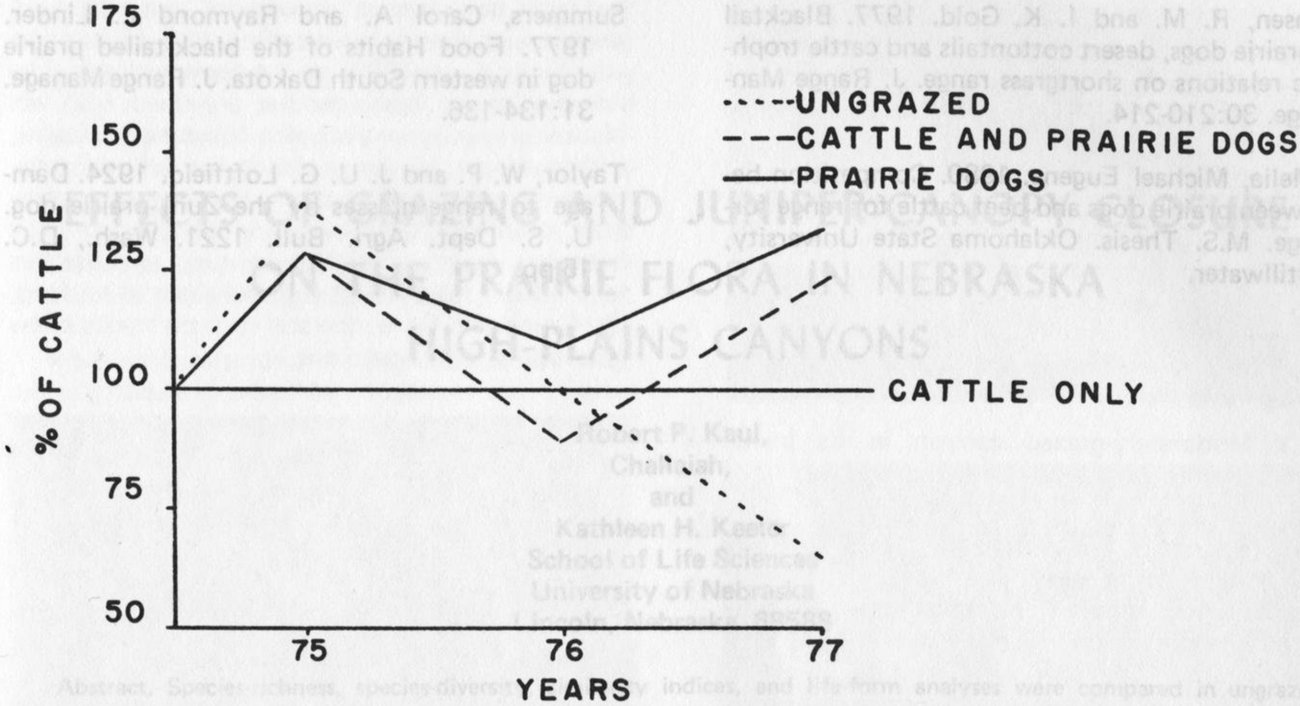


Fig. 2. Production response of total vegetation under different treatments adjusted as a percent of cattle-only treatment over 3 years.

was higher under the prairie dog only grazing (+165%) followed by no grazing (+91%) and the cattle and prairie dog together grazing treatment (+76%) when compared to the cattle only grazing treatment. It appears that dry years may be the most critical in evaluating the various treatments for interactions among animals and forage.

Four years after initiation of the study, the area where only prairie dogs grazed had 43 active burrows per acre, while the area where cattle and prairie dogs grazed together had 95 active burrows per acre. This reduction in active burrow densities on the prairie dog treatment was attributed to taller vegetation occurring on the study areas. It appears that tall vegetation is not conducive to maintaining stable populations. Higher prairie dog densities are more closely related to livestock grazing, especially when rangelands are heavily grazed.

Several studies have examined weight gains of livestock on and off prairie dog towns. Hansen and Gold (1977) reported in Colorado that during the winter months cattle averaged no gains or losses on native and old field dog towns over 2 winters. O'Melia (1980) evaluated the effects that prairie dogs have on forage availability, utilization and steer gains. He found that prairie dogs decreased forage availability; however, this reduction did not influence steer weight gains when compared to steers not on prairie dog towns.

The black-tailed prairie dog is an ecosystem regulator as they manipulate the soil, increase plant diversity (Gold 1976, Bonham and Lerwick 1976) and increase animal density (Hansen and Gold 1977). Prairie dogs will enhance the habitat for desert cottontails, burrowing owls, rattlesnakes and some species of plants. O'Melia (1980) reported that 63% more small animals (other than prairie dogs) were live trapped on pastures having steers plus prairie dogs than on pastures with steers only. In addition, arthropod biomass on the steer-only pastures was significantly greater than on the steer-plus-prairie dog pastures. O'Melia stated that the number of arthropods in the steer-plus-prairie dog pastures were reduced by high populations of grasshopper mice, ground squirrels and burrowing owls.

Our study does show that increased plant production occurs on areas grazed by prairie dogs only and cattle plus prairie dogs. However, this increase may or may not account for the forage consumed by prairie dogs.

Literature Cited

Bonham, Charles D. and Alton Lerwick, 1976. Vegetation changes induced by prairie dogs on shortgrass range. J. Range Manage. 27:221-225.

Gold, Ilyse Karen. 1976. Effects of blacktail prairie dog mounds on shortgrass vegetation. M.S. Thesis. Colorado State University, Fort Collins.

Hansen, R. M. and I. K. Gold. 1977. Blacktail prairie dogs, desert cottontails and cattle trophic relations on shortgrass range. J. Range Manage. 30:210-214.

O'Melia, Michael Eugene. 1980. Competition between prairie dogs and beef cattle for range forage. M.S. Thesis. Oklahoma State University, Stillwater.

Summers, Carol A. and Raymond L. Linder. 1977. Food Habits of the black-tailed prairie dog in western South Dakota. J. Range Manage. 31:134-136.

Taylor, W. P. and J. U. G. Loftfield. 1924. Damage to range grasses by the Zuni prairie dog. U. S. Dept. Agri. Bull. 1221. Wash., D.C. 15 pp.

EFFECTS OF GRAZING AND JUNIPER-CANOPY CLOSURE ON THE PRAIRIE FLORA IN NEBRASKA HIGH-PLAINS CANYONS

Robert P. Kaul,
Challaiah,
and
Kathleen H. Keeler
School of Life Sciences
University of Nebraska
Lincoln, Nebraska 68588

Abstract. Species-richness, species-diversity, similarity indices, and life-form analyses were compared in ungrazed, moderately grazed, and heavily grazed canyons of the Nebraska high plains, and the effect of maturing of juniper forest on the herbaceous understory of prairie plants in these canyons was studied. Heavy grazing drastically reduces the number of species, while canopy closure gradually eliminates the prairie species, which are replaced by a very low number of shade-tolerant species. Comparisons were also made with the flora of a nearby sand dune, whose flora is much richer.

Introduction

Only a few unplowed or ungrazed sites remain in the North Platte River valley in Nebraska, and there is almost no literature on the native vegetation of the valley. The upland vegetation in presettlement times was short-grass prairie (Kaul 1975), but the escarpment on the south side of the valley is partially wooded and probably has been for a very long time (Wells 1968). We have studied the distribution and abundance of vascular plant species found in 4 canyons of the southern escarpment; some have never been grazed and others have been grazed at different intensities. Our purposes are to list all species in the canyons and on the prairies above them, to show the abundances of the species, to indicate possible effects of grazing and juniper growth on the prairie species, and to suggest further research.

The Study Sites

We studied 4 canyons near the Cedar Point Biological Station of the University of Nebraska, whic is located in Keith County, on the Colorado border. The canyons are about 300 feet deep at their deepest and a mile long at the longest. Their bases are ca. 3100 feet elevation where they open into the North Platte River valley. The canyons are more or less parallel and trend north-south. They were formed by short, north-flowing, intermittent streams that empty into the river at the foot of each canyon. They are usually dry but after heavy rains are prone to intense flashflooding. The canyons are U-shaped in section in their lower reaches and V-shaped in the uppermost reaches where their walls often form deep, narrow gorges. There is no comparable set of canyons on the north side of the river. Instead, the vast sandhills there cover the canyon-forming strata (Diffendal and Pabian undated).

The canyon walls are steep or even sheer in some places and sloping in others (Figs. 1 and 4). There are, altogether, 17 exposed horizons of Tertiary deposits of sands, silts, gravels, volcanic ashes, sandstones, and carbonate rocks; these are capped at the tops of the canyons by about 10 feet of Pleistocene loess (Diffendal and Pabian undated). Large and small carbonate boulders have broken from some strata and are visible on the lower slopes (Figs. 1-4). Many strata are fossiliferous and have yielded evidence of previous dry climates similar to that of the present day. Root casts of yucca, grasses, and other prairie plants are abundant in some of the horizons, as are fossil seeds of prairie-type plants and of *Celtis*, the hackberry tree, (Diffendal and Pabian undated) which still grows on some canyon floors. Animal fossils show that horses, rhinoceroses, camels, and elephants once lived here too (Diffendal and Pabian undated).

Deep erosion into these strata has occurred from Pleistocene times to the present and continuing erosion is easily demonstrated in the

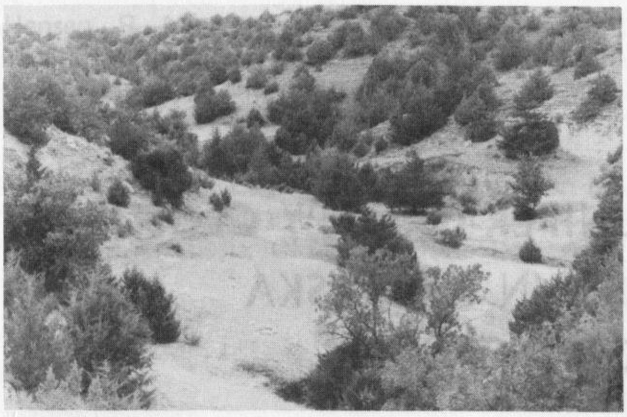


Fig. 1. Moderately-grazed canyon in its lower reaches; deciduous trees are *Populus*.

fresh deposits of alluvium that have partially buried some living trees. The fury of the water as it roars over some of the temporary waterfalls and gouges the channels can be witnessed after a thunderstorm. The colluvium of the slopes is very recent (Diffendal and Pabian undated) but is rather stable because of its cover of vegetation.

The canyon slopes are sandy silt, with abundant sandstone and carbonate rocks in some places. The canyon floors are somewhat more silty, except that the streambeds are almost pure sand. A large sand talus occurs at the mouth of on canyon and its flora is here compared with that of the canyons and also with that of the sandhills across the river.

The climate is strongly dry-continental, with about 18 in. of annual precipitation. Winter precipitation is mostly less than 1 inch per month, although heavy snows occur in some winters while others are dry for months. The wettest months are May, June, and July, with about 9 in. falling in those months, on average. Variations in monthly and annual precipitation between years are great and droughts, some of them extreme, occur in about 60% of the months.

Summer temperatures reach 90 F or higher on about 46 days of each year, on average, and air temperatures over 100 F are frequent. Soil and rock temperatures can reach 120 F. Winters are relatively less extreme, with only an average of 32 or fewer days with maxima below 32 F. Mean montly sunshine in May to September ranges from 60-72%. All climatological data are from Lawson et al. (1977).

The summers of 1976 and 1978, when the field studies were made by the first author, were exceptionally hot and dry. The summer of 1975 was also very hot and dry, but that of 1977 was unusually wet and cool.

There is extensive growth of *Juniperus virginiana* (apparently intergrading with *J. scopulorum* (Flake et al. 1978) on the canyon slopes. The streams in the lower reaches are lined with ash (*Fraxinus pennsylvanica*), elm (*Ulmus americana*), and hackberry *(Celtis occidentalis)*; a few cottonwoods (*Populus* spp.) occur at the canyon mouths. Most of the large junipers are supposed to have been cut in the mid-19th century and used as railroad ties for the first transcontinental railroad, the Union Pacific, which still runs on tracks a few miles south of the canyons.

Fig. 2. Ungrazed canyon slopes; *Yucca glauca* is prominent with *Opuntia* spp. in middle foreground.

Fig. 3. Ungrazed canyon slope with *Yucca* and *Bouteloua;* sandy soil is largely obscured by heavy growth of gelatinous lichen and/or its phycobiont *Nostoc.*

Methods

Eighteen sites in 3 zones of the canyons were sampled, the canyon floors, the canyon slopes, and the loess prairie of the canyon tops. A fourth zone, the sand talus at the mouth of one canyon, was also sampled. Three degrees of grazing intensity were recognized by inspection: ungrazed areas that cattle cannot reach because of the topography or that have been fenced off for at least 40 years; moderately grazed areas either not easily accessible to cattle or preserved as reserve pastures and grazed only occasionally, according to local ranchers; and obviously heavily grazed areas where cattle regularly browse and congregate. We defined 8 site categories by topography and grazing; a ninth category is defined by canopy closure. All sites are visited by deer, with white-tailed deer preferring the canyons themselves and mule deer preferring the canyon tops.

We have interpreted the inaccessible and long-time exclosure areas to represent the original vegetation and we use them as the bases for comparison.

Fig. 4. Moderately-grazed canyon slope with cowpaths (catsteps); vigorous juniper reproduction is evidenced by the presence of all age classes.

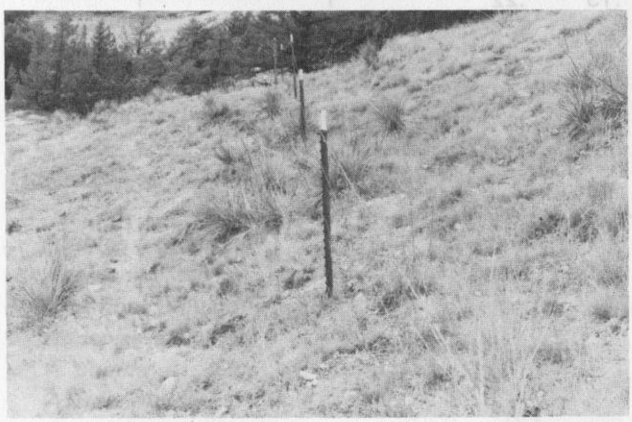


Fig. 5. Moderately-grazed canyon top (left, with cowpath) and canyon top ungrazed for at least 35 years (right).

Random quadrats were used to gather abundance data in 6 or the 9 categories. Most were 16x16 ft. but a few were 12x12 ft. These sizes are somewhat above the minimal suggested for grasslands by Westhoff and van der Maarel (1973). The choice of size was somewhat regulated by topography, inasmuch as the large quadrats could not be accommodated on the steeper rocky slopes. Data from all canyons were combined and standardized for 100 m^2. Some quadrats were counted in both years. In addition, extensive and repeated reconnaissance of the canyons in both years yielded numerous additions to the species lists beyond those found in the quadrats. These additions are mostly of the rarer and very widely distributed species of the canyons, and of a few, such as *Comandra umbellata var. pallida, Paronychia jamesii*, and *Astragalus kentrophyta*, that are restricted to ledges or the loess margins. Others, such as *Pellaea atropurpurea* and *Cystopteris fraiglis*, are found only in a few cool gorges.

Fig. 6. Closed-canopy juniper grove with *Oryzopsis micrantha* forming a sod under the trees.

Forbs and some grasses were counted as 1 plant if single-stemmed or if obviously clonal; most grasses and *Carex filifolia* were counted as 1 plant for each clump.

In 3 of the categories studied only species lists were made. These are presented in Table 1 along with abundance data from the other 6 categories. Also, all species found on sites where abundance data were taken are included, even though they did not occur in any of the quadrats.

Diversity Indices were calculated from the formula of Simpson (1948):

$$DI = 1 - \sum_{i=1}^{s} (P_i)^2$$

where P_i is the proportion of each species in the community. Values of the Community Dominance Index are obtained from the formula of McNaughton (1968):

$$CDI = 100 \times \frac{y_1 + y_2}{Y}$$

where y_1 and y_2 are the abundances of the 2 most dominant species, and Y is the total abundances of all species.

To compare floristic similarities we used the Index of Similarity of Sorenson (1948):

$$S = \frac{2C}{A+B} \times 100,$$

where A and B are the numbers of species in each of 2 sites being compared, and C is the number of species they have in common. Thus 2 sites with all species in common will have S = 100, and 2 sites with no species in common will have S = 0.

Voucher specimens of most species are deposited in the reference herbarium at Cedar Point Biological Station and in the State Herbarium at the University of Nebraska, Lincoln. Most of the specimens were collected by the first author. Generic and specific nomenclature used here follows that of the Atlas of the Flora of the Great Plains (Great Plains Flora Association 1977).

Table 1. Relative species abundance as percent of total number of individuals/100 m^2 by sites

Species	Site Category 1/								
	1	2	3	4	5	6	7	8	9
Compositae									
Ambrosia psilostachya		T[2]					.01		
A. trifida								T	
Artemisia campestris ssp. *caudata*						T		.15	
A. filifolia		T			.14	T		T	
A. frigida	1.08	T	.52	.11		T		4.79	
Aster spp.			.54	T		T			
Chrysopsis villosa			.04					.15	
Cirsium undulatum		T	.04	T		T			
Grindelia squarrosa						T	T	T	
Gutierrezia sarothrae	.03	T	.04	T				.45	
Haplopappus spinulosus		T	T	T		T		T	
Helianthus annuus				T		T	.27		
H. petiolaris								T	
Hymenopappus filifolius		T	.13	.22		T		T	
Iva xanthifolia								T	
Liatris punctata	.09	T	.65	.67				.15	
Lygodesmia juncea		T	.04	1.46		T		.90	
Ratibida columnifera				T		T			
Senecio plattensis				.11					
Solidago spp.			.43			T		T	
Thelesperma megapotamicum	.03	T	1.79	1.01		T		4.19	
Townsendia exscapa								T	
Tragopogon dubius								T	
Xanthium strumarium						T			
Gramineae									
Agropyron smithii									
Agropyron smithii					.28	T	.68		
Andropogon gerardi/hallii								.90	
A. scoparius		T	6.27	1.78		T		1.95	
Aristida fendleriana		T	.62	1.12	.04				
A. longiseta		T	.04	T		T		T	
Bouteloua curtipendula		T	.77	.11		T			
B. gracilis	67.00	T	36.88	62.00	11.72	T		62.11	
B. hirsuta			T	T	T	T		T	
Bromus japonicus								14.96	
B. tectorum					23.00		98.40		
Calamovilfa longifolia			.34					1.20	
Cenchrus longispinus								T	

Table 1. Continued

Species	1	2	3	4	5	6	7	8	9
	Site Category 1/								
Festuca octoflora					51.62		T	T	
Hordeum pusillum						T		T	
Koeleria pyramidata		T	.16					T	
Muhlenbergia cuspidata			T					T	
M. pungens								T	
Munroa squarrosa								T	
Oryzopsis hymenoides						T		T	
O. micrantha		T	T					T	
Panicum virgatum								T	
Paspalum setaceum v. *stramineum*								T	
Sitanion hystrix			.04	T				T	
Stipa comata	8.45	T	.44	2.68	11.35	T		4.19	
S. viridula								T	
Triplasis purpurea								T	
Leguminosae									
Astragalus adsurgens v. *robustior*			.09						
A. kentrophyta			.04	T				T	
Dalea enneandra	.02	T		.11	.05	T		T	
Glycyrrhiza lepidota						T		T	
Lupinus pusillus			T					T	
Melilotus albus						T		.15	
M. officinalis								T	
Oxytropis lambertii			.04	T				T	
Petalostemon candidum		T	2.01	.44				.15	
P. purpureum	T	.90							
P. villosum			T	T				T	
Psoralea argophylla				T				T	
P. digitata								T	
P. linearifolia			T			T		T	
P. tenuiflora	.06	T	.78	1.12	.06	T		.15	
Thermopsis rhombifolia		T	T					T	
Other Species									
Abronia fragrans								T	
Anemone patens			.39	T				T	T
Argemone polyanthemos						T	.01	T	
Asclepias lanuginosa								T	
A. pumila		T						T	
A. stenophylla								T	
A. spp.			.04	.11				T	
A. viridiflora				T					
Calylophus serrulatus		T	.38	.44				T	
Carex filifolia	23.00	T	37.96	16.52	.76	T		2.25	
Celtis occidentalis						T		T	
Cheilanthes feei			T	T					
Chenopodium spp.								T	
Clematis ligusticifolia				T		T		T	
Cleome serrulata						T	.49		
Comandra umbellata v. *pallida*		T	1.72	.33				T	
Commelina erecta								T	
Coryphantha vivipara				T				T	
Croton texensis						T	.01	T	

Table 1. Continued

Species	Site Category 1/ 1	2	3	4	5	6	7	8	9
Cryptantha jamesii					.06	T		.15	
Eriogonum annuum								T	
Euphorbia marginata				T		T	.03		
E. missurica						T	T	T	
Fraxinus pennsylvanica						T		T	
Gaura spp.						T			
Hedeoma drummondii			T	.11					
Ipomoea leptophylla			.04					T	
Juniperus scopulorum/virginiana			.04	T	T	T		T	T
Lappula echinata						T			
Lesquerella ludoviciana			.11	T				T	
Linum rigidum			.04	T		T		T	
Lithospermum incisum	.03	T				T		T	
Mentzelia nuda		T	.04	T		T		T	
Opuntia fragilis								T	
O. cf. *humifusa*	.03	T	.30	.67	.05			.74	T
Paronychia jamesii			.23	T					
Parthenocissus vitacea						T		T	
Pellaea atropurpurea				T					T
Penstemon angustifolius	.01	T	.04	.22				.15	
Plantago patagonica				T			T		
Polygala alba				T					T
Polygonum ramosissimum								T	
Prunus virginiana						T			T
Rhus trilobata			.12	T		T			
Ribes odoratum						T			
Salsola iberica						T	.04	T	
Sisymbrium altissimum								T	
Smilacina stellata								T	T
Solanum nigrum								T	
S. rostratum						T	T		
Sphaeralcea coccinea					1.00	T			
Symphoricarpos occidentalis			.04	T	.05	T			
Toxicodendron rydbergii				T					T
Tribulus terrestris								T	
Verbena stricta						T	.06		
Ulmus americana						T			
Woodsia oregana			T	T					
Yucca glauca	T	T	5.86	8.48	.09	T		.15	T
Total	99.83		99.99	99.82	100.00		99.98		
Total individuals/100 m^2	12,852		1,101	761	8,990		31,101	2,526	
Total species	13	30	52	54	17	55	15	80	11

1/ 1, 2 = Canyon tops, ungrazed and grazed respectively; 3, 4, 5 = canyon slopes, ungrazed, lightly grazed and heavily grazed; 6, 7 = canyon floors, lightly grazed and heavily grazed; 8 = sand talus, ungrazed; 9 = closed juniper forest, ungrazed.

2/ T = present but not observed in sampling plots.

Observations

Our observations in 3 summers show that cattle stay on the floorplain until the grass there is well-cropped before they move into the canyons where the sparse and rather dry vegetation is apparently less attractive, and where there is no standing water. White-tailed deer also graze on the floodplains, but at night, and in the daytime they graze on the canyon slopes. Mule deer prefer to remain on the upper slopes and canyon tops. Pronghorn antelope, though common nearby, are not known in these canyons.

Grasshoppers have a strong and obvious effect on the vegetation, especially on the lower canyon slopes and sand talus. In the dry summers of our observations they defoliated many of the forbs and some of the grasses by late summer, eating flowers and fruits of some as well. They are less abundant in wetter years.

Loess prairies of the canyon tops (categories 1 and 2). Short-grass prairie of the high plains occurs at the tops of the canyons (Fig. 5). Here the ungrazed prairie is dominated by *Bouteloua gracilis* (67%) and *Carex filifolia* (23%) which together form an open sod with the cover in most places not more than ca. 70% (Table 1). *Stipa comata* (8.5%) is also abundant but other grasses are very widespread. *Buchloe dactyloides* is absent and *Yucca glauca,* while visually prominent, is infrequent. Only 13 species occur on the ungrazed sites but 30 are found on the grazed sites. The Similarity Index of the 2 sites is 60, with 13 species in common (Table 2).

The isolated canyon slopes (categories 3, 4 and 5). Because the canyons trend north-south almost all slopes are exposed to intense insolation for most of the day. Sites for study were selected on east, south and west-facing slopes, the north-facing slopes of tributary canyons mostly have closed-canopy juniper groves and are treated separately. On the ungrazed slopes (Figs. 2 and 3) *Carex filifolia* (ca. 38%) and *Bouteloua* (ca. 36%) are most abundant; data for *Bouteloua* include both *B. gracilis* and *B. hirsuta.* In places the cover is less than 50% and in no place sampled is it close to 100%. In some sites the open soil is covered with gelatinous lichens and blue-green algae, and mosses are abundant especially below carbonate rocks. Yucca, juniper, and little bluestem (*Andropogon scoparius*) are prominent, as are prickly pear (*Opuntia*) and taller forbs such as *Petalostemon candidum* and *Thelesperma megapotamicum.* The lightly-grazed slopes are also characterized by *Bouteloua gracills* and B. hirsuta (ca. 62%) and *Carex filifolia* (ca. 62%) in somewhat reduced amounts. Many of the visually dominant species are shared with the ungrazed slopes. Only a few weedy species appear on the light-grazed slopes, e.g., a few *Euphorbia marginata* and *Plantago patagonica.* These slopes are shown in Figs. 1, 4, and 5.

The ungrazed slopes have 52 species, the lightly-grazed slopes have 54, and there are 41 species in common for a Similarity Index of 77. By contrast, the heavily-grazed slopes have only 17 species, of which 10 occur in common with the ungrazed slope and 11 (not all the same 8) with the lightly-grazed slopes, reducing the Similarity Indices to 29 and 31 respectively. The most abundant plants are annual grasses: *Festuca octoflora* (ca. 52%) and *Bromus tectorum* (23%). *Carex filifolia* is reduced to less than 1% and *Bouteloua gracilis* to ca. 12%, but *Stipa comata* is increased to ca. 11% from the much lower figures of the other slopes. The forbs are mostly unpalatables, e.g., *Cryptantha jamesii, Opuntia* cf. *humifusa, Artemisia filifolia. Yucca* is also greatly reduced. However, the density of plants is much higher than on the other 2 slopes.

The canyon floors (categories 6 and 7). Drastic differences are evident in the numbers of species on the lightly grazed (Fig. 1) and heavily grazed canyon floors. (There are no ungraged caynon floors in these canyons.) While the light-grazed floors have 55 species the heavily grazed floors have only 15. There are 11 species in common, producing a Similarity Index of 22. *Bouteloua (B. curtipendula, B. gracilis, B. hirsuta)* is the most abundant on the lightly-grazed floors, with 7 other grasses also present in small quantities. Grasses also predominate on the heavily grazed floors, with *Bromus tectorum* (ca.98%) most abundant and *Agropyron smithii* (68%) rather common. Forbs as unpalatables include *Agremone polyanthemos, Ambrosia psilostachya, Grindelia squarrosa, Cleome serrulata, Euphorbia marginata,* etc. *Yucca glauca* is absent, as are cacti, but they occur on the lightly grazed canyon floors. Perhaps their absence is due to trampling.

The sand talus (category 8). The soil is a loose, fine sand at least 5 feet deep. It is rather water-retentive because of its fine texture and it supports the greatest number of species (78) of any of the sites studied. While *Bouteloua gracilis* and *B. hirsuta* are abundant (ca. 62%), and *Bromus japonicus* is common in places (ca. 15%), the site has other grasses. Among these are *Andropogon gerardi* (reportedly hybridizing and introgressing with *A. hallii* in this part of the state (Kestner 1974)), *Paspalum setaceum, Panicum virgatum, Stipa viridula* and *Triplasis purpurea.* The flora shows the highest Similarity Index (49) with the lightly grazed canyon floors, which are also sandy. Nevertheless nearly half its species are not shared by the canyon floors. The individual plants

Table 2. Similarity indices of the floras and numbers of shared species in all site categories

	Index of Floristic Similarity								
Total species:	(13)	(30)	(52)	(54)	(17)	(55)	(15)	(80)	(11)
Site category:	1	2	3	4	5	6	7	8	9
(13) 1		60	34	33	47	24	0	28	17
(30) 2	13		61	57	38	40	9	44	10
(52) 3	11	25		77	29	41	0	48	19
(54) 4	11	24	41		31	44	9	40	28
(17) 5	7	9	10	11		32	19	25	29
(55) 6	8	17	22	24	12		22	47	12
(15) 7	0	2	0	3	3	11		13	0
(80) 8	13	24	32	27	12	32			9
(11) 9	2		6	9	4	4	0	4	

are widely spaced at this site, with the cover seldom exceeding 70%. Visually dominant are the taller grasses such as *Andropogon gerardi/hallii, A. scoparius,* and *Stipa comata,* while the taller forbs such as *Mentzelia nuda, Ipomoea leptophylla, Artemisia* ssp. *Petalostemon candidum,* and *Yucca glauca* are prominent to the eye. The aspect is that of tallgrass prairie. There is no grazed counterpart to this site, so a comparison of grazing effects cannot be made. However, it is worthy to compare this site with more typical sandhills vegetation that covers thousands of square miles across the river. Recent data from Arapaho County, some 15 miles to the north (as reported by Keeler, Harrison, and Vescio 1981) show that the sand talus of our study has 54 upland species in common with true sandhills prairie of that site. The Arapaho study revealed 166 upland species (as well as numerous wetland species excluded from our comparison here) from 2 square miles. The sand talus, with 80 species on ca. 6 acres (yielding a Similarity Index of 44) is nevertheless probably richer in species/acre than the Arapaho Prairie.

The closed-canopy juniper groves (category 9). These groves occur on north and east-facing slopes where the steepness of the canyon walls allows shading. There are a few groves on more exposed slopes as well (Figs. 1 and 4); these are in various stages of closure and we do not report on them here. There are 11 species in the closed groves, collectively, with from 0 to 9 species in common with other sites. Thus the Similarity Indices do not exceed 29 and average only 16. No species are shared with the heavily grazed canyon floors, while 9 are shared with the lightly grazed slopes. Most obvious, after the trees themselves, is the sod of *Oryzopsis micrantha* under the trees in many of the groves. This delicately-textured, luxuriant grass remains green long after the more exposed grasses have withered in the summer heat, and it is eaten by cattle that will force their way among the juniper branches when more available grasses are gone. It is the only shade-tolerant grass in any of the study sites. Its absence from the closed-canopy groves of grazed sites (upon which we do not report here) is undoubtedly due to grazing. In a few groves the ferns *Pellaea atropurpurea* and *Cystopteris fragilis* occur on cooler soils and rocks. The only other fern in the sites, *Cheilanthes feei,* prefers more exposed carbonate boulders and ledges. There is an occasional clump of *Prunus virginiana* in the deep shade of the groves, probably introduced by roosting birds. Also present is some poison ivy *(Toxicodendron rydbergii). Polygala alba* and a few other small forbs are also found here. *Anemone patens* (pasque flower) is abundant in some shady groves but is more common on exposed slopes. Its presence under the trees probably antedates the closure of the canopy, as is certainly the case for yucca and prickly pear found beneath the trees. These latter two are commonly found persisting in the *Oryzopsis micrantha* sod, usually as rather spindly individuals. In some of the groves the trees are closely spaced. In one grove they are only an average of ca. 5 ft. apart ranging from 1-10 ft. The trees in this grove are about 35 years old, as determined from annual-ring counts. Trees in some other groves are much larger and certainly much older. Using the diameter of trees of known age as a gauge, there seems to be no juniper older than 90-110 years anywhere in the canyons. This is consistent with supposed logging in the middle of the last century. Because it is unlikely that yucca or prickly pear would establish in the shade of the trees, the ages of these plants where they are found in the groves must be at least equal to, and probably greater than, the number of years since closure of the canopy.

All sites. The native flora is mostly perennial. There is only one bulbous species, *Allium textile,* which is spring-flowering. Several spring-flowering species tend to be showy and low-growing. These include *Anemone patens, Townsendia exscapa,* and *Lathyrus polymorphus.* Other spring-flowering (late April-May) plants are *Cymopteris acaulis* and *Carex filifolia.* After the spring flowering flush there is an absence of conspicuously-flowered plants, with a few cool-season grasses in bloom. *Yucca glauca* is the showiest of the early summer-flowering plants, and taller plants such as *Mentzelia nuda, Ipomoea leptophylla, Petalostemon* spp. are prominent in midsummer, although not dominant in any statistical snese. The Compositae are especially prominent in late summer and autumn. A few species show high constancy among the study sites. *Yucca glauca* occurs in 8 of the 9 sites, while *Carex filifolia, Bouteloua gracilis, Stipa comata,* and prickly pear occur in 7 of 9 sites. Six sites contain *Artemisia frigida, Psoralea tenuiflora, Dalea enneandra,* and *Juniperus.*

Table 1 indicates that some species increase with moderate grazing and others decrease. The increasers include *Aristida fendleriana, Stipa comata, Yucca glauca,* prickly pear, *Psoralea tenuiflora, Lygodesmia juncea,* and *Hymenopappus filifolius.* Also increasing is *Andropogon scoparius,* well-known as an increaser under grazing in the Great Plains (e.g., Kelting 1954). Prickly pear was shown to be more influenced by precipitation than by grazing in eastern Montana (Houston 1963). Costello and Turner (1941) and Moir and Trlica (1976) discussed vegetational and floristic changes with grazing in similar prairies in nearby northern Colorado, and Hanson (1955) characterized those prairies in floristic detail. Many of the species of northern Colorado are the same as those in our study sites, providing us with some basis for reference for comparative studies.

Most species can be characterized as western or southwestern taxa whose main distributions are west of 100° west longitude (cf. Atlas of the Flora of the Great Plains 1977). Fifteen of these are at the very eastern of their ranges in our study area: *Artemisia filifolia, Astragalus Kentrophyta, A. sericoleucus, Clematis ligusticifolia, Cryptantha jamesii, Cymopteris acaulis, Hedeoma drummondii, Hymenopappus filifolius, Lupinus pusillus, Orzopsis hymenoides, O. micrantha, Paronychia jamesii, Psoralea linearifolia, Thermopsis rhombifolia,* and *Townsendia exscapa.* Only a few species reach the southern edge of this part of their ranges here: *Anemone patens, Asclepias lanuginosa, Astragalus adsurgens,* and *Lappula echinata.* The fern *Pellaea atropurpurea* is disjunct in its range east and west of here. *Juniperus virginiana* is at its western edge here (Flake et al. 1978).

Species known to be in the study sites but which were not observed include: *Allium textile, Astragalus gracilis, A. lotiflorus, A. missouriensis, A. millissimus, A. sericoleucus, Castilleja sessiliflora, Coryphantha missouriensis, C. vivipara, Cymopteris acaulis, Erigeron pumilus, Evolvulus nuttallianus, Hedeoma hispida, Juniperus horizontalis, Lathyrus polymorphus, Lepidium densiflorum, Oenothera albicaulis, O. laciniata, Orobanche fasciculata, Penstemon albidus, Polanisia dodecandra, Psoralea esculenta, Townsendia hookeri.* Voucher specimens of these are in the reference herbarium at Cedar Point Biological Station and in the State Herarium, Lincoln.

Discussion

Because there are no reports of the original flora and vegetation of these canyons, we must reconstruct it from present-day observations. While the human population has always been very low in Keith County, the cattle population has been high since European settlement. The county was, after all, the northern terminus of the Ogallala cattle trail. The canyons are completely unsuited to crop culture because of their topography, but have provided enough pasturage to sustain about 30 beef cattle in recent years. Certainly in the past buffalo also grazed here, so the presence of cattle in small herds perhaps equals the effects of the buffalo on the plants. Prairie floras have co-evolved with herbivores as part of the ecosystem, so the replacement of buffalo with cattle does not necessarily mean severe disruptions. It is the confinement of cattle by fences and topography, and the distribution of water, that causes uneveness in grazing intensity in an area like this.

The fire history of these canyons is unknown. The typically dry nature of the herbaceous vegetation from early or midsummer through autum, coupled with the high frequency of thunderstorms, some of them with spectacular displays of lightning, indicates that the fire potential is high. It is likely that in the past prairie fires swept across the loess prairies of the canyon tops on the prevailing south winds. Probably the sparse vegetation of the canyon slopes and its leeward position reduced the number of fires. In 6 years we have not seen naturally-caused fires in these canyons, although grass fires started by lightning occur on nearby prairies.

One change that seems to have occurred is an increase in the number of juniper trees due probably to grazing, decrease in fire frequency, and recovery after logging. Trees of all size and age classes are evident up to ca. 100 years old, especially on the canyon slopes, and all degrees of canopy closure can be observed. It is likely that eventually the canyons will be completely clothed with juniper and the prairie flora thus extirpated, unless fires or cutting control the trees. Rapid invasion of junipers following decrease in fire frequency on similar dry calcareous slopes in northern Kansas was shown by Bragg and Hulbert (1976).

We conclude that the junipers are native to these canyons, rather than having invaded with settlement. The natural range of juniper includes this area. The age of some of the largest trees antedating European settlement, and the abundance of *Oryzopsis micrantha,* a very site-restricted grass, suggest that the junipers have been there a long time.

Our data show that grazing does not necessarily reduce the number of species and may increase it in some cases. It is only heavy grazing that decreases the number of species. Similar conclusions were reached for similar prairies in Colorado by Moir and Trlica (1976). Heavy grazing drastically increases the number of species and individuals of annuals, especially exotic annuals. There are only 2 common shrubs, *Rhus trilobata* and *Symphoricarpos occidentalis.* Neither appears to be browsed by cattle or deer. We have some evidence that *S. occidentalis* increases with heavy grazing in our sites, but *R. trilobata* may be unaffected. *Shepherdia argentea* occurs in nearby canyons.

Closure of the juniper canopy eventually eliminates all the prairie species, but at different rates. While a few very low-branched groves have no understory vegetation at all, most are characterized by a more or less tight sod of *Oryzopsis micrantha* with only a few forbs intermixed. Some of these forbs (*Anemone patens, Yucca glauca* and prickly pear) are prairie relicts that persist but seem not to thrive (i.e., do not flower or produce abundant foliage) in the dappled shade of the trees. Younger groves with more light reaching the ground prior to closure, contain such persistent plants as *Petalostemon* spp. and *Carex filifolia.* We did not sample these more open groves but comparative analysis of them with younger and mature groves should reveal the rate and order of disappearance of prairie species. Grazed groves are quickly stripped of *Oryzopsis micrantha.*

Some plants in all but the heavily grazed sites are apparently very old. Studies are needed on such important species as *Carex filifolia, Yucca glauca,* and *Ipomoea leptophylla* to determine their ages and rates of growth. Our observations suggest that the age of a clump of *Carex filifolia* that is 1 ft. in diameter might well be measured in decades or even centuries. The growth rate of *Yucca glauca,* as observed for 6 years in the field, suggests that some of them may be very old. Several specimens on the sand talus and 5 feet tall and have thick, prominent trunks that may have taken 50 or more years to grow. Studies of juniper trees are also needed to determine their age and to reconstruct fire history in the canyons by seeking fire-scars in the growth rings.

Controlled experiments on the effects of grazing by both cattle and deer would provide more definite proof than our comparative studies. Long-term exclosure studies would be most instructive. Nevertheless we believe that our data indicate that moderate grazing does little harm to the native flora but heavy grazing virtually eliminates it in favor of exotic annuals and a few unpalatable native perennials.

Chi-square tests indicate that the categories we have studied are statistically different. But there are other categories present as well that need study such as the ledge communities of the slopes, and those occurring at the edge of the sand talus. Still others include those found in damp gorges, and lastly the cryptogamic communities of the soil.

Further work will undoubtedly reveal the presence of other species. Such characteristic plants as *Buchloe dactyloides, Evolvulus nattallianus,* and *Phlox andicola,* found in nearby communities, are likely to be found in our sites. Conversely, some species on our list could well be difficult to locate in some years. Many of the prairie plants are abundant one year but scarce the next. Documentation of this phenomenon, which was strikingly evident in 2 summers of field work and 6 summers of general observations, might point toward its causes, particularly when correlated with annual climatic aberrations and grasshopper infestations.

Eco-physiological studies could help explain plant distributions in many cases. For example, on the nearby sandhills Heinisch (1981) found that *Bouteloua hirsuta* favors coarser soils than does *B. gracilis;* this probably explains the absence of *B. hirsuta* from the loess prairies of the canyon tops and its presence on the sandy soild of the slopes and floors..

Acknowledgements

Appreciation is extended to graduate students Martha Kaul, Donald Mahoney, and Linda Vescio for gathering some of the specimens, and to numberous students in classes who scouted potential study sites. The field observations and most of the collections and identifications were done by the first author, who is also responsible for many of the conclusions. The second author analyzed the data, and the third provided an autecological viewpoint and helped in formulating ideas.

Literature Cited

Bragg, T. B. and L. C. Hulbert. 1976. Woody plant invasion of unburned Kansas bluestem prairie. J. Range Manage. 29:19-24.

Costello, D. G. and G. T. Turner. 1941. Vegetation changes following exclusion of livestock from grazed ranges. J. Forestry 39:310-315.

Diffendal, R. F. and R. Pabian. Undated (ca. 1979). Geological field guide to the Cedar Point Biological Station, Keith County, Nebraska. Conservation and Survey Division, University of Nebraska, Lincoln.

Flake, R. H., L. Urbatsch and B. L. Turner. 1978. Chemical documentation of allopatric introgression in *Juniperus.* Syst. Bot. 3:129-144.

Great Plains Flora Association. 1977. Atlas of the Flora of the Great Plains. Iowa State University Press, Ames.

Hanson, H. C. 1955. Characteristics of the *Stipa comata-Bouteloua gracilis-Bouteloua curtipendula* association in northern Colorado. Ecology 36:269-280.

Heinisch, S. 1981. Water allocation and rooting morphology of two *Bouteloua* species in relation to their distribution in Nebraska sandhills. M.S. thesis, University of Nebraska, Lincoln.

Houston, W. R. 1963. Plains prickly pear, weather and grazing in the northern Great Plains. Ecology 44:569-574.

Kaul, R. B. 1975. Vegetation of Nebraska: a map in 13 colors, 1:1,000,000. Conservation and Survey Division, University of Nebraska, Lincoln.

Keeler, H. G., A. T. Harrison, and L. S. Vescio. 1981. The flora and sandhills prairie communities of Arapaho Prairie, Arthur County, Nebraska. Prairie Nat. (in press).

Kelting, R. W. 1954. Effects of moderate grazing on composition and plant production of a native tall-grass prairie in central Oklahoma. Ecology 35:200-207.

Lawson, M. P., K. F. Dewey, and R. E. Neild. 1977. Climatic Atlas of Nebraska. University of Nebraska Press, Lincoln.

McNaughton, S. J. 1968. The structure and function in California grasslands. Ecology 49:962-972.

Moir, W. H., and M. J. Trlica. 1976. Plant communities and vegetation pattern as affected by various treatments in shortgrass prairies of northeastern Colorado. Southwest Nat. 21: 359-371.

Simpson, E. H. 1949. Measurement of diversity. Nature 163:688.

Sorenson, T. 1949. A method of establishing groups of equal amplitude in plant sociology based on similiarity of species content and its application to analyses of the vegetation on Danish Commons. Biol. Sk. 5:1-34.

Wells, P. V. 1968. Historical factors controlling vegetation patterns and floristic distributions in the central plains region of North America. In W. Dort and J. K. Jones, eds., pp. 211-221, Pleistocene and Recent Environments of the Central Great Plains. University of Kansas Press, Lawrence.

Westhoff, V., and E. van der Maarel. 1973. The Braun-Blanquet approach. In R. A. Whittaker, ed., Handbook of Vegetation Science, Part V. Ordination and Classification of Communities. Dr. W. Junk, The Hague.

with annual climatic variations and grasshopper infestations.

Ecophysiological studies could help explain plant distributions in many cases. For example, on the nearby sandhills Heinisch (1981) found that *Bouteloua hirsuta* favors coarser soils than does *B. gracilis*; this probably explains the absence of *B. hirsuta* from the loess prairies of the canyon tops and its presence on the sandy soils of the slopes and floors.

Acknowledgements

Appreciation is extended to graduate students Martha Kaul, Donald Mahoney, and Linda Vescio for gathering some of the specimens, and to numerous students in classes who scouted potential study sites. The field observations and most of the collections and identifications were done by the first author, who is also responsible for many of the conclusions. The second author analyzed the data, and the third provided an ecological viewpoint and helped in formulating ideas.

Literature Cited

Bragg, T. B. and L. C. Hulbert. 1976. Woody plant invasion of unburned Kansas bluestem prairie. J. Range Manage. 29:19-24.

Costello, D. G. and G. T. Turner. 1941. Vegetation changes following exclusion of livestock from grazed ranges. J. Forestry 39:310-315.

Diffendal, R. F. and R. Fabiani. Undated (ca. 1979). Geological field guide to the Cedar Point Biological Station, Keith County, Nebraska. Conservation and Survey Division, University of Nebraska, Lincoln.

Flake, R. H., L. Urbatsch and B. L. Turner. 1978. Chemical documentation of allopatric introgression in *Juniperus*. Syst. Bot. 3:129-144.

Great Plains Flora Association. 1977. Atlas of the Flora of the Great Plains. Iowa State University Press, Ames.

Hanson, H. C. 1955. Characteristics of the *Stipa comata-Bouteloua gracilis-Bouteloua curtipendula* association in northern Colorado. Ecology 36:269-280.

Heinisch, S. 1981. Water allocation and rooting morphology of two *Bouteloua* species in relation to their distribution in Nebraska sandhills. M.S. thesis, University of Nebraska, Lincoln.

Houston, W. R. 1963. Plains prickly pear, weather and grazing in the northern Great Plains. Ecology 44:569-574.

Kaul, R. B. 1975. Vegetation of Nebraska, a map in 13 colors, 1:1,000,000. Conservation and Survey Division, University of Nebraska, Lincoln.

Keeler, H. G., A. T. Harrison, and L. S. Vescio. 1981. The flora and sandhills prairie communities of Arapaho Prairie, Arthur County, Nebraska. Prairie Nat. (in press).

Kelting, R. W. 1954. Effects of moderate grazing on composition and plant production of a native tall-grass prairie in central Oklahoma. Ecology 35:200-207.

Lawson, M. P., K. F. Dewey, and R. E. Neild. 1977. Climatic Atlas of Nebraska. University of Nebraska Press, Lincoln.

McNaughton, S. J. 1968. The structure and function in California grasslands. Ecology 49:962-972.

Moir, W. H., and M. J. Trlica. 1976. Plant communities and vegetation pattern as affected by various treatments in shortgrass prairies of northeastern Colorado. Southwest Nat. 21:359-371.

Simpson, E. H. 1949. Measurement of diversity. Nature 163:688.

Sorensen, T. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content, and its application to analyses of the vegetation on Danish Commons. Biol. Skr. 5:1-34.

Wells, P. V. 1968. Historical factors controlling vegetation patterns and floristic distributions in the central plains region of North America. In W. Dort and J. K. Jones, eds., pp. 211-221, Pleistocene and Recent Environments of the Central Great Plains. University of Kansas Press, Lawrence.

Westhoff, V., and E. van der Maarel. 1973. The Braun-Blanquet approach. In R. A. Whittaker, ed., Handbook of Vegetation Science, Part V. Ordination and Classification of Communities. Dr. W. Junk, The Hague.

FIELD RESEARCH AND PRAIRIE INVESTIGATIONS AT THE UNIVERSITY OF KANSAS

W. Dean Kettle
and
Henry S. Fitch
Department of Systematics and Ecology
Snow Hall
The University of Kansas
Lawrence, Kansas 66045

Abstract. The University of Kansas owns 594 ha of land set aside for environmental research and education on the tallgrass prairie and associated ecosystems. This land is composed of a diversity of habitats including virgin tallgrass prairie, reseeded prairie, mature hardwood forest, and land under current agricultural management. These areas fall into 2 categories: 1) **natural areas**-where ecological processes occur independently of direct human manipulation and 2) **experimental areas**-for controlled, experimental manipulation of environmental and biological factors. The Rockefeller Experimental Prairie is an experimental area, established in 1957, to assess the effect different management practices (burning, mowing, grazing and total protection) on prairie. Results indicate burning and mowing maintain the prairie in good condition.

Introduction

The University of Kansas currently owns 595 ha (1470 acres) of land set aside for environmental research and education. This land is administered by the Program of Experimental and Applied Ecology. Acquisition of these areas was brought about through efforts of the Kansas University Endowment Association and the generosity of environmentally concerned citizens. Two different philosophies govern the use of our areas, although both have as a common denominator the devotion to environmental research and education. The Natural History Reservation and Baldwin Woods (324 ha) are maintained as natural areas where ecological processes occur independently of direct human manipulation and serve as baselines for comparisons with distrubed areas. The combined Nelson Environmental Study Area and Robinson Tract (312 ha) are used for the controlled, experimental manipulation of biological and environmental factors which regulate structure and function of plant and animal populations.

The purpose of this paper is to acquaint the reader with University of Kansas ecological research areas present in northeastern Kansas and to describe the status of our long-term experimental prairie projects.

Study Areas

All areas lie adjacent to each other in 1 of 2 major groupings: Those 15 km south of the University of Kansas (located in Lawrence, Kansas) and those north of the Kansas River, 10 km north of the University. Lawrence, Kansas is at 38°58′ latitude and 95°16′ longitude with an elevation of 305 m and has a typical continental climate with large seasonal fluctuations in temperature and large monthly variations in rainfall. Lawrence is situated in what is traditionally regarded as the tallgrass prairie-eastern deciduous forest ecotone, bordering the Great Plains. Written records of the history of the areas date from 1819 and have been researched in detail by Fitch (1965). The pre-White Man vegetative condition of northeastern Kansas was likely an interdigitating pattern of tallgrass prairie and hardwood forest, each predominating the areas for which it was best adapted with well-defined boundary lines between them.

The Natural History Reservation. The 239 ha (590 acre) Natural History Reservation in Northeastern Douglas County is located 10.5 km (6.5 miles) north of Lawrence and is maintained as an undisturbed area. In 1947 the area was set aside as a reservation where native plants and animals might be protected and studied under natural conditions. In 1950 a laboratory and residence were constructed and Professor H. S. Fitch became the resident naturalist and superintendent of the area (he remains in this capacity today). The objectives of the area are to accomplish research in ecology, to teach biology with an emphasis on natural history, and to conserve a sample of Kansas Flora and Fauna. In administering the area since 1950, the policy has been "hands off", allowing natural seccession to proceed at its own rate.

The NHR consists of a wide variety of habitats ranging from a former virgin tallgrass prairie to a relatively mature hardwood forest with large red oaks. Intermediate between these successional stages are former farmland, pastures and young forest stands which have been undergoing succession undisturbed for over 30 years.

Research on NHR has been a long-term program of study concerning the interrelations of native animals and plants with their physical and biotic environments, and their population dynamics under natural conditions. To this end dozens of papers and dissertations have resulted from research on NHR. These are a portion of the tens of thousands of capture and occurrence records and observations made at NHR since its inception.

Thousands of visitors (ranging in age from kindergarten to senior citizens, often from nearby cities but with some from the most remote foreign countries) have been treated to a natural history lesson from Professor Fitch via nature walks and demonstrations on the NHR.

The Nelson Environmental Study Area. Known to its many researchers by the acronym NESA, the John H. Nelson Environmental Study Area lies adjacent to the Natural History Reservation. This 223 ha (590 acre) area is located in southeastern Jefferson County approximately 12 km from campus. NESA and NHR are both included in the national register of Experimental Ecology Reserves prepared for the National Science Foundation by the Institute of Ecology.

The acquisition of NESA in 1970 initiated a new phase of studies by the Program of Experimental and Applied Ecology. This new phase emphasizes the experimental manipulation of the environment in order to more quickly learn the underlying factors regulating processes in natural ecosystems. In addition, it became possible to set up long term experimental studies of environmental problems of concern to state and nation.

NESA consists of a wide variety of habitats, ranging from land presently under agricultural management to a relatively stable oak-hickory forest. Two virgin tallgrass prairie areas (5 ha) are maintained by annual burning and mowing as well as a 5 ha reseeded tallgrass area. The 65 ha experimental prairie project will be described later.

Although research projects on NESA are far too voluminous to be described here, let it suffice to say that research efforts in population biology and community ecology of plants, insects, reptiles, small mammals, birds and freshwater organisms as well as research with the physical-chemical components of the biosphere are underway. In addition to research, over 25 University classes have made use of the area. Also, many tours of the facility are provided annually to acquaint students and other interested parties with modern experimental ecology.

Environmental research requires more than raw land. Located on NESA is a biological field laboratory, weather station and seismograph. Specialized research facilities include an experimental pond facility of 20 ponds, an irrigated garden facility, 2-3 ha small mammal enclosures and an aviary. Four road vehicles as well as a farm tractor with a complement of equipment are maintained by the Program of Experimental and Applied Ecology for use on its areas. In addition a residence for a caretaker, a full time superintendent and graduate student assistants are employed in the Program.

The Baldwin Woods. Located 15 km south of Lawrence in southeastern Douglas County is a group of tracts referred to as Baldwin Woods. The Breidenthal Tract of 28 ha was purchased in 1965 and the 4 ha Robison Tract was added in 1973. The 32 Ethel and Raymond F. Rice Forest Preserve was purchased through the Nature Conservancy in 1972 by Ethel and Raymond Rice and the title later transferred to the University Endowment Association. The 12 ha Wall Tract and 4 ha Yukon Tract were added in 1974. All of the Baldwin Woods area is treated as a biological preserve where experimental manipulation is not permitted. As stated by Wells and Morley (1964), the Baldwin Woods is remarkably rich in species (31 species of trees, 21 species of shrubs and vines) for a forest situated in the transition zone between eastern deciduous forest and tallgrass prairie. A nature trail is being constructed in the Rice Forest to facilitate public education and enlightenment and to minimize disruption due to human influences. The entire Baldwin Woods has just recently been designated as a National Natural Landmark by the Secretary of the Interior.

The Robinson Tract. This 45 ha tract, located 8 km north of campus and in Douglas County, is bordered by Mud Creek (a tributary of the Kansas River) on half of its western boundary. The southern portion of this area lies within the Kansas River floodplain. The majority of this area is a grassland dominated by smooth brome (*Bromus inermis*) with a scattering of perennial prairie grasses. Experimental manipulation is permitted on this area and much work has been done on the population dynamics of small mammals and their response to burning of vegetation.

The Rockefeller Experimental Prairie. The 65 ha (160 acre) Rockefeller Experimental Tract is located on the western side of the Nelson Environmental Study Area in southeast Jefferson County. It was acquired in 1956 through the generosity of the late John D. Rockefeller. The area at that time consisted of 11 ha (27 acres) of forest with the balance as pasture and cultivated farmland. In 1957, 43 ha (107 acres) of the formerly grazed and cultivated land was reseeded to tallgrass prairie consisting of big bluestem (*Andropogon gerardi*), little bluestem (*Andropogon scoparius*), Indiangrass (*Sorghastrum avenaceum*) and switchgrass (*Panicum virgatum* L.). Objectives were to evaluate the effectiveness of different management practices in maintaining a tallgrass prairie and to research the plant-animal interactions involved in the maintenance of a fire subclimax ecosystem such as the tallgrass prairie. In 1962, after the prairie was established, it was divided into 5 similar tracts with a different management practice applied to each of 4 tracts. These 4 parallel north-to-south experimental tracts were of approximately 6 ha (15 acres) each. The manipulations were burning (in late March or early April), mowing (to ground level in late July), grazing (from June 1 to late summer by 15 head of cattle), and control (protected).

Although detailed sampling of the flora and fauna has been periodically conducted on each tract, the difference in successional development of the areas is, and has been for several years, quite apparent by simple observation. As seen from Fig. 1 and Fig. 2, the tracts that are mowed or burned have been maintained in good condition. Conversely, the tracts that have been grazed or protected have been invaded by weedy shrubs and trees with a concomitant loss of prairie grasses. The tracts, in order of increasing species diversity of flora and fauna (decreasing order of prairie maintenance) are burned, mowed, grazed and control.

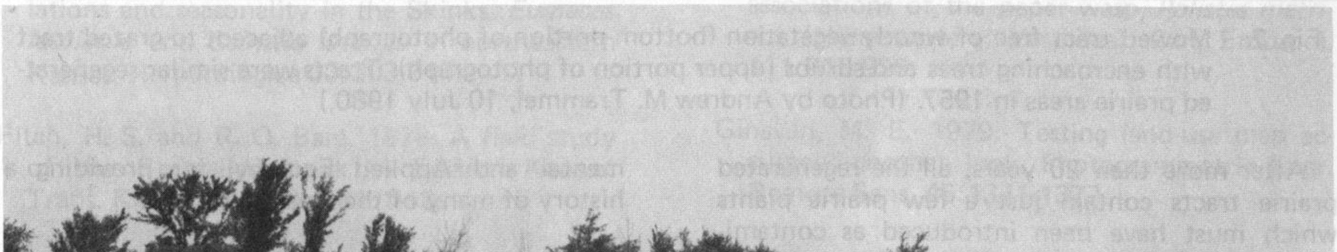


Fig. 1. Burned tract of prairie free of woody vegetation (bottom portion of photograph) adjacent to protected tract with dense stands of woody vegetation (upper portion of photograph). Tracts were similar regenerated prairie areas in 1957. (Photo by Andrew M. Trammel, 10 July 1980.)

Fig. 2. Mowed tract free of woody vegetation (bottom portion of photograph) adjacent to grazed tract with encroaching trees and shrubs (upper portion of photograph). Tracts were similar regenerated prairie areas in 1957. (Photo by Andrew M. Trammel, 10 July 1980.)

After more than 20 years, all the regenerated prairie tracts contain just a few prairie plants which must have been introduced as contaminants in the grass seed. The fifth regenerated prairie tract mentioned earlier borders a virgin prairie (which contains numberous prairie species) for 270 m. This tract contains no more prairie plants than the regenerated prairie tracts that are further removed, although some prairie plants have invaded just a few feet into the regenerated tract. The fragile nature of native prairie is demonstrated by its inability to reestablish itself once destroyed. Research indicates that a reseeded tallgrass prairie may be established but that regular burning or mowing is required to maintain it; otherwise it will be outcompeted by invading forest species. All the experimental tracts of the Rockefeller Prairie are adjacent to an improved public roadway and have large informative signs explaining the project. This greatly facilitates public awareness and education.

Acknowledgements

The authors wish to thank the many scientists whose works have been cited in this paper. A special thanks goes to Professor Kenneth B. Armitage, Director of the Program of Experimental and Applied Ecology, for providing a history of many of the areas.

Literature Cited

The following is the bibliography for the University of Kansas Program of Experimental and Applied Ecology (1973-1979):

Armitage, K. B. and C. H. Lei. 1979. Temperature acclimatization in the filtering rates of oxygen consumption of *Daphnia ambigua* Scourfield. Comp. Biochem. Physiol. 62A:807-812.

Bickford, M. E., L. R. Silka, R. D. Shuster, E. E. Angino and C. R. Ragsdale. 1978. Determination of sub-nanogram amounts of silver in rainwater by stable isotope dilution. Anal. Chem. 50:469-471.

Birdsell, R. and J. L. Hamrick. 1978. The effect of slope-aspect on the composition and density of an oak-hickory forest in eastern Kansas. Univ. Kansas Sci. Bull. 51¾565-573.

Cink, C. L. 1974. Breeding bird census No. 100, Floodplain tallgrass prairie. Am. Birds 28:1031-1032.

Cink, C. L. 1974. Breeding bird census No. 47, Oak-hickory forest. Am. Birds 28:1010-1011.

Cink, C. L. 1976. The influence of early learning on nest site selection in the house sparrow. The Condor 78:103-104.

Dew, H. and C. D. Michener. 1978. Foraging flights of two species of *Polistes* wasps (Hymenoptera: Vespidae). J. Kansas Entomol. Soc. 51: 380-385.

Fitch, H. S. 1975. A demographic study of the Ringneck snake (*Diadophis punctatus*) in Kansas Mus. Nat. Hist. Misc. Pub. 62, 53 pp.

Fitch, H. S., R. O. Bare, and H. A. Stevens. 1973. Road counts of hawks in Kansas. Kansas Ornithol Soc. Bull 24:33-36.

Fitch, H. S. and P. von Achen. 1973. Yellow-billed cuckoo nesting at University of Kansas Natural History Reservation. Kansas Ornithol. Soc. Bull. 24:12-15.

Fitch, H. S. and P. von Achen. 1977. Spatial relations and seasonality in the Skinks, *Eumeces fasciatus* and *Scinella laterale* in northeastern Kansas. Herpetologica 33:303-313.

Fitch, H. S. and R. O. Bare. 1978. A field study of the Red-tailed hawk in Eastern Kansas. Trans. Kansas Acad. Sci. 81:1-13.

Fitch, H. S. 1978. Reproductive strategies of reptiles. In Part II Reproductive Biology of Captive Reptiles. SSAR Symposium Volume, "The Reproductive Biology and Disease of Captive Reptiles," Joseph T. Collins, co-ed.

Fitch, H. S. 1978. A field study of the prairie kingsnake (*Lampropeltis calligaster*). Trans. Kansas Acad. Sci. 81:353-363.

Fitch, H. S. and E. R. Hall. 1978. A 20-year record of succession on reseeded fields of tallgrass prairie on the Rockefeller experimental tract. Univ. Kansas Mus. Nat. Hist. Spec. Pub. 4:1-15.

Gains, M. S. and R. K. Rose. 1976. Population dynamics of *Microtus ochrogaster* in eastern Kansas. Ecology 57:1145-1161.

Gaines, M. S., R. K. Rose and L. R. McClenaghan, Jr. 1977. The demography of *Synaptomys cooperi* populations in eastern Kansas. Canadian J. of Zool. 1584-1594.

Gaines, M. S., K. J. Vogt, J. L. Hamrick and J. Caldwell. 1974. Reproductive strategies and growth patterns in sunflowers (*Helianthus*). Am. Nat. 108:889-894.

Gaines, M. S., C. L. Baker and A. M. Vivas. 1979. Demographic attributes of dispersing southern bog lemmings (*Synaptomys cooperi*) in eastern Kansas. Oecologia 40:91-101.

Gaines, M. S., L. R. McClenaghan, Jr. and R. K. Rose. 1978. Temporal patterns of allozymic variation in fluctuating populations of *Microtus ochrogaster*. Evolution 32:723-739.

Gamboa, G. J. 1978. Intraspecific defense: Advantage of social cooperation among paper wasp foundresses. Science 199:1463-1463.

Gamboa, G. J., B. D. Heacock, and S. L. Wiltjer. 1978. Division of labor and subordinate longevity in foundress associations of the paper wasp, *Polistes metricus* (Hymenoptera: Vespidae). J. Kansas Entomol. Soc. 51:343-352.

Gamboa, G. J. and J. A. Dropkin. 1979. Comparisons, of behaviors in early vs. late foundress associations of the paper wasp, *Polistes metricus* (Hymenoptera: Vespidae). Can. Entomol. 111:919-926.

Ginevan, M. E. 1979. Testing land-use map accuracy; another look. Photogrammetric Engr. Remote Sens. 45:1371-1377.

Hunt, J. H. and G. J. Gamboa. 1978. Joint nest use by two paper wasp species. Insectes Sociaux 25:373-374.

Johnston, R. F. 1977. Composition of woodland bird communities in eastern Kansas. Kansas Ornithol. Soc. Bull. 28:13-18.

Johnston, R. F. 1979. Replication of habitat profiles for birds. Univ. Kansas Mus. Nat. Hist. Occas. Papers 32:1-11.

Kring, R. L. and W. J. O'Brien. 1976. Accomodation of *Daphnia pulex* to altered pH conditions as measured by feeding rate. Limnol. and Oceanogr. 21:313-315.

Kring, R. L. and W. J. O'Brien. 1976. Effect of varying oxygen concentrations on the filtering rate of *Daphnia pulex*. Ecology 57:808-814.

Lichtwardt, R. W. 1968. Why stop with the animals? Turtox News. 46:194-196.

Lowther, P. E. and R. F. Johnston. 1977. Influences of habitat on Cowbird host selection. Kansas Ornithol. Soc. Bull. 28:36-40.

Maughan, E. O. and H. S. Fitch. 1976. A new Pholcid spider from Northeastern Kansas. Univ. Kansas Mus. Nat. Hist. Occas. Papers 74:1-16.

McClenaghan, L. R. and M. S. Gaines. 1978. Reproduction in marginal populations of the Hispid Cotton Rat (*Sigmodon hispidus*) in Northeastern Kansas. Univ. Kansas Mus. Nat. Hist. Occas. Papers. 74:1-16.

O'Brien, W. J. 1979. The predator-prey interaction of planktivorous fish and zooplankton. Am Scientist 67:572-581.

Rose, R. K. and M. S. Gaines. 1976. Levels of aggression in fluctuating populations of the prairie vole, *Microtus orchrogaster,* in eastern Kansas. J. of Mammal. 57:43-57.

Rose, R. K. and M. S. Gaines. 1978. The reproductive cycle of *Microtus orchrogaster* in eastern Kansas. Ecol. Monogr. 48:21-42.

Rose, R. K., N. A. Slade and J. H. Honacki. 1977. Life trap preference among grassland mammals. Acta Theriologica 22:296-307.

Sanders, T. B., J. L. Hamrick and L. R. Holden. 1979. Allozyme variation in *Elymus canadensis* from the tallgrass prairie region: geographic variation. Am. Mid. Nat. 101:1-12.

Shump, K. A., Jr. 1978. Ecological importance of nest construction in the hispid cotton rat (*Sigmondon hispidus*). Am. Midl. Nat. 100:103-115.

Shump, K. A., Jr., and D. P. Christian. 1978. Differential burrowing by hispid cotton rats (*Sigmondon hispidus*: Rodentia). Southwest. Nat. 23:681-709.

Steeples, D. W. 1978. Microearthquake network in Kansas. In A. Vogel, ed., pp. 115-130, Terrestrial and Space Techniques in Earthquake Prediction Research. Triedr. Viewq & Sohn, Braunschweig/Wiesbaden.

Steeples, D. W., S. M. DuBois and F. W. Wilson. 1979. Seismicity, faulting, and geophysical anomalies in Nemaha County, Kansas: relationship to regional structures. Geology 7: 134-138.

Vinyard, G. L. and W. J. O'Brien. 1974. Dorsal light response as an index of prey preference in Bluegill (*Lepomis macrochirus*) J. Fish. Res. Board Can. 32:1860-1863.

Vinyard, G. L. and W. J. O'Brien. 1976. Effects of light and turbidity on the reactive distance of Bluegill (*Lepomis macrochirus*). J. Fish. Res. Board Can. 33:2845-2849.

Wells, P. V. and G. E. Morley. 1964. Composition of Baldwin Woods: An Oak-Hickory forest in eastern Kansas. Trans. Kansas Acad. Sci. 67: 65-69.

Young, C. W. 1978. Comparison of the crane flies (*Diptera*: *Tipulidae*) of two woodlands in eastern Kansas with a key to the adult crane flies of eastern Kansas. Univ. Kansas Sci. Bull. 51:407-440.

APPENDIX I. Number of species of major groups recorded on the University of Kansas Natural History Reservation since 1948

Group	Number of Species
Trees, shrubs and woody vines	63
Flowering plants (herbaceous dicotyledons)	220
Grasses, rushes, sedges, lilies (monocotyledons)	60
Lichens	26
Mosses	29
Liverworts	5
Ferns	6
Mammals	33
Birds	178
Reptiles	27
Amphibians	10
Fishes	5
Beetles	165
Crickets, grasshoppers, katydids, roaches (Orthoptera)	32
Ants, bees, wasps (Hymenoptera)	33
Moths	226
Butterflies	21
Spiders	191
Chiggers	22
Crustaceans	10
Earthworms	1
Clams	2
Snails and slugs	28

DESTRUCTION OF SANDSAGE PRAIRIE IN SOUTHWEST KANSAS

Mark L. Sexson
District Game Biologist
Kansas Fish and Game Commission
Garden City, Kansas 67846

Abstract. Sandsage prairie (*Andropogon-Artemesia-Calamovilfa*) is primarily located adjacent to the Arkansas and Cimarron Rivers in southwest Kansas. Lesser prairie chicken (*Typanuchus pallidicinctus*) occupies this prairies association. During the past decade, center pivot irrigation systems have enabled landowners to convert the rolling sandsage prairie to cropland and to utilize the vast underground supplies of water that exist along the Arkansas and Cimarron Rivers. Development of center pivot irrigation systems began along the Arkansas River near Garden City in 1965, and rapidly spread throughout sandsage prairie in southwest Kansas. Conversion of sandsage prairie along the Cimarron River to irrigated cropland is reaching similar proportions. Because it supplied a quality winter food supply, early development of center pivot irrigation systems appeared to benefit prairie chicken populations. However, as more sandsage prairie was broken out, other critical habitat requirements were lost, causing a decrease in prairie chicken populations. The Kansas Fish and Game Commission, in conjunction with the Space Technology Center at Kansas University, began monitoring expansion of center pivot irrigation systems in southwest Kansas through the use of remote imagery. Data gathered in the spring of 1975 indicated that sandsage prairie in Kearny, Finney and Gray Counties along the Arkansas River had been reduced from nearly 209,312 ha to 88,994 ha. It is considered impossible to grow dryland crops in sandsage prairie due to the soil type and the climate of southwest Kansas. As irrigation becomes obsolete due to over-mining of the Ogallala aquifer, severe ecological problems will result if intensive management is not used to stabilize these sandy soils with native vegetation. The future of lesser prairie chickens in southwest Kansas is gloomy as center pivot irrigation continues to expand annually.

Introduction

The sandsage prairie is a unique vegetation type located along the Arkansas and Cimarron River drainage of southwestern Kansas. The area is characterized as having a sandy type soil usually classified as Tivoli fine sand or Tivoli-Dune land complex and are in the Choppy Sands range site. Among the native plants to be found on these areas are sand bluestem (*Andropogon hallii*), switchgrass (*Panicum virgatum*), little bluestem, (*Andropogon scoparius*), big sandreed (*Calamovilfa gigantica*), sand dropseed (*Sporobolus cryptandrus*), sand sage brush (*Artemisia filifolia*), sand lily (*Nuttallia nuda*), and annual funflower (*Helianthus annuus*). The sandsage prairie supports a variety of animal life. The usual dryness of the sandsage makes it a kind of southwest connection for wildlife. Forty-nine of 119 Kansas species and subspecies of mammals have ranges which include the sandsage prairie. It has been found that in extreme southwestern Kansas, 276 of 413 species of birds have ranges that include the sandsage prairie. Because this prairie constitutes a harsh environment, many of the species found there have become specialized for survival. The best examples of this are the kangaroo rat (*Dipodomys ordii*), scaled quail (*Callipepla squamata*), and lesser prairie chicken (*Tympanuchus pallidicinctus*). Other species found on these areas include the roadrunner (*Geococcyx californionus*), dust-colored Brewer's sparrow (*Spizella breweri*), and black-tailed jackrabbit (*Lepus californicus*) (Waddel and Hanzlick 1978).

Effects of Agricultural Practices

Attempts were made in the early 1900's to farm portions of the sandsage prairie for winter wheat production. Although only small areas with better soil were broken out for crops, it quickly became evident that the sandy soil of the sandsage prairie was not adapted for dryland farming. When the drought of the 1930's set in, much of western Kansas was broken out and laid open to the dry winds. During the 1930's the sandhills became moving sand dunes and many wildlife species which depended on sandsage prairie for survival were nearly wiped out. One of the hardest hit species was the lesser prairie chicken. Limited evidence indicates that the lesser prairie chicken was abundant until the 1930's and may have been nearly eliminated in Kansas during the 1930's due to drought and poor cover conditions (Schwilling 1955).

Due to conservation practices the sandhills stabilized and most of the native species reoccupied their native ranges. Hard lessons were learned from the dirty Thirties, especially about sandsage prairie. But, unfortunately, some lessons are forgotton too quickly.

Beneath a large portion of the High Plains is a large underground lake known as the Ogallala aquifer. The Ogallala extends from Texas and New Mexico northward to South Dakota and Wyoming. Until recently, within the past 10-15 years, the aquifer was used very little, due to its extreme depths and inaccessibility. But as man often does, technology was developed to pump this water to the surface for irrigation. Initially, the practice of irrigation was used on relatively level land, enabling crops to be watered by gravitational flow. As time went on, machinery was developed to water rough terrain. This machinery was called center pivot irrigation. After this irrigation system was developed, any land of rolling terrain was considered as a possible irrigation field. Center pivot irrigation systems in southwest Kansas sprinkle irrigate in a circular pattern. Four pivot units are utilized on each section of land, with each system watering 53.4 ha (132 acres).

The sandsage prairie was considered non-farmable until the center pivot irrigation system was developed. This was due to the sandy soils having unstable characteristics, with low fertility and high water infiltration. To grow crops in such a soil in the southwestern Kansas climate, dictates use of large amounts of water and fertilizer. The center pivot is able to supply the needed water, and artifical fertilizers are used to provide needed nutrients.

The first irrigation fields were an advantage to wildlife such as the lesser prairie chicken as they supplied a tremendous winter food supply. However, as more and more ground was broken out, other critical requirements, such as gobbling grounds, nesting habitat and protective cover, were lost. It was found by Crawford (1974) that Texas areas of less than 63% rangeland appear incapable of supporting stable lesser prairie chicken populations. Crawford stated that, "The greatest potential threat to the preservation of existing populations of the lesser prairie chicken is cultivation of remaining native rangelands." For this reason, the lesser prairie checken went from a growing population in the first years of irrigation to a much reduced population at present.

Originally, there were approximately 547,773 ha (1,353,000 acres) of sandsage prairie located in Kansas (Kuchler 1974). By 1978, this was reduced to 207,509 ha (512,547 acres) due to the expansion of center pivot irrigation. One county (Finney) along with the Arkansas River recorded 11 center pivot in 1965, 252 units in 1971, 338 units in 1972, 459 units in 1973, 590 units in 1974, and nearly 700 units in 1975. Conversion of sandsage prairie along the Cimarron River to irrigated cropland is reaching similar proportions. Today there are thousands of center pivot units located in the sandsage prairie covering nearly 344,130 ha (850,000 acres), and each year this number grows larger.

In recent years, the Kansas Fish and Game Commission, in conjunction with the Space Technology Center at Kansas University, began monitoring expansion of center pivot irrigation systems in southwest Kansas through the use of remote imagery. A map of all center pivot units in southwest Kansas was prepared. Data gathered in the spring of 1975 indicated that sandsage prairie in Kearny, Finney and Gray Counties along the Arkansas River have been reduced from nearly 209,312 ha (517,000 acres) to 88,994 ha (219,815 acres). Cropland comprises 57.4% of the area.

Because the Ogallala aquifer is connected and runs for almost 1,300 km (812 miles) beneath 8 states, it must be pointed out that Kansas is not the only state mining water. The aquifer only renews itself several inches each year, and irrigation drops the water table several feet a year, thus creating a problem. As additional wells are drilled into the Ogallala, the water table will continue to drop at an exponential rate. This is due to the bottom topography of the aquifer. Although the Ogallala is considered one solid body of water, it is actually a series of lakes which are connected. As is true with most surface lakes, the Ogallala has deeper areas near the center of each individual lake and shallow areas around their perimeter. This means the wells operating in shallow areas will be the first to go dry, leaving smaller amounts of water to be pumped from the deeper areas. It is believed that in some areas there is still 300-400 feet of saturated aquifer in the deep portion of each lake, but the drying of wells can already be seen in the marginal areas. As the water table continues to drop, more and more wells will be shut down because of the lack of water. Although there is question as to how long the aquifer can hold out, one thing is certain, the Ogallala aquifer is running out of water and with it the capability to grow crops on sandsage prairie. Without water to grow crops, it will be impossible to stabilize these sandy soils, thus leading to severe ecological instability in southwest Kansas.

In the past few years, there has been discussion of obtaining alternate water sources. This includes pumping excess water from the Missouri River in northeast Kansas to western Kansas or bringing water from Canada. The economical and ecological problems of either of these would be staggering and for the most part impossible. However, if alternate water is obtained, it will be many years in the future and maybe too late to save the sandsage prairie.

Conclusions

Because of the slow successional rate of sandsage prairie, if this former native prairie is not revegetated before the water runs out, there will probably be a much worse problem than that of the 1930's. At the present time, there is much more ground broken out than in the 1920's. For this reason, if the remaining water is not used to reestablish native vegetation on the disturbed areas, and if restrictions are not placed on the amount of sandsage prairie which can be broken out or the number of wells which can be drilled each year controlled, moving sand dunes may be the end result of what is now an economic boom in southwestern Kansas. If this were to happen, many species of unique wildlife species would be eliminated from Kansas.

Literature Cited

Waddell, B. and B. Hanzlick. 1978. The vanishing sandsage prairie. Kansas Fish and Game Magazine, March-April.

Crawford, J. A. 1974. The effects of land use on lesser prairie chicken populations J. Range Manage. 29:59.

Schwilling, M. B. 1955. A study of the lesser prairie chicken in Kansas. Job Completion Report, Kansas Forestry, Fish and Game Commission, Pratt. Mimeo.

Kuchler, A. W. 1974. A new vegetation map of Kansas. Ecology 55:586-604.

ing the 1950's due to drought and poor cover conditions (Schwilling 1955).

Due to conservation practices the sandhills stabilized and most of the native species reoccupied their native ranges. Hard lessons were learned from the dirty Thirties, especially about sandsage prairie. But, unfortunately, some lessons are forgotton too quickly.

Beneath a large portion of the High Plains is a large underground lake known as the Ogallala aquifer. The Ogallala extends from Texas and New Mexico northward to South Dakota and Wyoming. Until recently, within the past 10-15 years, the aquifer was used very little, due to its extreme depths and inaccessibility. But as man often does, technology was developed to pump this water to the surface for irrigation. Initially, the practice of irrigation was used on relatively level land, enabling crops to be watered by gravitational flow. As time went on, machinery was developed to water rough terrain. This machinery was called center pivot irrigation. After this irrigation system was developed, any land of rolling terrain was considered as a possible irrigation field. Center pivot irrigation systems in southwest Kansas sprinkle irrigate in a circular pattern. Four pivot units are utilized on each section of land, with each system watering 53.4 ha (132 acres).

The sandsage prairie was considered non-farmable until the center pivot irrigation system was developed. This was due to the sandy soils having unstable characteristics, with low fertility and high water infiltration. To grow crops in such a soil in the southwestern Kansas climate, dictates use of large amounts of water and fertilizer. The center pivot is able to supply the needed water, and artifical fertilizers are used to provide needed nutrients.

The first irrigation fields were an advantage to wildlife such as the lesser prairie chicken as they supplied a tremendous winter food supply. However, as more and more ground was broken out, other critical requirements, such as gobbling grounds, nesting habitat and protective cover, were lost. It was found by Crawford (1974) that Texas areas of less than 63% rangeland appear incapable of supporting stable lesser prairie chicken populations. Crawford stated that, "The greatest potential threat to the preservation of existing populations of the lesser prairie chicken is cultivation of remaining native rangelands." For this reason, the lesser prairie checken went from a growing population in the first years of irrigation to a much reduced population at present.

Originally, there were approximately 547,773 ha ([illegible] acres) of sandsage prairie located in Kansas (Kuchler 1974). By 1978, this was reduced to [illegible] ha ([illegible] acres) due to the expansion of center pivot irrigation. One county (Finney) along with the Arkansas River recorded 1 center pivot in 1965, [illegible] units in 1971, [illegible] units in 1972, [illegible] units in 1973, [illegible] units in 1974, and nearly 700 units in 1975. Conversion of sandsage prairie along the Cimarron River to irrigated cropland is reaching similar proportions. Today there are thousands of center pivot units located in the sandsage prairie covering nearly 344,130 ha (850,000 acres), and each year this number grows larger.

In recent years, the Kansas Fish and Game Commission, in conjunction with the Space Technology Center at Kansas University, began monitoring expansion of center pivot irrigation systems in southwest Kansas through the use of remote imagery. A map of all center pivot units in southwest Kansas was prepared. Data gathered in the spring of 1979 indicated that sandsage prairie in Kearny, Finney and Gray Counties along the Arkansas River have been reduced from nearly 209,312 ha (517,000 acres) to 88,994 ha (219,815 acres). Cropland comprises 57.4% of the area.

Because the Ogallala aquifer is connected and runs for almost 1,300 km (812 miles) beneath 8 states, it must be pointed out that Kansas is not the only state mining water. The aquifer only renews itself several inches each year, and irrigation drops the water table several feet a year, thus creating a problem. As additional wells are drilled into the Ogallala, the water table will continue to drop at an exponential rate. This is due to the bottom topography of the aquifer. Although the Ogallala is considered one solid body of water, it is actually a series of lakes which are connected. As is true with most surface lakes, the Ogallala has deeper areas near the center of each individual lake and shallow areas around their perimeter. This means the wells operating in shallow areas will be the first to go dry, leaving smaller amounts of water to be pumped from the deeper areas. It is believed that in some areas there is still 300-400 feet of saturated aquifer in the deep portion of each lake, but the drying of wells can already be seen in the marginal areas. As the water table continues to drop, more and more wells will be shut down because of the lack of water. Although there is question as to how long the aquifer can hold out, one thing is certain, the Ogallala aquifer is running out of water and with it the capability to grow crops on sandsage prairie. Without water to grow crops, it will be impossible to stabilize these sandy soils, thus leading to severe ecological instability in southwest Kansas.

ECOLOGICAL SUCCESSION IN VEGETATION AND SMALL MAMMAL POPULATION ON A NATURAL AREA OF NORTHEASTERN KANSAS

Henry S. Fitch
and
W. Dean Kettle
Department of Systematics and Ecology, Snow Hall
The University of Kansas
Lawrence, Kansas 66045

Abstract. The University of Kansas Natural History Reservation, protected since 1948, includes a variety of habitats, both woodlands and grasslands. A 3.2 ha bottom land pasture was dominated by the introduced pasture grass *Bromus inermis,* with smaller amounts of bluegrass, and various seral weeds were prominent. About 9% of the area was shaded, mainly by American elms. After 4 years of protection the grasses had increased greatly and the seral weeds were becoming much scarcer. The Prairie Vole and the Hispid Cotton Rat increased from low levels when the area was grazed to peaks in 1951 (450 voles/ha) then decreased. By 1979 woody plants were replacing the herbaceous vegetation (tree cover 56%). Grassland small mammals formerly present had disappeared entirely (Deer Mouse, Plains Harvest Mouse) or declined to very low levels (Prairie Vole, Western Harvest Mouse, Hispid Cotton Rat, Southern Bog Lemming). The White-footed Mouse, a woodland and edge species had increased, however, and outnumbered all other species combined.

Introduction

The research reported here is a small portion of a continuing study documenting the changes in plant and animal populations as influenced by natural succession on the University of Kansas Natural History Reservation (NHR). The scope of this paper is limited to the 30-year change in vegetation and small mammals on a former bottomland posture, one of the many types of habitats constituting the NHR. Since the NHR was created in 1947, Fitch and others (see literature cited) have described succession in a variety of habitats including hilltop pastures, bottomland old fields and regenerated prairie, and the natural history of numerous species found therein.

The Study Site

House Field, an irregularly shaped 3.2 ha former bottomland pasture, was our study site. The 239 ha NHR is located 10.5 km north of Lawrence, Kansas in northeastern Douglas County. In 1947 the area was set aside as a reservation where native plants and animals might be protected and studied under natural conditions. All human disturbances such as farming, ranching, logging and hunting were eliminated in 1947. No fire has swept over the area since then.

The pre-White man vegetation of the NHR was likely a combination of tallgrass prairie and hardwood forest, each predominating in areas for which it was best adapted with well-defined boundary lines separating them. House Field, a lowland with a 3-7% slope, was probably composed of tallgrass prairie. Written records of the native vegatation in this region dated from Major W.S. Long's 1819 exploring expedition and have been described in detail by Fitch (1965). House Field was probably used solely for the grazing of domestic livestock from the time of the earliest settlers, in the 1850's, until the establishment of the NHR in 1947.

The NHR, at 38°58′ latitude and 95°16′ longitude with an elevation of approximately 300 m, has a typical continental climate with large seasonal fluctuations in temperature and large monthly variations in rainfall. Weather data have been continually collected on NHR.

Methods

Vegetation. Herbaceous vegetation was sampled in mid-summer by a series of 40.5m^2 (0.01 acre) circular plots. Each plant species within a plot and its relative density (percentage vegetative cover) was recorded. Estimates were also made of percentage ground cover and average height of vegetation. Woody vegetation was sampled using the circular plots previously described with larger trees and dense stands described by stem counts and DBH measurements.

The percentage of House Field covered by trees and brush in 1951 was determined by measuring crown diameter of existing trees. In 1964 and 1979 the forested areas were mapped and the relative cover determined by using a compensating polar planimeter.

Scientific names for species referred to by common name in the text are given in Table 1.

Table 1. Scientific names for species of plants referred to in the text by common names

Common Name	Scientific Name
Grasses	
Big bluestem	*Andropogon gerardi* Vitman
Little Bluestem	*Andropogon scoparius* Michx.
Awnless brome	*Bromus inermis* Leyss.
Japanese chess	*Bromus japonicus* Thunb.
Fowl mannagrass	*Glyceria striata* (Lam.) Hitchc
Blue grass	*Poa pratensis* L.
Seral weeds	
Ragweed	*Ambrosia artemisiifolia* L.
Composites	*Aster novae-angliae* L., *A. pilosus* Willd., *Helianthus tuberosus* L., *Solidago missourienses* Nutt., *S. nemoralis* L.
Carex	*Carex gravida blanda hyalinolepix*
Legumes	*Desmanthus illioniensis* Michx., *Lespedesa violacea* Michx., *Melilotus alba* Adans., *M. officinalis* Adans.,
Germander	*Teucrium canadense* L.
Avens	*Geum canadense* Jacq., *G. vernum* (Raf.) T. & G.
Wood nettle	*Laportea canadenses* (L.) Wedd.
Lobelia	*Lobelia siphilitica* L.
Nightshades	*Physalis heterophylla* Nees., *Solanum carolinense* L.
Ironweed	*Vernonia baldwini* Torr.
Trees, shrubs and vines	
Grape	*Ampelopsis cordata* Michx.
Dogwood	*Cornus drummonda* Meya
Honey locust	*Gleditsia triacanthos* L.
Walnut	*Juglans nigra* L.
Red cedar	*Juniperus virginiana* L.
Osage orange	*Maclura pomifera* (Raf.) Schneid.
Virginia creeper	*Parthenocissus quinquefolia* (L.) Planch.
Crabapple	*Pyrus ioensis* (Wood) Bailey
Sumac	*Rhus aromatica* Ait.
Poison ivy	*Rhus radicans* L.
Gooseberry	*Ribes missouriense* Nutt.
Blackberry	*Rubus ostryifolius* Rydb.
Greenbriar	*Smilax bona-nox* L.
Coral berry	*Symphoricarpos orbiculatus* Moench
American elm	*Ulmus americana* L.

Small mammals. Estimates of animal populations were based primarily on live-trapping results. The live traps used were modeled after the trap described by Fitch (1952). Traps were baited with a mixture of scratch grain (cracked corn, milo and wheat) and rolled oats. Ninety traps were positioned in a grid at intervals of 15.2m. At first captured animals were individually marked by toe-clipping. The following data were recorded for each individual captured during a trapping period: location on grid, weight, total length, sex and reproductive condition. An attempt was made to trap on a monthly schedule from December 1978 through June 1980, trapping 5-7 days each month. Exceptions were made when conditions threatened animal survival. A total of 6,600 trap days were sampled in the 1978-1980 survey. It is emphasized that all methods and locations for the 1978-1980 survey were identical to those of previous years.

Scientific names for animals referred to by common name in the text are presented in Table 2.

Table 2. Scientific names for species of animals referred to in the text by common names.

Common Name	Scientific name
Short-tailed shrew	*Blarina brevicauda*
Least shrew	*Cryptotis parva*
Prairie vole	*Microtus ochrogaster*
Pine vole	*Microtus pinetorum*
House mouse	*Mus musculus*
White-footed mouse	*Peromyscus leucopus*
Deer mouse	*Peromyscus maniculatus*
Western harvest mouse	*Reithrodontomys megaletis*
Plains harvest mouse	*Reithrodontomys montanus*
Cotton rat	*Sigmodon hispidus*
Southern bog lemming	*Synaptomys cooperi*
Meadow jumping mouse	*Zapus hudsonius*

Results

In 1952 the tree canopy cover of House Field was nearly 9%. Fourteen large American elms made up 80% of this cover. Many of these elms died from Dutch elm disease (phloem necrosis resulting from attacks of bark bettles) during the early 1960's and by 1979 only 3 of these trees remained alive. The tree cover in 1964 was similar to the total coverage of 1952 but largely composed of species that were insignificant in the early years (walnut, locust, and Osage orange). The removal of the elms opened up the canopy, allowing invasion by woody and weedy species. In 1979 the canopy cover had increased to 56%, with several species making up that total.

In 1949, after grazing on the field was discontinued, the closely cropped pasture became covered with weeds and tall grasses. Common in the 1952 sample (Table 3) were ragweeds, ironweed, nightshade and American germander-all symptomatic of previous overgrazing conditions by domestic livestock. These weeds were almost entirely eliminated by 1964, outcompeted by grasses which were no longer subject to grazing pressure. Grasses made up approximately 78% of the field vegetation in 1964. By 1979 the grasses were greatly reduced due to competition and shading from trees and shrubs. However, in unforested areas grasses remained the dominant vegetation (brome makes 75% of the cover in open areas in 1980). Meanwhile small clumps of perennial tallgrasses (big and little bluestem) have become reestablished and expanded. They compete well with the herbaceous vegetation, but cannot tolerate the shade of encroaching trees.

Table 3. Percentage cover of vegetation in unforested areas and forest understory on House Field from 1952-1979.

Type of Vegetation	1952	1964	1979
Grasses			
awnless brome	60.6	72.6	34.3
Japanese chess	7.4	trace	absent
blue grass	10.9	5.3	7.4
fowl mannagrass	trace	trace	7.5
Seral weeds			
composites	trace	trace	3.8
germander	1.9	trace	trace
carex	1.9	trace	5.0
legumes	trace	trace	1.1
ironweed	2.9	trace	trace
nightshades	0.4	trace	trace
ragweeds	1.5	trace	trace
weed nettle	trace	trace	3.9
avens	trace	trace	2.1
Shrubs and vines			
sumac	trace	1.2	1.5
coral berry	5.8	2.2	13.8
poison ivy	trace	trace	1.7
miscellaneous vines	trace	trace	1.3
Trees (DBH < 2.0 cm)	trace	9.1	13.5
Miscellaneous vegetation	6.7	9.6	6.1

By 1964 many of the annual species had been replaced by perennials, such as goldenrod, which still persist in open areas. With the establishment of a maturing forest community, the field has developed a community including herbaceous species not present previously (wood nettle, avens and lobelia) and also certain woodland shrubs and vines (blackberry, gooseberry, poison ivy, Virginia creeper, grape and greenbriar).

Since any change in vegetational structure may affect the livelihood (food supply, availability of nest sites, or protective cover) of animals, it is not surprising to note changes in the densities of animal populations as well as the species composition of House Field. The mammal community of House Field has shifted from one dominated by grassland species with high population numbers to one more characteristic of shrub or forest community as seen in Table 4. For a period of years in the early 1950's, after the closely grazed pasture became dominated by grasses with the cessation of grazing, the dominant mammal was the prairie vole. Its peak population exceeded 450 individuals/ha. The cotton rat and western harvest mouse were also common. The population of these 3 species has been reduced with the invasion of trees and shrubs until today, only isolated small populations of each exist. One previously common grassland species, the deer mouse, has been completely eliminated from the field.

The most common mammal on the grid now is the white-footed mouse, which was rare in the early 1950's. Its habitat has been greatly improved with the invasion of brush and trees. The southern bog lemming first appeared on the area in the mid-1960's and has been present in low numbers ever since.

The least shrew, short-tailed shrew and meadow jumping mouse have been present throughout the 30-year study but always in very low densities. Their low population levels combined with poor bait acceptance in live traps make population estimates of these species difficult.

Table 4. Relative densities of small mammals on House Field from 1951 - 1979, with estimated densities in ( ) as animals / ha

Species	1951	1963	1979
Prairie vole	very high (370.0)	moderate	very low (2.2)
Pine vole	P[1]	P	P
Deer mouse	high	moderate	absent
White-footed mouse	P	P	high (28.6)
Cotton rat	high (44.0)	moderate	P
Western harvest mouse	high (37.0)	moderate	very low (1.0)
Plains harvest mouse	P	absent	absent
House mouse	moderate	moderate	P
Meadow jumping mouse	P	P	P
Southern bog lemming	absent	P	P
Short-tailed shrew	P	P	P
Least shrew	P	P	P

[1]P, present but in numbers too low to estimate.

Acknowledgements

The authors wish to thank L. Raynor for assistance in the 1979 animal trapping and especially V. Fitch for support in the field and in data synthesis.

Literature Cited

Fitch, H. S. 1952. The University of Kansas Natural History Reservation. Univ. Kansas Publ., No. 4:1-38.

______. 1954. Seasonal acceptance of bait by small mammals. J. Mammal. 35:39-47.

______. 1957. Aspects of reproduction and development in the prairie vole (*Microtus ochrogaster*). Univ. Kansas Publ., Mus. Nat. Hist. 10: 120-161.

______. 1958. Natural History of the six-lined racerunner (*Cnemidophorus sexlineatus*). Univ. Kansas Publ., Mus. Nat. Hist., 11:11-62.

______. 1958. Home ranges, territories and seasonal movements in vertebrates of the Reservation. Univ. Kansas Publ. Mus. Nat. Hist., 11:63-326.

———. 1963. Natural history of the black rat snake (*Elaphe obsoleta*) in Kansas. Copeia, 1963:649-658.

———. 1978. A field study of the prairie kingsnake (*Lampropeltis calligaster*). Trans. Kansas Acad. Sci. 84:353-363.

Fitch, H. S. and R. L. McGregor. 1956. The forest habitat of the University of Kansas Natural History Reservation. Univ. Kansas Publ. Mus. Nat. Hist., 10:77-127.

Fitch, H. S. and H. W. Shirer. 1970. Comparison from radiotracking of movements and denning habits of the raccoon, striped skunk, and opossum in northeastern Kansas. J. Mamm., 51: 491-503.

Fitch, H. S. and P. L. VonAchen. 1973. Yellow-billed cuckoo nesting at University of Kansas Natural History Reservation. Kansas Ornithol. Soc. Bull. 24:12-15.

Gaines, M. S. and R. K. Rose, 1976. Population dynamics of *Microtus ochrogaster* in eastern Kansas. Ecology 57:1145-1161.

Martin, E. P. 1956. A population study of the prairie vole (*Microtus ochrogaster*). Univ. Kansas Publ. Nat. Hist., 8:366-416.

[illegible] 1963. Many of the annual species had been replaced by perennials, such as goldenrod, which still persist in open areas. With the establishment of a maturing forest community, the field has developed a community [illegible] species now present [illegible] and lobelia) and also certain woody shrubs and vines (blackberry, gooseberry, poison ivy, Virginia creeper, grape and greenbrier).

[illegible] may affect the livelihood [illegible] of nest sites, or protective cover of animals, it is [illegible] composition of [illegible] The small mammal community of House Field has shifted from one dominated by grassland species with high population numbers to one more characteristic of shrub or forest community as seen in Table 4. For a period of years in the early 1950's, after the closely grazed pasture became dominated by grasses with the cessation of grazing, the dominant mammal was the prairie vole. Its peak population exceeded

[illegible] and western [illegible] population of these 3 species has [illegible] with the invasion of trees and shrubs until today, only [illegible]. One [illegible] mouse, has been [illegible] the Field.

The most common mammal on the grid now is the white-footed mouse, which was rare in the early 1950's. Its habitat has been greatly improved with the invasion of brush and trees. The southern bog lemming first appeared on the area in the mid-1950's and has been present in low numbers ever since.

The least shrew, short-tailed shrew and meadow jumping mouse have been present throughout the 30-year study but always in very low densities. Their low population levels combined with poor bait acceptance in live traps make population estimates of these species difficult.

Table 4. Relative densities of small mammals on House Field from 1951 - 1979, with estimated densities in ( ) as animals / ha.

Species	1951	1963	1979
Prairie vole	very high (370.0)	moderate	very low (2.2)
Pine vole	P[1]	P	P
Deer mouse	high	moderate	absent
White-footed mouse	P	P	high (28.6)
Cotton rat	high (44.0)	moderate	P
Western harvest mouse	high (37.0)	moderate	very low (1.0)
Plains harvest mouse	P	absent	absent
House mouse	moderate	moderate	P
Meadow jumping mouse	P	P	P
Southern bog lemming	absent	P	P
Short-tailed shrew	P	P	P
Least shrew	P	P	P

[1] P, present but in numbers too low to estimate.

Acknowledgements

The authors wish to thank L. Raynor for assistance in the 1979 animal trapping and especially V. Fitch for support in the field and in data synthesis.

Literature Cited

Fitch, H. S. 1952. The University of Kansas Natural History Reservation. Univ. Kansas Publ., No. 4:1-38.

_________ 1954. Seasonal acceptance of bait by small mammals. J. Mammal. 35:39-47.

_________ 1957. Aspects of reproduction and development in the prairie vole (*Microtus ochrogaster*). Univ. Kansas Publ., Mus. Nat. Hist. 10:129-161.

_________ 1958. Natural History of the six-lined racerunner (*Cnemidophorus sexlineatus*). Univ. Kansas Publ., Mus. Nat. Hist. 11:11-62.

_________ 1958. Home ranges, territories and seasonal movements in vertebrates of the Reservation. Univ. Kansas Publ., Mus. Nat. Hist. 11:63-326.

THE DYNAMICS OF A SAND PRAIRIE PLANT COMMUNITY

Mary Lee Plumb-Mentjes
Greenhills Environmental Center
Route 1, Box 861
Cedar Hill, Texas 75104

Abstract. In a sand prairie plant community in southwestern Wisconsin a large proportion of the species had maximal demand in a unique 6-week portion of the growing season and derived their continued presence on the basis of 1 of 3 resource utilization strategies: *persistent, ephemeral,* or *peripheral.* The *persistent* species determine the major structuring of biotic use on the sand prairie by their persistence, numbers, size and spacing. The *ephemeral* species are dependent on the occurrence of a greater than average amount of resources becoming available for a short interval in the growing season. The *peripheral* species depend on small spatial openings, such as pocket gopher mounds or small-scale erosion sites, and include "fugitive species". As a consequence of the changing character of resource availability during the growing season, the proportion of species belonging to each guild was observed to change.

Introduction

The timing of events, both biotic and abiotic, is considered to be critical to community dynamics. The particular juxtaposition of events, such as of precipitation and different life histories, as well as their frequency and duration, will distinguish different communities. The hypothesis to be examined here states that the spatial distribution of plants and the timing of their life history events are governed by recurring patterns of resource distribution in space and time. The differentiation of the spatial and temporal availability of resources was basic to testing of hypotheses concerning variation in biotic occupation. Emphasis was placed on apparent differences in timing of demand on resources by plants having different life history strategies and seasonal changes in moisture availability.

In this study a sand prairie was regarded as a spatial mosaic of patches, each patch having a different amount of critical resources. The boundaries of these patches were considered to change through the growing season as resources of space and moisture became more or less available. Plant colonization and expansion could occur only as long as moisture and space were adequate to sustain active growth. The timing of patch closure was determined as functions of the phenology of competitors and changes in the abiotic resource states. Abiotic and biotic fluctuations when viewed from the perspective of the growing season as a whole comprise what appear to be recurring patterns which may act as selective forces of coherent groups of species.

Site Description

The sand prairie of this study is located in southwest Wisconsin on the Spring Green Reptile Reserve administered by the Head Foundation and Nature Conservancy. The sand prairie developed on glacial outwash over the last 10,000 years. In the last 100 years it was subject to cattle grazing, and for a short period of time a small portion of it was cultivated. All grazing and cultivation ceased about 20 years ago.

A 15-ha portion of the sand prairie was mapped and the wide variety of soil profiles was grouped into 3 soil types on the basis of the depth to the original mollic epipedon (Fig. 1). Aerial photos from 1940, prior to any cultivation in the area, indicate alluvial deposits from gullies on the northeastern and northwestern portions of the site. Alluvial deposits from these gullies are assumed to have been the source of the overburden. An east-west transect across the central portion of the site corroborated the extent of deposition to a depth of 120 cm.

The possible biological significance of the existence of several soil types on the sand prairie was investigated by nutrient analyses and studies of moisture retention. Cation exchange capacities ranged from 1.4 - 4.2 milliequivalents. The stratum with the original A1 horizon has a much higher clay and organic matter content than the alluvial overburden; thus the upper 30 cm of the undisturbed profile have a much higher cation exchange capacity than profiles in the alluvial fans. The moisture retention curve (Fig 2) of samples

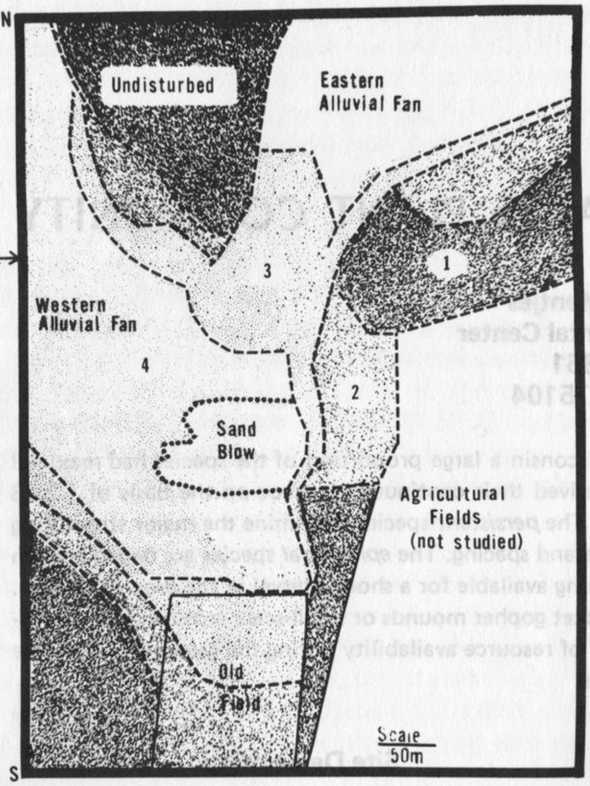


Fig.1. Distribution of soil types on research site: Type 1, undisturbed, AI at 0-15 cm; Type 2, AI at 25-46 cm; Type 3, AI at 46-92; Type 4, alluvial fans, AI below 92 cm.

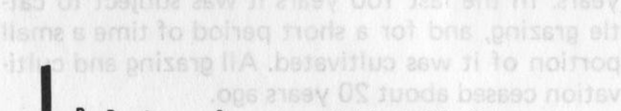


Fig. 2. Soil moisture retention at different suctions. Data taken with a ceramic pressure plate. Moisture content measured gravimetrically on a oven-dry basis.

taken from the upper 30 cm of undisturbed and disturbed sites shows that given a certain amount of precipitation, a difference will exist among the different soil types in the amount of precipitation available to plants. The differences in moisture retention appear to be due to the presence of 2.6% more clay and to a lesser degree more organic matter in the undisturbed soil type. Two percent organic matter was found in samples from the undisturbed sites and only 0.2% in samples from the severely eroded sites. In a sandy soil 1 bar suction was considered to be the lower limit of available water, thus 3.5% moisture was considered the lower limit on the undisturbed sites and 1.2% on the distrubed sites. Thus, the 3 soil types do appear to have potentially significant differences for plant growth.

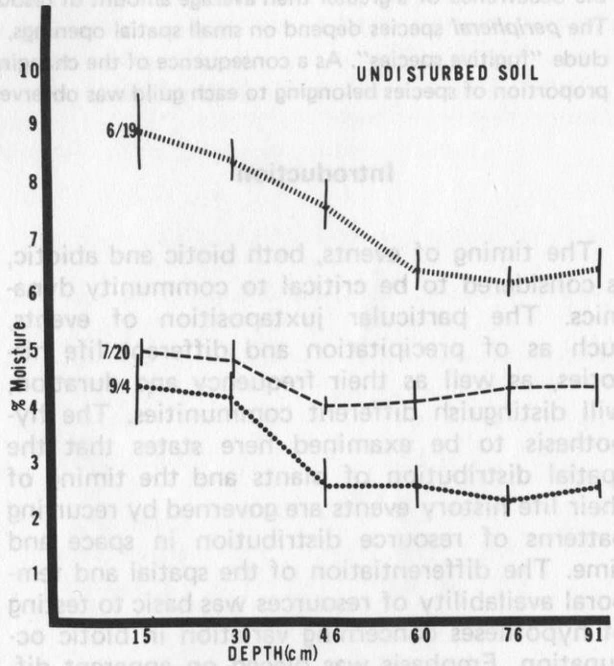


Fig. 3. Gravimetric soil moisture content measurements of samples from undisturbed soil type. Samples taken 6/19/78, 7/20/78, and 9/4/78. Percent moisture is derived from the ratio of weight of water in sample to weight of dry sample. The vertical lines indicate standard deviations.

Soil type differences were found to become increasingly significant as the growing season progressed. The distribution of moisture in a relatively undisturbed profile and in a disturbed profile which is composed primarily of aeolian and alluvial deposits was studied during 2 growing seasons by gravimetric sampling. In the undisturbed profile (Fig. 3) moisture was retained in the upper portion of the profile at a level believed adequate for growth during most of the growing season. In the disturbed profile (Fig. 4), that composed of alluvial and aeolian deposits, moisture

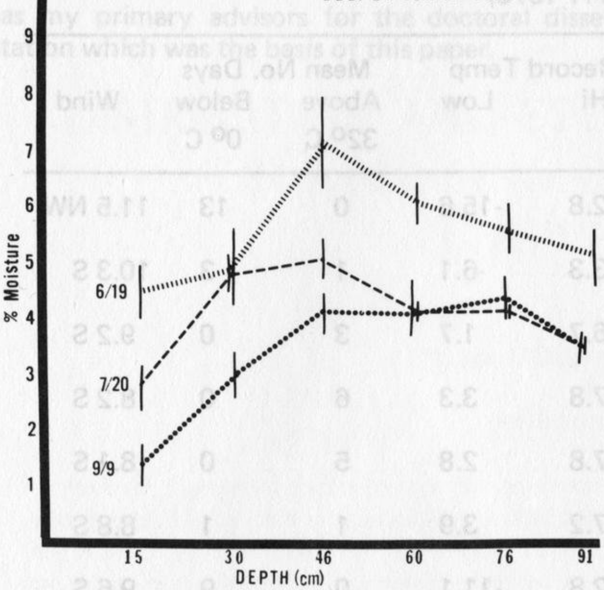


Fig. 4. Gravimetric soil moisture content measurements of samples from deeply buried soil type (original A horizon below 100 cm depth). Samples taken 6/19/78, 7/20/78, and 9/9/78. Percent moisture is derived from the ration of the weight of water in sample to weight of dry sample. The vertical lines indicate standard deviations.

rapidly drained from the upper portion, and the remainder tended to evaporate. This moisture behavior has serious consequences for seedling establishment. These graphs show how the differences between the 2 profiles become accentuated as the growing season continues. Initially large patches have adequate resources; later the boundaries of these areas contract.

Differentiation of the Growing Season

A correlation was sought between phenology and the changing character of resource availability during the growing season. On the basis of phenological observations, 5 6-week subdivisions were termed pheno-periods. These pheno-periods roughly correspond to observed phenological changes on the prairie, starting in April and ending in October. Growing conditions in each pheno-period were characterized on the basis of mean precipitation from the last 45 years (Table 1) and mean wind, temperature, and insolation data from the previous 25 years (Table 2). The standard deviation was calculated to indicate the degree of predictability of rainfall. This summary method provides a standard against which to compare precipitation patterns of other years.

Plant species were grouped according to the pheno-period during which each was observed to

Table 1. Average precipitation by pheno-periods of approximately 6 weeks, based on data for Richland, Wisconsin (1930-1974)

Pheno-period	cm ($\pm$S.D.)	Percent ($\pm$S.D.) of Growing Season
I. April - Mid-May	10.9 ± 4.5	17.8 ± 6.5
II. Mid-May - Late June	13.8 ± 4.9	22.6 ± 6.6
III. Late June - July	12.2 ± 4.9	19.3 ± 8.1
IV. August - Early Sept.	11.9 ± 6.7	17.6 ± 7.1
V. Mid-Sept. - Mid-Oct.	11.3 ± 6.3	17.6 ± 8.5

have its maximum growth and in which it appeared to be most responsive to deviation from the mean weather conditions. Coupled with frequency distribution data a composite picture was developed of how the sand prairie substrate is not a static mosaic (Fig 1) of areas with different soil types, but a changing response surface in which moisture resources become more or less available during the growing season on the bases of the amount and distribution of rainfall, the amount of insolation, wind speeds, temperatures, as well as the size and distribution of competitors.

Differentiation of 3 Resource Utilization Strategies

Each species on the sand prairie appears to derive its continued presence on the basis of 1 of 3 utilization strategies: persistent, ephemeral, or peripheral. The persistent species determine the major structuring of biotic use on the sand prairie by their persistence, numbers, size, and spacing. The ephemeral species are dependent on the occurrence of a greater than average amount of resources becoming available for a short interval in the growing season. The peripheral species depend on small spatial openings, such as pocket gopher mounds or small-scale erosion sites, and include "fugitive species". They are termed "peripheral" due to their avoidance of the middle of such sites, in part as a result of extreme temperatures. As a consequence of the changing character of resource availability during the growing season, the proportion of species belonging to each guild was observed to change.

The first pheno-period in April and early May is occupied by about 6 species, all ephemerals like *Viola pedata.* The second pheno-period (mid-May through June) has the largest mean rainfall ($13.8 cm \pm 4.9$) with a low standard deviation and the largest number of species. At least 35 species complete most of their growth in this pheno-period, and these include members of all 3 guilds.

Table 2. Insolation, temperature (^{o}C), and mean wind velocity data (km/hr) for each month in the growing season, temperature data are for Richland, Wisconsin (1951-1975), with wind and percent possible sunshine data for Madison, Wisconsin (1941-1970)

Month	% Possible Sunshine	Temperature Max	Temperature Min	Record Temp Hi	Record Temp Low	Mean No. Days Above 32^{o} C	Mean No. Days Below 0^{o} C	Wind
April	52	15.6	1.6	32.8	-15.6	0	13	11.5 NW
May	59	22.2	7.3	33.3	-6.1	1	3	10.3 S
June	65	26.9	12.6	36.7	1.7	3	0	9.2 S
July	69	29.3	15.1	37.8	3.3	6	0	8.2 S
August	68	28.3	14.1	37.8	2.8	5	0	8.1 S
September	62	23.6	9.5	37.2	3.9	1	1	8.8 S
October	57	17.8	3.9	32.8	-11.1	0	9	9.6 S

Examples of the persistent species include *Poa pratensis, Koeleria cristata,* and *Opuntia compressa*; the ephemeral species include *Tradescantia ohiensis* and *Arabis lyrata*. The peripheral species include *Lepidium densiflorum* and *Plantago patagonica*. All of these are thus able to avoid direct competition with a large number of grasses in the next pheno-period.

The third pheno-period (end of June and all of July) is used by a minimum of 28 species, 11 of which are grasses. Eighty-six percent of the species are persistent species like *Panicum virgatum* and *Andropogon scoparius*; the remaining 14% are peripheral species like *Chenopodium leptophyllum* and *Salsola kali*.

The fourth pheno-period (August and the beginning of September) is used maximally only by about 11 persistent species. These include *Ambrosia psilostachya, Liatris aspera,* and *Polygonum tenue*. No species did most of its growth in the fifth pheno-period (the latter half of September and the first half of October). Small spatial openings were found to have a different significance in each pheno-period on various parts of the site.

The co-existence of a large number of species on the sand prairie is possible due to the underlying heterogeneity of the environment, both of the substrate and of the character of abiotic inputs during the growing season. A greater abundance and diversity of short-lived species were found on the alluvial and aeolian deposits than on the undisturbed substrate. This appears to be due to the sporadic availability of moisture, low level of nutrients, and low density of competitors. The short-lived species were more responsive to differences in abiotic inputs within a pheno-period than were the long-lived species.

In areas which have been subject to large-scale disturbances, like alluvial and aeolian deposition, the occurrence of gopher mounds and small-scale erosion sites were not found to provide opening for additional species. Small spatial openings like these increase the variety of openings for colonization only when the small openings occur on a substrate with a resource based adequate to sustain the occurrence of large, long-lived species. The additional presence of ephemeral and peripheral species in highly disturbed areas is believed to be due to the brief occurrence of favorable growing conditions in the second pheno-period and the capacity of short-lived species to respond to this ephemeral temporal opportunity in the absence of dense occupation by perennials.

The significance of spatial heterogeneity for plant growth and species diversity on a sand prairie appears to be as critically determined by the abiotic resource base and the timing of abiotic inputs as by biotic competition. The study of differences in the use of the growing season by plants having different life histories and resource utilization strategies may best reveal the particular structuring and inter-relationships of the member of a community found on a particular substrate having geographically determined climate, as well as indicating possible consequences for the evolution of the species and the community.

Acknowledgements

Dr. Orie Loucks and Dr. Francis Hole served as my primary advisors for the doctoral dissertation which was the basis of this paper.

Literature Cited

Plumb, M. L. 1979. The dynamics of short-lived species in sand prairie. Ph.D. Thesis, University of Wisconsin, Madison.

Table 2. Insolation, temperature (°C), and mean wind velocity data (km/h) for each month in the growing season; temperature data are for Richland, Wisconsin (1951-1975), with wind and percent possible sunshine data for Madison, Wisconsin (19[illegible]-1975).

Month	% Possible Sunshine	Temperature Max	Temperature Min	Record Temp Hi	Record Temp Low	Mean No. Days Above 32° C	Mean No. Days Below 0° C	Wind
April	52	15.6	1.6	32.8	-15.6	0	13	11.5 NW
May	59	22.2	7.3	33.3	-6.1	1	3	10.3 S
June	65	26.9	12.6	36.7	1.7	3	0	9.2 S
July	69	29.3	15.1	37.8	3.3	6	0	8.2 S
August	68	28.3	14.1	37.8	2.8	5	0	8.1 S
September	62	23.6	9.5	37.2	3.9	1	1	8.8 S
October	57	17.8	3.9	32.8	-11.1	0	9	9.6 S

Examples of the persistent species include *Poa pratensis*, *Koeleria cristata*, and *Opuntia compressa*; the ephemeral species include *Tradescantia ohiensis* and *Arabis lyrata*. The peripheral species include *Lepidium densiflorum* and *Plantago patagonica*. All of these are thus able to avoid direct competition with a large number of grasses in the next pheno-period.

The third pheno-period (end of June and all of July) is used by a minimum of 28 species, 11 of which are grasses. Eighty-six percent of the species are persistent species like *Panicum virgatum* and *Andropogon scoparius*; the remaining 14% are peripheral species like *Chenopodium leptophyllum* and *Salsola kali*.

The fourth pheno-period (August and the beginning of September) is used maximally only by about 11 persistent species. These include *Ambrosia psilostachya*, *Liatris aspera*, and *Polygonum tenue*. No species did most of its growth in the fifth pheno-period (the latter half of September and the first half of October). Small spatial openings were found to have a different significance in each pheno-period on various parts of the site.

The co-existence of a large number of species on the sand prairie is possible due to the underlying heterogeneity of the environment, both of the substrate and of the character of abiotic inputs during the growing season. A greater abundance and diversity of short-lived species were found on the alluvial and aeolian deposits than on the undisturbed substrate. This appears to be due to the sporadic availability of moisture, low level of nutrients, and low density of competitors. The short-lived species were more responsive to differences in abiotic inputs within a pheno-period than were the long-lived species.

In areas which have been subject to large-scale disturbances, like alluvial and aeolian deposition, the occurrence of gopher mounds and small-scale erosion sites were not found to provide opening for additional species. Small spatial openings like these increase the variety of openings for colonization only when the small openings occur on a substrate with a resource based adequate to sustain the occurrence of large, long-lived species. The additional presence of ephemeral and peripheral species in highly disturbed areas is believed to be due to the brief occurrence of favorable growing conditions in the second pheno-period and the capacity of short-lived species to respond to this ephemeral temporal opportunity in the absence of dense occupation by perennials.

The significance of spatial heterogeneity for plant growth and species diversity on a sand prairie appears to be as critically determined by the abiotic resource base and the timing of abiotic inputs as by biotic competition. The study of differences in the use of the growing season by plants having different life histories and resource utilization strategies may best reveal the particular structuring and inter-relationships of the member of a community found on a particular substrate having geographically determined climate, as well as indicating possible consequences for the evolution of the species and the community.

DISTRIBUTION AND ECOLOGY OF LOESS HILL PRAIRIES IN ATCHISON AND HOLT COUNTIES IN NORTHWESTERN MISSOURI

Greg F. Iffrig
Missouri Department of Natural Resources
P.O. Box 176
Jefferson City, Missouri 65102

Abstract. Loess hill prairies provide the only example of mixed grass prairie known in Missouri. Field investigation and sampling on 14 loess hill prairies allowed a determination of 3 vegetational communities. These are classified as: dry loess hill prairie, dry mesic loess hill prairie and mesic loess hill prairie. The community classification is based on dominant graminoid taxa. Occurring on these hill prairies are several western prairie species which reach the eastern limit of their geographical range. Several morphological characteristics of the species which occur on these hill prairies are adaptive to harsh environmental conditions. These include small leaves, low stature, abundant surface hairs and a thick epidermal tissue. These morphological characteristics enable the occurrence of more western species on these loess hill soils which are sandy, have a south and west-facing exposure, low moisture retaining capabilities and which continually receive the prevailing westerly winds.

Introduction

Loess hill prairies harbor the only example of a mixed-grass-prairie community type in Missouri. These hill prairies occur on the deep loess soils of the Missouri River bluffs with the best known examples found in the extreme northwestern part of the state. The deep loess soils along the Missouri River extend north into Iowa and a notable example of this prairie community type occurs at Waubonsie State Park in Fremont County.

A notable feature of the loess hill prairies along the Missouri River bluffs in Missouri and Iowa is the occurrence of prairie species characteristic of the mixed grass prairie in western Nebraska and Kansas. Characteristic of these types of prairie are both tallgrass species, greater than 122 cm (48 inches) at maturity, and shortgrass species, less than 61 cm (24 inches) at maturity. Additionally, several prairie species common on the Great Plains reach the eastern limit of their geographical range on the loess hill prairies along the Missouri River bluffs (Steyermark 1963). These mixed-grass prairies are separated from the mixed-grass prairie of the Great Plains by grasslands characterized as true prairie (dominated by several important tallgrass species) located in southeastern Nebraska, south of the Platte River, and northeastern Kansas, north of the Kansas River and east of the Flint Hills region (Weaver 1960). The transition region between true prairie and mixed prairie is 242 km (150 miles) west of Missouri's loess hill prairies (Fig. 1). Conditions of soil, topography, slope, aspect and moisture are responsible for the occurrence of the mixed prairie in Missouri

Methods

A preliminary field investigation was conducted during the summer of 1978 to locate and describe the best examples of loess hill prairies in Atchison and Holt Counties, Missouri. Two loess hill prairie preserves protected as Missouri Natural Areas and 1 Federal Research Natural Area were within the study area. These were Jamerson C. McCormack Loess Mounds Natural Area, Brickyard Hill Loess Mound Prairie Natural Area and Loess Hills Research Natural Area (Missouri Natural Areas Committee, 1981, Federal Committee on Ecological Reserves 1977). Field investigations were conducted for these areas; however, the major effort of this study was to locate additional hill prairie sites, not previously known or described.

Information was gathered on the occurrence of hill prairies using aerial photographs housed at county Agricultural Stabilization and Conservation Service (ASCS) offices. Photographs for Atchison and Holt Counties were flown in 1967. Hill prairie occurrences were plotted on county maps and on USGS topographic maps. These

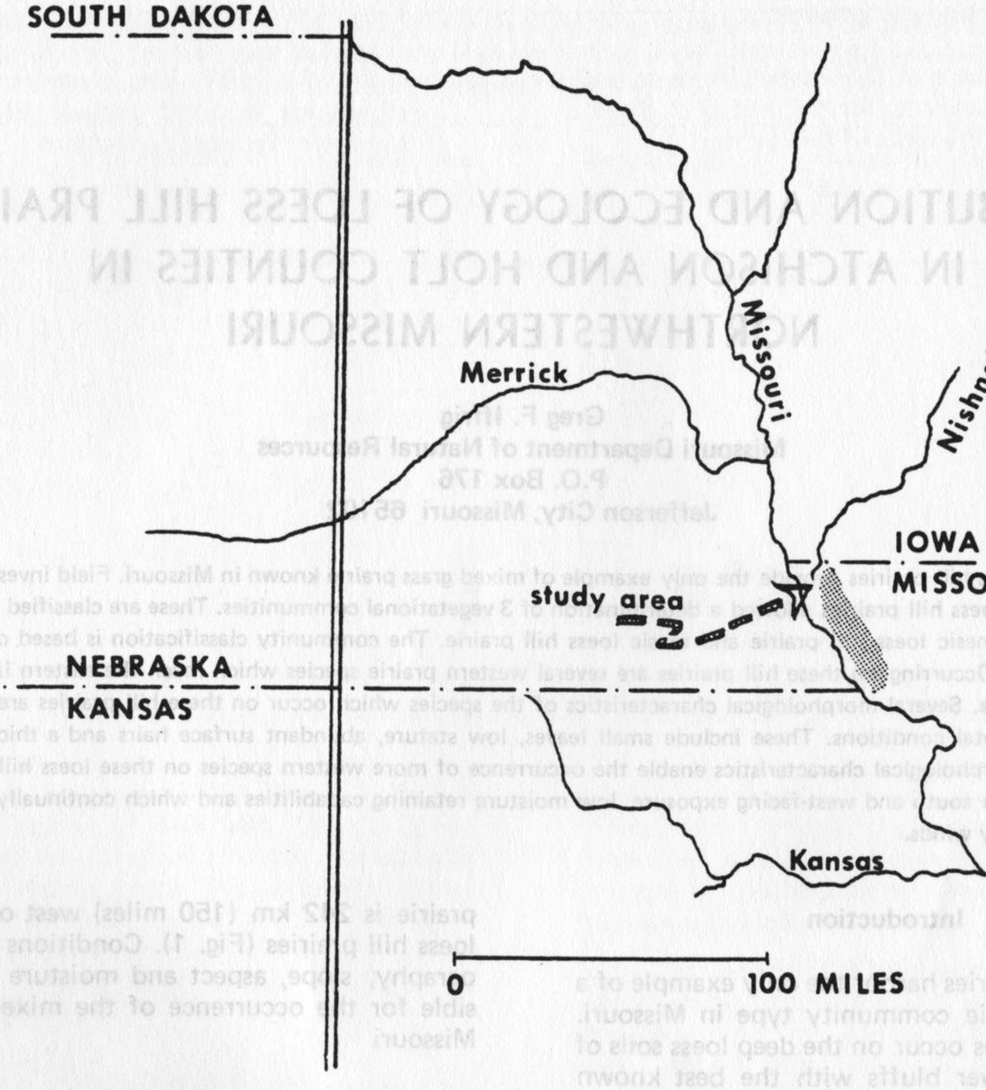


Fig. 1. The heavy double line running north-south (98° 30′ longitude) represents the area of transition from the true prairie (tallgrass prairie) to mixed prairie (taken from Weaver and Bruner 1954). This is referenced to the study area for this project representing an eastern extension of the mixed-prairie community.

areas were then evaluated in the field for lack of disturbance, either man-made or natural, and the extent to which the vegetational community represented presettlement conditions. Species occurrences were noted and information was collected regarding community types relative to dominant graminoid taxa. Nomenclature for vascular flora described in this study follows Steyermark (1963).

Results and Discussion

Fourteen stations representing moderate to high natural quality loess hill prairie were found (Fig. 2). Twelve of these loess-hill prairies are in Atchison County and 2 are in Holt County. Ten stations were unknown prior to this study. The pattern of loess-hill prairie distribution is attributed in part to soil and topographic relief. According to Steyermark (1963) the peculiar topography resulting from the thick accumulation of loess and its subsequent erosion has formed perhaps the most unusual part of Missouri's Glaciated Plains Natural Division (Thom and Wilson, in press).

The 14 loess hill prairies occur on very dry wind-deposited soils along the east side of the Missouri River where the loess mantle reaches depths of 30 m (100 feet) (Schrader et al. 1953). Mixed-grass prairie generally occurs on the south and west-facing slopes on very fine sandy loam soils of the Hamburg series. Slopes of these hill prairies range from 30° - 75°. Occasionally, slopes are encountered in excess of 75°. The soil of the Hamburg series is more extensive in Atchison County (Mann and Krusekopf 1910) but occurs as a narrow band on the bluff face in the central part of Holt County (Schrader et al. 1953). The very fine sandy loam soil is low in

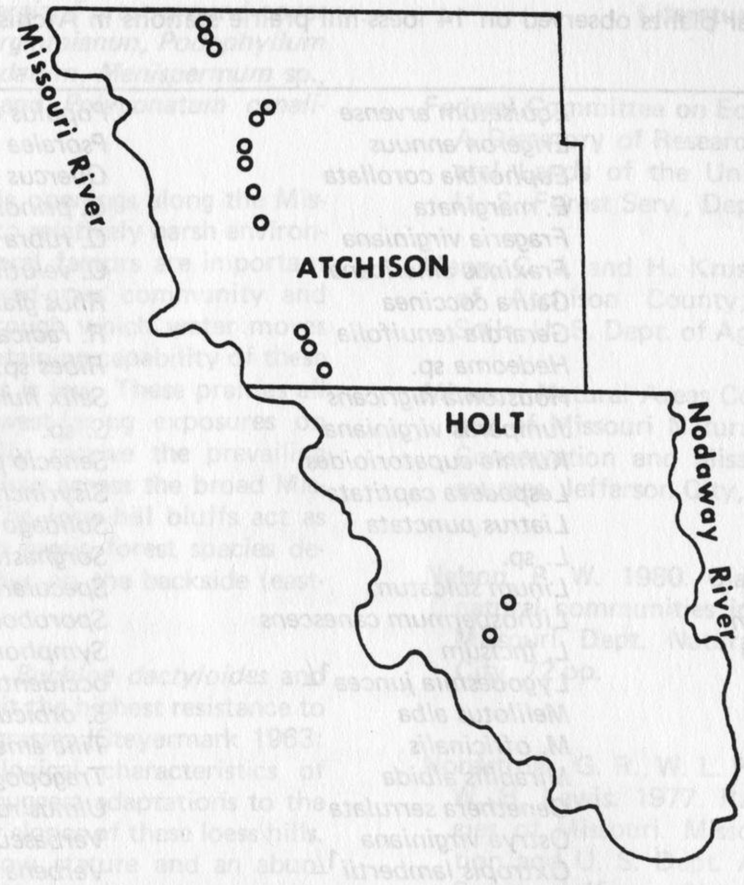


Fig. 2. Distribution of 14 loess hill prairies in Atchison and Holt Counties, Missouri.

water-holding capacity and water moves rapidly through the soil structure.

Average topographic relief for the Missouri River bluffs in Atchison County is greater than that in Holt County. In Atchison County where loess hill prairies occurred, elevations averaged 300-360 m (1000-1180 feet). Elevations in Holt County similar to those in Atchison County were present only in the central western section south of Mound City. These river bluff elevations compare to an elevation of 270-275 m (885-900 feet) in the Missouri River floodplain.

Several western species occur on these loess hill prairies but are more typical of the Great Plains. Many of these are indicator species and part of the rare and endangered flora of the state (Table 1). Although occasionally introduced east of Missouri, they reach the eastern limit of their range along the Missouri River bluffs. These are species adapted to the dry conditions and low moisture availability on the river bluffs and include *Astragalus lotiflorus, Psoralea argophylla, Oxytropis lambertii, Buchloe dactyloides, Gaura coccinea, Oenothera serrulata, Lactuca pulchella,* and *Yucca glauca* (Steyermark 1963:908)

Occurrences of these species, particularly the grasses, can be delineated according to their position on the hill prairie openings, species associates and soil moisture conditions. The following community descriptions follow in part Nelson (1980). The soil moisture descriptions are adopted from the U. S. Department of Agriculture, Soil Survey Manual.

As discussed earlier, the mixed-grass prairie type in Missouri is known only from the loess hill prairies and this community type typically occurs along the ridgetops and occasionally on steep, south and west-facing sideslopes. Dominant grasses are *Bouteloua hirsuta, B. curtipendula, Buchloe dactyloides* and *Andropogon scoparius.* Also found are the following characteristic species: *Bouteloua gracilis, Muhlenbergia cuspidata, Sporobolus airoides* and *S. cryptandrus.* This is the only grassland community in Missouri which is classed as mixed prairie; it is the only community type in Missouri where shortgrass species occur as dominants or co-dominants in the community structure. Boundaries for this community type are not as extensive as for the other community types found on the loess-hill prairies.

Dry-mesic loess-hill prairie typically occurs along the side slopes below the ridgetop and intergrades between the dry and mesic communities. The grasses are *Andropogon scoparius* and *Sorghastrum nutans.*

Table 1. List of vascular plants observed on 14 loess-hill prairie stations in Atchison and Holt Counties, Missouri

Adiantum pedatum
Ambrosia artemisiifolia
Amorpha canescens
Anemone sp.
Andropogon gerardi
A. scoparius
Antennaria sp.
Arisaema atrorubens
Aristida oligantha
Artemisia sp.
Asclepias tuberosa
A. verticillata
Asimina triloba
Aster brachyactis 1/
A. sericeus
Astragalus lotiflorus 1/
Botrychium virginianum
Bouteloua curtipendula
B. hirsuta
Bromus enormus
Buchloe dactyloides
Cacalia tuberosa
Carex tetanica 1/
Carex sp.
Carya ovata
Castilleja sessiliflora 1/
Ceanothus americanus
C. ovatus
Celastrus scandens
Cercis candensis
Cirsium undulatum var. megacephalum
Coreposis palmata
Cornus drummondi
Dalea enneadra 1/
Delphinium virescens
Desmanthus illinoensis
Equisetum arvense
Erigeron annuus
Euphorbia corollata
E. marginata
Fragaria virginiana
Fraxinus americana
Gaura coccinea
Gerardia tenuifolia
Hedeoma sp.
Houstonia nigricans
Juniperus virginiana
Kuhnia eupatorioides
Lespedeza captitata
Liatrus punctata
L. sp.
Linum sulcatum
Lithospermum canescens
L. incisum
Lygodesmia juncea 1/
Melilotus alba
M. officinalis
Mirabilis albida
Oenethera serrulata
Ostrya virginiana
Oxtropis lambertii 1/
Parthenocissus Quinquefolia
Penstemon digitalis
P. grandiflorus 1/
Petalostemum candidum
P. purpureum
Physalis sp.
Plantago virginica var. *virginica*
Podophyllum peltatum
Ploygonatum canaliculatum
Populus deltoides
Psoralea argophylla
Quercus macrocarpa
Q. prinoides
Q. rubra
Q. velutina
Rhus glabra
R. radicans
Ribes sp.
Salix humilis
S. sp.
Senecio plattensis
Sisyrinchium campestre
Solidago sp.
Sorghastrum nutans
Specularia leptocarpa
Sporobolus heterolepis
Symphoriocarpos occidentialis 1/
S. orbiculatus
Tilia americana
Tragopogon dubius
Ulmus rubra
Verbascum thapsus
Verbena simplex
Vernonia baldwini
Vitis riparia
Yucca glauca var. *glauca* 1/

1/ Plant species currently listed in Rare and Endangered Species of Missouri (Nordstrom et al. 1977). In addition, the following species not observed in this study are characteristic of the loess-hill prairie in Missouri: *Anemone cylindrica, Lactuca ludoviciana f. ludoviciana, L. pulchella, Rubus idaeus* var. *strigosus* (borders loess-hill prairies on wooded slopes), and *Sporobolus airoides.*

Mesic loess-hill prairie occurs at the base of the hill prairie openings where available moisture is greatest. Dominant grasses are *Andropogon gerardi, Sorghastrum nutans* and *Panicum virgatum.*

Other plants characteristic of these loess hill prairie communities are listed in Table 1. On these steep loess-hill slopes transitions between grassland, shrub and forest communities are evident on the less disturbed areas around the perimeter of the hill prairie openings. The best example of this transition was found in Atchison County on Brickyard Hill Loess Mound Prairie Natural Area. However, total diversity was low and forbs characteristic in the dry and dry-mesic communities were not as abundant. Absence of fire and grazing as management controls have allowed maximum development of the shrub community bordering the forest.

Shrub community development on Missouri loess-hill prairies includes *Salix humilis-Symphoriocarpos orbiculatus-Ceanothus ovatus-C. americanus* intergrading between the grassland communities and the forest. Forest species along the east-facing slopes are fairly rich with an overstory composition of *Ostrya virginiana, Cornus drummondi, Tilia americana, Morus alba, Quercus* *rubra*, and *Q. muhlenbergia*. Forest ground cover includes *Botrychium virgininianun, Podophyllum peltatum, Adiantum pedatum, Menispermum* sp., *Arisaema atrorubens*, and *Polygonatum canaliculatum*.

These loess hill prairie openings along the Missouri River are subject to relatively harsh environmental conditions. Several factors are important in maintaining the mixed-grass community and include sandy soils through which water moves rapidly. The moisture-retaining capability of these soils during dry periods is low. These prairies all occur on south and west-facing exposures on slopes which continually receive the prevailing westerly winds which flow across the broad Missouri River bottoms. The loess-hill bluffs act as a wind break and more mesic forest species described from above occur on the backside (east-facing) slopes.

Of the short grasses, *Buchloe dactyloides* and *Bouteloua gracilis* exhibit the highest resistance to drought of the native grasses (Steyermark 1963: 186). Several morphological characteristics of both grasses and forbs suggest adaptations to the dry conditions of upper slopes of these loess hills. These include leaves, low stature and an abundance of surface hairs. *Yucca glauca* is a western species which was generally found along the side slopes of the hill prairie as well as along the ridges. It appears ideally suited, with a thick epidermal tissue and greater height than most other indicator forbs. The higher stature allows this species to do well on the lower slopes of the hill prairies where the taller grasses occur.

The short grass species and lower stature forbs (*Oxytropis lambertii, Castilleja sessiliflora, Astragalus lotiflorus*) were dominant on the ridge tops and drier uplands. These western species compete successfully where water availability is low and where soils do not allow moisture sufficient for good development of tallgrass species. Lower slopes of these loess-hills are characterized by tall grasses typical of more mesic conditions. The short grasses from the hilltops intermingle with tall grasses typical of more mesic conditions. The short grasses from the hilltops intermingle with tall grasses from the lower slopes and create a 2-layered vegetational mix typical of mixed prairies. The short grasses and forbs were also prevalent on lower slope areas with exposed soil, where either artificial or natural disturbance had caused a break in the vegetative cover.

Literature Cited

Federal Committee on Ecological Reserves. 1977. A Directory of Research Natural Areas on Federal Lands of the United States of America. U. S. Forest Serv., Dept. of Agri., Wash., D.C.

Mann, C. J. and H. Krusekopf. 1910. Bureau of of Atchison County, Missouri. Bureau of Soils, U. S. Dept. of Agric., Wash., D. C. 36 pp.

Missouri Natural Areas Committee. 1981. Directory of Missouri Natural Areas. Missouri Dept. Conservation and Missouri Dept. Natural Resources, Jefferson City, 8 pp.

Nelson, P. W. 1980. Classification of terrestrial natural communities in Missouri. Unpubl. ms. Missouri Dept. Natural Resources, Jefferson City, 72 pp.

Nordstrom, G. R., W. L. Pflieger, K. C. Sadler and W. H. Lewis. 1977. Rare and endangered species of Missouri. Missouri Dept. of Conservation and U. S. Dept. Agri., Soil Conservation Service, Jefferson City, 129 pp.

Schrader, W. D., M. E. Springer, and N. S. Hall. 1939. Soil Survey of Holt County, Missouri. Soil Conservation Serv., U. S. Dept. Agric., Wash., D. C., 61 pp.

Steyermark, J. A. 1963. Flora of Missouri. Iowa State University Press, Ames.

Thom, R. H. and J. H. Wilson. 1980. The natural divisions of Missouri. Trans. Missouri. Acad. Sci. 14:9-23.

U. S. Dept. Agriculture. 1951. Soil Survey Manual, Agriculture Handbook 18. Soil Conservation Serv., Wash., D. C.

Weaver, J. E. 1960. Comparison of vegetation of the Kansas-Nebraska drift loess-hills and loess-plains. Ecology 41:73-88.

Weaver, J. E. and W. E. Bruner. 1954. Nature and place of transition from true prairie to mixed prairie. Ecology 35:117-126.

Table 1. List of vascular plants observed on 14 loess-hill prairie stations in Atchison and Holt Counties, Missouri

[illegible]	[illegible] arvense	Populus deltoides
[illegible]	Erigeron annuus	Psoralea argophylla
[illegible]	Euphorbia corollata	Quercus macrocarpa
[illegible]	E. [illegible]	[illegible]
Andropogon gerardi	Fragaria virginiana	[illegible]
[illegible]	[illegible] americana	[illegible]
[illegible]	[illegible]	Rhus glabra
[illegible]	[illegible] tenuifolia	R. radicans
Aristida oligantha	Hedeoma sp.	[illegible]
[illegible]	[illegible] nigricans	Salix humilis
[illegible]	[illegible] virginiana	[illegible] sp.
[illegible]	[illegible] eupatorioides	Senecio plattensis
Asimina triloba	Lespedeza captitata	Sisyrinchium campestre
Aster brachyactis 1/	Liatrus punctata	Solidago sp.
A. sericeus	L. sp.	Sorghastrum nutans
Astragalus lotiflorus	Linum sulcatum	Specularia leptocarpa
Botrychium virginianum	Lithospermum canescens	Sporobolus heterolepis
Bouteloua curtipendula	L. incisum	Symphoriocarpos
B. hirsuta	Lygodesmia juncea	[illegible]
Bromus enormus	Melilotus alba	[illegible]
Buchloe dactyloides	M. officinalis	[illegible]
[illegible]	Mirabilis albida	[illegible]
Carex [illegible]	Oenothera serrulata	[illegible]
Carex sp.	Ostrya virginiana	[illegible]
Carya ovata	Oxytropis lambertii 1/	Verbena simplex
Castilleja sessiliflora	Parthenocissus	[illegible]
Ceanothus americanus	Quinquefolia	[illegible]
[illegible]	Penstemon digitalis	[illegible]
[illegible]	[illegible] grandiflorus 1/	Yucca glauca var.
[illegible]	[illegible] candi[illegible]	glauca
Cirsium undulatum var.	[illegible]	
megacephalum	Physalis sp.	
Coreopsis palmata	Plantago virginica var.	
Cornus drummondi	[illegible]	
Dalea enneadra 1/	Podophyllum peltatum	
Delphinium virescens	Ploygonatum	
Desmanthus illinoensis	canaliculatum	

1/ Plant species currently listed as Rare and Endangered Species of Missouri (Nordstrom et al. 1977). In addition, the following species not observed in this study are characteristic of the loess-hill prairie in Missouri: Anemone cylindrica, Lesquerella ludoviciana, [illegible] Rubus idaeus var. strigosus (borders loess-hill prairies on wooded slopes), and Sporobolus airoides.

Mesic loess-hill prairie occurs at the base of [illegible] ardi, Sorghastrum nu[illegible] [illegible] these steep loess-hi[illegible] grassland, shrub and forest communities are evident on the less disturbed areas around the perimeter of the hill prairie openings. The best example of this transition was found in Atchison County on Brickyard Hill Loess Mound Prairie Natural Area. However, total diversity was low [illegible] loess-hill prairies include [illegible] Symphoricarpos orbiculatus-Ceanothus ovatus-C. americanus intergrading between the grassland communities and the forest. Forest species along the east-facing slopes are fairly rich with an overstory composition of Ostrya virginiana, Cornus drummondi, Tilia americana, Morus alba, Quercus

A MAPPING SURVEY OF PRAIRIE AND PRAIRIE-RELATED VEGETATION IN THE GREATER SCUPPERNONG WILDLIFE AREA (1979)

J. A. Schwarzmeier
Retzer Nature Center 1/
Highway DT
Waukesha, Wisconsin 53186
and
John Bielefeldt
Wisconsin Society of Biological Scientists
P.O. Box 162
Waukesha, Wisconsin 53187

Abstract. A survey of prairie and prairie-related vegetation on 3500 ha (8700 acres) in the Scuppernong Wildlife Area, of the Kettle Moraine State Forest-South Unit (KMSF-SU), in southeastern Wisconsin was conducted to provide a detailed prairie map as an aid to the master planning process in the KMSF-SU. Significant stands of prairie within this area have been known for some years, but this survey had the particular aim of delineating the many new stands and stand expansions where fire—induced prairie succession had been seen in the 11 preceding years. Results show that such succession was both rapid enough and extensive enough—38 stands now occupy about 37% of a 1600-acre prairie landscape zone within the study area—to lend strong support to use of the concept of prairie corridors, with appropriate natural management, as a strategy of land-use planning.

Introduction

This survey of the distribution of prairie and prairie-related vegetation in and near the Scuppernong Wildlife Area, of the Kettle Moraine State Forest-South Unit (KMSF-SU), in southeastern Wisconsin was conducted in order to provide a detailed prairie map as an aid to the master planning process in the KMSF-SU. Significant stands of prairie within the Scuppernong Wildlife Area have been known for some years, but this study had the particular objective of delineating the many new stands and stand expansions where active prairie succession had been seen in the 11-year period since 1968. A tangential purpose was to provide further practical detail in support of the concept of prairie corridors as a land-use planning and land management strategy (Reed and Schwarzmeier 1978).

Methods

The study area comprises about 3500 ha (8,700 acres) including virtually all state-owned lands in the Scuppernong Wildlife Area plus some adjacent, privately-owned lands. Highways 67 on the east, GN and 59 on the south, Z on the west, and ZZ and 106 on the north here tend to follow the natural boundaries of a large wetlands system that covers most of the study area, although some associated uplands were also part of this survey (Fig. 1).

Vegetation of an approximately natural condition is present over roughly two-thirds of the study area. During the fall of 1979, all wetlands and other natural vegetational types were field-mapped onto 1″ = 400′ aerial photos of the area; those few parts of the area not visited in the 1979 fieldwork had previously been investigated by 1 or both authors at least once during the last 5 years. Although prairie and prairie-related stands were the major concern, all mapped stands of natural character were classified on the basis of predominant vegetation into 1 of 11 cover types:

1) Prairies
2) Prairie-related, about one-half prairie elements by foliar cover
3) Prairie-related, about one-fourth prairie elements by foliar cover
4 - 6) Timber and shrub swamps

1/ Nature program of the Waukesha County Park & Planning Commission

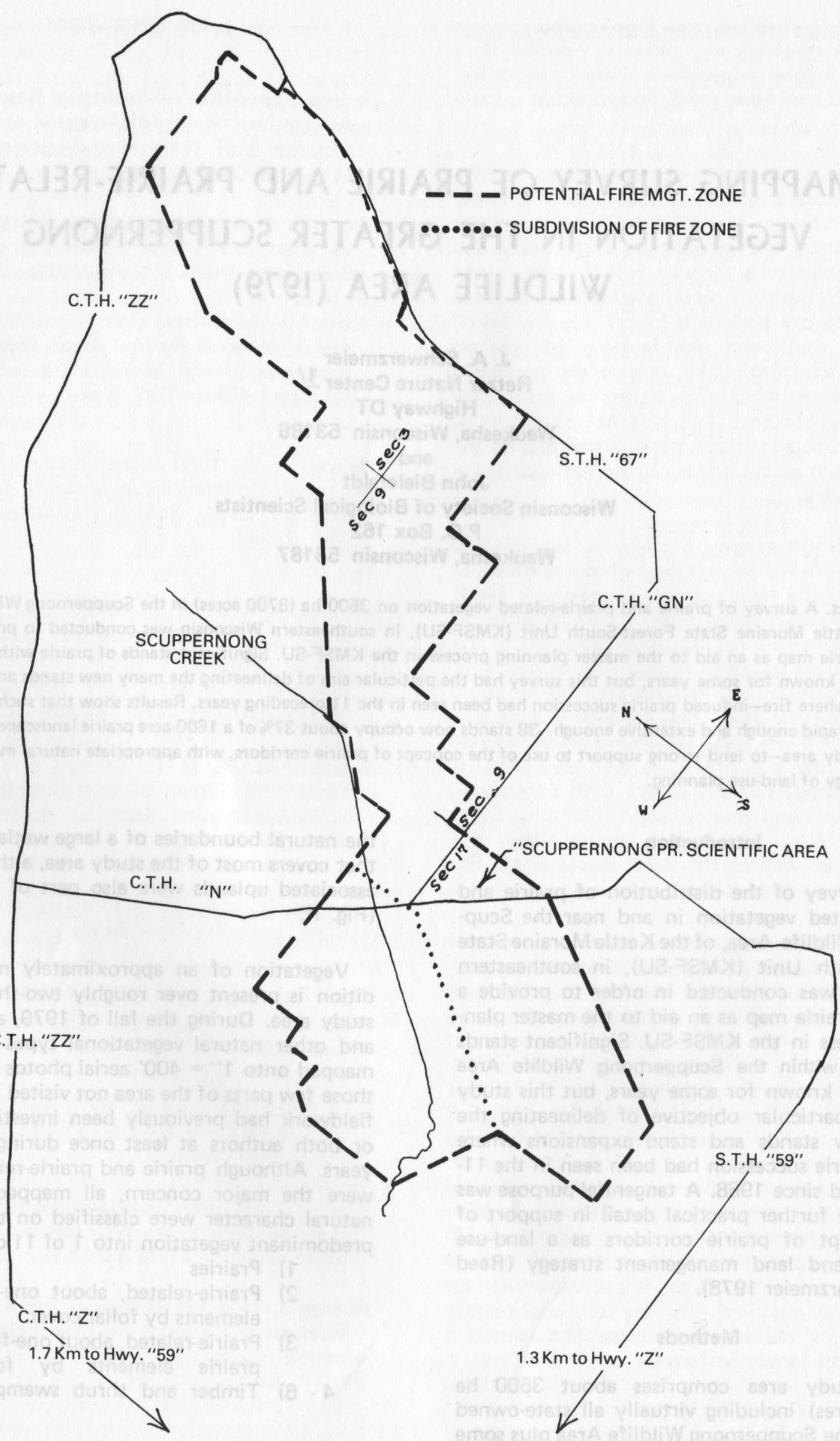


Fig. 1. Scuppernong Wildlife Area.

7 - 9) Marshes and lowland meadows
10) Old fields
11) Upland woods

Some recreational, residential, cropland, and open water areas plus an unclassifiable but exceptionally interesting area of marl flats at Ottawa Lake were also indicated on the map.

Cover classifications were transferred to the field maps on the aerial photos and double-checked against field notes. A color-coded tracing of all mapped stands in the entire area was then prepared at the same 1″ = 400′ scale; this large map was carefully reduced to the sketch map (at a scale of 1″ = 2000′) presented at the conference. All prairie and prairie-related stands (classes 1-3) were color-coded on this smaller map and each author independently outlined an area of prairie and prairie-related landscape including all contiguous and logically adjacent stands but excluding isolated stands. A final version of this prairie landscape zone was jointly prepared after a comparison of the individual versions, and is delineated in Fig. 1 by the heavy dashed line.

Results and Discussion

As expected, and as predicted under processes postulated by Reed and Schwarzmeier (1978), substantial amounts of recovering, expanding, or developing prairie vegetation were discovered in this survey. Extensive wildfires had swept eastern and central parts of the Scuppernong Wildlife Area in 1968 and 1975, respectively, and by 1979 prairie and prairie-related stands were common enough to form a nearly continuous band about one-half mile wide, on the average, along the entire southern and eastern rim of the study area. The number and extent of these stands within the area enclosed by the map's dashed line are presented in Table 1.

Table 1. Status of prairie vegetation lying within the dashed boundaries (see Fig. 1), fall 1979

	No. Stands	Area - ha
1. Prairies	16	46 (113 acres)
2. Recovering or expanding prairies--ca. 50% prairie cover	13	40 (98 acres)
3. Developing or incipient prairies--ca. 25% prairie cover	9	152 (376 acres)
Total	38	238 (587 acres)

These 238 ha of prairie and prairie-related vegetation constitute about 37% of the total area of approximately 650 ha (1600 acres) surrounded by the dashed line in Figure 1. The circumscribed area already can be considered a functional prairie corridor in the sense advanced by Reed and Schwarzmeier (1978). Subjecting all or selected parts of the marked area to regular burning, prescribed for the purpose of releasing prairie vegetation, will in a relatively short time allow the establishment of an essentially solid and continuous prairie cover on all or selected parts of that area. The study area was subject to closer scrutiny of area biologists and naturalists after the 1968 fire. Even so, most of the prairie vegetation found in the 1970's was in areas where it was not well enough developed to be visible previously. Table 2 brings out this relationship.

Table 2. Increase in number and extent of "prairies" and "recovering prairies" in the study area during period of observation by the authors, with areas less than 25% prairie cover not included

Year	No. Stands	Total ha (acres)
1968	7	10.1 (25 acres)
1976	19	36.0 (89 acres)
1979	29	85.0 (211 acres)

Much of the area enclosed by the dashed line, because of land-use history and prevailing conditions of natural and artificial drainage, consists of marginally wet lands — lowland meadows, ground shrub swamps, and lowland prairies. Quadrennial burning to suppress bluegrass (*Poa* spp.) and shrubs, should work well under such conditions while releasing prairie species. It is interesting to note, that the whole area enclosed by the dashed line was classed as wet prairie by Johnson and Schwarzmeier (1973) in their generalized map of presettlement vegetation of Waukesha County in 1836.

Recommendations

The scarcity of remnant prairie landscapes in the Great lakes region, and particularly the rarity of large prairie tracts, suggest that the entire area within the dashed line (Fig 1) should be treated in master planning as a potential fire management zone. From this perspective, it would seem that the very minimal degree of implementation of prescribed burning in successive priority should encompass:

1) The area lying within Section 9 of the Town of Eagle (R17E T5N S9), plus

the immediately adjacent Scuppernong Prairie Scientific Area which already is managed by fire.

2) The area lying south of the dotted line, primarily within Section 17 of the Town of Eagle (R17E T5N S17).

3) The area lying northeast of priority-area 1, primarily within Section 3 and the NE ¼ of Section 9 of the Town of Eagle (R17E S3, 9).

4) The remainder of the potential fire management zone, lying northwest of priority-area 2 and the dotted line, primarily within Section 17 of the Town of Eagle (R17E T5N S17).

The authors also believe that periodic brush-cutting management rather than prescribed burning should be applied, as a fifth and last priority item, to the isolated stand of dry, prairie-related vegetation (Class 3) in the NE ¼ SE ¼ of Section 28 of the Town of Ottawa (R17E T6N S28) and the adjacent dry old field stand (class 10) to the east; this small area is not depicted (Fig. 1). Prairie succession can be aided by control of shrub and sapling invasion on this 51-ha (125 acre) site, lying outside the designated fire management zones.

Acknowledgements

We thank Jerrine Osenga for color-coding community types on overlay tracings of the aerial photos, and the Wisconsin Department of Natural Resources and Ron Kurowski, Naturalist, KMSF-SU, for assistance in obtaining aerial photos of the study area as well as cooperation in efforts to apply this work in the planning process of the DMSF-SU.

Literature Cited

Johnson, Marlin and Jerry Schwarzmeier. 1973. Presettlement vegetation of Waukesha County 1836. Unpublished map.

Reed, Donald M. and J. A. Schwarzmeier. 1978. The prairie corridor concept: possibilities for planning large-scale preservation and restoration, Proc. Fifth Midwest Prairie Conference, pp. 158-165, David C. Glenn-Lewin and Roger Q. Landers, eds. Iowa State University, Ames.

VEGETATIONAL ANALYSIS OF THE SAMUEL H. ORDWAY JR. MEMORIAL PRAIRIE

Charles L. Lura
Graduate Research Assistant
Biology Department
South Dakota State University
Brookings, South Dakota 57007

Abstract. The S. H. Ordway Jr. Memorial Prairie is a 3,127 ha mixed-grass prairie in north-central South Dakota purchased by the Nature Conservancy in 1975. This study was conducted to establish base-line data on the present vegetational composition against which future changes can be determined, and the effects of management techniques measured. Sampling was conducted during 2 consecutive growing seasons. Data were collected on productivity, species frequency, species density, and percent basal cover. Diversity indices, similarity coefficients, and various plant groupings were analyzed for further ecological information.

the immediately adjacent Scuppernong Prairie Scientific Area which already is managed by fire.

2) The area lying south of the dotted line, primarily within Section 17 of the Town of Eagle (R17E T6N S17).

3) The area lying northeast of priority area 1, primarily within Section 3 and the NE ¼ of Section 9 of the Town of Eagle (R17E S3, 9).

4) The remainder of the potential fire management zone, lying [illegible] of priority area 2 and the dotted line, primarily within Section 17 of the Town of Eagle (R17E T5N S17).

The authors also believe that periodic brush-cutting management rather than prescribed burning should be applied, as a fifth and last priority item, to the isolated stand of dry, prairie-related vegetation (Class 3) in the NE ¼ SE ¼ of Section 28 of the Town of Ottawa (R17E T6N S28) and the adjacent dry old field stand (Class 10) to the east; this small area is not depicted (Fig. 1). Prairie succession can be aided by control of shrub and sapling invasion on this 51-ha (125 acre) site, lying outside the designated fire management zones.

Acknowledgements

We thank Jerrine Osenga for color-coding community types on overlay tracings of the aerial photos, and the Wisconsin Department of Natural Resources and Ron Kurowski, Naturalist, KMSF-SU, for assistance in obtaining aerial photos of the study area as well as cooperation in efforts to accomplish work in the planning process of the DMSF-SU.

Literature Cited

[illegible] Marlin and Jerry Schwarzmeier. 1973. Presettlement vegetation of Waukesha County 1836. Unpublished map.

[illegible], Donald M. and J. A. Schwarzmeier. 1978. The prairie corridor concept: possibilities for planning large-scale preservation and restoration. Proc. Fifth Midwest Prairie Conference, pp. 158-165, David C. Glenn-Lewin and Roger Q. Landers, eds. Iowa State University, Ames.

FLORISTICS AND ECOLOGY OF ST. JOHNS PRAIRIE

Paul W. Thompson
Cranbrook Institute of Science
17503 Kirkshire Road
Birmingham, Michigan 48009

Abstract. A survey of the area in the southern part of St. Clair County revealed the presence of an excellent wet—mesic prairie designated as St. Johns Prairie. The 35—ha tract possesses a diverse collection of wetland habitats including wet prairie meadow, giant reedgrass stands, buttonbush swamp, sedge and rush meadow, wetland shrubs, mesic prairie, bluejoint grass stands, and prairie cordgrass colonies. The survey showed that the area contains a total of 141 species of plants. The Composite family is highest with 40 species, and the grass and sedge group has 22 species.

Introduction

Most prairies in Michigan were located in the southern part of the state in the 2 southernmost tiers of counties (Butler 1947). A few remnants of these prairies still exist today such as the Dayton Prairie (Thompson 1980) located several miles west of Niles, Michigan, just north of the Indiana state line. However, travellers sailing the St. Clair River in the early days observed prairies along the river (Martineau 1923, Coulson 1883). In recent times a number of small prairie stands were noted by the writer in the vicinity of Algonac, Michigan and a study was made of prairies in Algonac State Part (Thompson 1975).

A more critical survey of this general area revealed an excellent prairie stand 5 km (3 mi) west of Algonac. The tract, designated as St. Johns Prairie, adjoins the southeastern corner of the well-known St. Johns Marsh, a 1200 ha (3000 acres) wetland consisting of cattail, rush, giant reedgrass and open water habitat. The prairie consists of approximately 35 ha (87 acres) of relatively flat land located in the NW¼ of section 6 of Clay Township in St. Clair County. Separated on the west from St. Johns Marsh by a small dike, it has 300 m (1000 feet) of frontage on the north side of Highway M-29, and extends northward for 1000 m (3300 ft).

Ecological Communities

Although the land is relatively flat, the water table is fairly high so that with only a few feet change in elevation the vegetation varies considerably. The water level also varies with wet or dry periods during the year, usually quite wet in the spring and becoming drier towards the end of the summer. The soil is primarily Sanilac very fine sandy loam with a few inclusions of Bach very fine sandy loam (Soil Conservation Service 1974), both poorly drained soils, usually having a high content of free lime.

The southwestern section of the tract is the wetter portion and is occupied by a buttonbush swamp, often with areas of open water during the wet period of the year. A large stand of giant reedgrass lines the southern border of the community. The southeastern section of the tract is covered by wet prairie meadow dominated by asters and goldenrods. Riddell's and grassleaf goldenrod occur frequently, mixed with narrowleaf loosestrife and mountain mint. The area exhibits several colorful stands of swamp candles and giant evening primrose. Locally, in the wetter spots, there are colonies of sedges and rushes.

The northeastern sector is more mesic in character and is dominated by big bluestem and Indiangrass. Here one frequently finds spiked blazing star, golden alexanders, ironweed, and tall coreopsis. A band of lowland shrubs separates the northeastern and southeastern sectors. The principal species are sandbar willow, red osier and skily dogwood mixed with occasional gray dogwood. In the northwestern area a mixed type of community is found composed of elements of the prairie from the northeastern section mixed with sedges and rushes and widely scattered shrubs from that zone, including hawthorn. Much of the central portion of the tract is occupied by large patches of Canada blue joint grass and the mixed community. Small stands of prairie cordgrass are found along the edges of wet areas. The St. Johns prairie tract shows a wide variety of plant communities.

Floristics

To check the flora of the area, several trips were made during the growing season from 1977-1979. A total of 141 species was tabulated, the largest family being the Composites with 40 entities. The second largest group consisted of grasses and sedges with 22 species followed by mints, 7, and legumes and figworts each with 5 representatives. A complete list of species is listed in the Appendix. Curtis (1959) listed 44 species as prevalent on Wisconsin wet prairies, and of these 33 are found at the St. Johns prairie. Also, of 62 species listed for wet-mesic prairies in Wisconsin, 40 occur at St. Johns, indicating the wetland character of this tract.

Of interest is the occurrence here of centaury (*Centaurium pulchellum*), a rare plant in Michigan, and yellow stargrass *(Hypoxis hirsuta)* which is on the Michigan list of rare and endangered plants (Wagner et. al. 1977). The yellow and white ladyslippers *(Cypripedium calceolus* and *C. candidum,* respectively) also on this list are found at the prairie.

Literature Cited

Butler, A. F. 1947. Rediscovering Michigan's Prairies. Michigan History 31:267-286; 32: 15-36; 33:117-130, 220-231.

Coulson, C. 1883. Tour of the Lakes in 1830. Michigan Pioneer and Historical Collection 6:420.

Curtis, John T. 1959. The Vegetation of Wisconsin. University of Wisconsin Press, Madison.

Martineau, Harriet. 1923. Travels in and around Michigan — 1836. Michigan History Magazine 7:47.

Soil Conservation Service. 1974. Soil Survey of St. Clair County, Michigan. U.S. Dept. Agri., Wash., D.C. 113 pp.

Thompson, Paul W. 1974. The floristic composition of prairie stands in southern Michigan. Proc. Fourth Midwest Prairie Conf. pp. 317-331, M. K. Wali, ed. The University of North Dakota, Grand Forks.

Thompson, Paul W. 1980. Dayton Prairie--A remnant of prairie Terre Coupee. Proc. Sixth North American Prairie Conf., R. L. Stuckey, ed. (in press) The Ohio State University, Columbus.

Wagner, W. W., E. G. Voss, J. H. Beaman, E. A. Bourdo, F. W. Case, J. A. Churchill and P. W. Thompson. 1977. Michigan's endangered and threatened species program. Michigan Bot. 16:99-110.

APPENDIX I. Floristic composition of St. Johns Prairie

A. Herbaceous Species

Composites

Achillea millifolium	yarrow
Antennaria plantaginifolia	3-vein pussytoes
Aster ericoides	heath aster
A. faxoni	faxon aster
A. laterifolia	New England aster
A. pilosa	hairy aster
A. simplex	panicle aster
Bidens spp.	sticktight
Centaurea maculosa	black knapweed
Chrysanthemum leucanthemum	white daisy
Cichorium intybus	chicory
Cirsium arvense	Canada thistle
C. discolor	prairie thistle
C. muticum	swamp thistle
C. vulgare	bull thistle
Coreopsis tripteris	tall coreopsis
Erechtites hieracifolia	fireweed
Erigeron strigosus	narrowleaf fleabane
Eupatorium maculatum	Joe-Pye weed

E. perfoliatum	boneset
Helenium autumnale	sneezeweed
Helianthus gigantea	giant sunflower
H. grosseserratus	largetooth sunflower
Krigia virginica	dwarf dandelion
Liatris cylindracea	spiked blazing star
Prenanthes racemosa	hairy lion paw
Rudbeckia hirta	brown-eyed susan
Senecio pauperculus	narrowleaf ragwort
Solidago altissima	tall goldenrod
S. canadensis	Canada goldenrod
S. gigantea	giant goldenrod
S. graminifolia	grassleaf goldenrod
S. juncea	early goldenrod
S. nemoralis	gray goldenrod
S. ohioensis	Ohio goldenrod
S. riddellii	Riddell's goldenrod
Sonchus uliginosus	sow thistle
Vernonia missurica	ironweed
Xanthium strumarium	cocklebur
Grasses	
Agrostis gigantea	redtop
Andropogon gerardi	big bluestem
Bromus inermis	smooth brome
Calamagrostis canadensis	blue joint
Glyceria striata	manna grass
Hierochloe odorata	sweetgrass
Hordeum jubatum	squirreltail
Leersia oryzoides	rice cutgrass
Panicum capillare	tumblegrass
P. virgatum	switchgrass
Phleum pratense	timothy
Phragmites australis	giant reedgrass
Poa compressa	Canada bluegrass
Sorghastrum nutans	Indiangrass
Spartina pectinata	prairie cordgrass
Sedges, Rushes, etc.	
Carex aurea	golden sedge
Juncus balticus	baltic rush
J. canadensis	canada rush
J. effusus	common rush
J. torreyi	torrey rush
Scirpus americanus	3-square bulrush
S. atrovirens	green bulrush
S. cyperinus	woolgrass
Mints	
Lycopus americana	cutleaf horehound
Mentha piperata	peppermint
Monarda fistulosa	wild bergamot
Prunella vulgaris	self heal
Pycnanthemum virginianum	mountain mint

Scutellaria galericulata	skullcap
Stachys tenuifolia	smooth hedge nettle
Legumes	
Desmodium canadense	Canada ticktrefoil
Lathyrus palustris	marsh pea
Medicago sativa	white sweetclover
Trifolium hybridum	pink clover
Figworts	
Gerardia purpurea	purple gerardia
mimulus rigens	monkeyflower
Pedicularis lanceolata	swamp betony
Pentstemon digitalis	foxglove beardtongue
Veronicastrum virginicum	Culver's-root
Crowfoots	
Anemone canadensis	Canada anemone
A. virginiana	thimbleweed
Ranunculus acris	buttercup
Thalictrum dasycarpum	tall meadowrue
Roses	
Fragaria virginiana	wild strawberry
Potentilla anserina	silverweed
Rosa palustris	swamp rose
Spiraea alba	meadowsweet
Umbels	
Cicuta maculata	water hemlock
Daucus carota	wild carrot
Sanicula marilandica	black snakeroot
Zizia aurea	golden alexanders
Milkweeds	
Apocynum sibiricum	sessile Indian hemp
Asclepias incarnata	swamp milkweed
A. tuberosa	butterfly weed
A. syriaca	common milkweed
Lilies	
Asparagus officinalis	asparagus
Hemerocallis fulva	orange daylily
Polygonatum pubescens	solomon seal
Other Species	
Alisma plantago-aquatica	water plantain
Barbarea vulgaris	yellow rocket

Other Species continued

Centaurium pulchellum	centaury
Comandra richardsiana	false toadflax
Convolvulus sepium	hedge bindweed
Cypripedium calceolus	yellow lady-slipper
C. candidum	white ladys-slipper
Epilobium adenocaulon	northern willowherb
Equisetum laevigatum	smooth scouring rush
Galium boreale	northern bedstraw
G. palustris	swamp bedstraw
Gentiana andrewsii	bottle gentain
Hypericum perforatum	common St. Johnswort
Hypoxis hirsuta	yellow stargrass
Iris virginica	blue iris
Lobelia spicata	pale spike lobelia
Lysimachia terestris	swamp candles
Lythrum alatum	prairie loosestrife
L. salicaria	large loosestrife
Oenothera biennis	evening primrose
O. pilosella	giant evening primrose
Penthorum sedoides	ditch stonecrop
Plantago rugelii	Rugel's plantain
Polygonum hydropiperoides	pepperweed
Rumex crispus	curly dock
Solanum dulcamara	bittersweet nightshade
Spiranthes cernua	nodding ladies tresses
Steironema quadriflorum	narrowleaf loosestrife
Triadenum fraseri	marsh St. Johnswort
Typha angustifolia	narrowleaf cattail
Verbena hastata	common vervain
Vitis aestivalis	riverbank grape

B. Trees and Shrubs

Acer rubrum	red maple
Celastrus scandens	bittersweet
Cephalanthus occidentalis	buttonbush
Cornus purpusi	silky dogwood
C. racemosa	gray dogwood
C. stolonifera	red osier dogwood
Crataegus spp.	haw
Populus deltoides	cottonwood
P. tremuloides	quaking aspen
Salix interior	sandbar willow

Scutellaria galericulata	skullcap
Stachys tenuifolia	smooth hedge nettle
Legumes	
Desmodium canadense	Canada tick-trefoil
Lathyrus palustris	marsh pea
Melilotus alba	white sweetclover
Trifolium [illegible]	pink clover
Figworts	
Gerardia [illegible]	pu[illegible]
Mimulus ringens	monkeyflower
Pedicularis lanceolata	swamp betony
Penstemon digitalis	foxglove beardtongue
Veronicastrum virginicum	Culver's root
Crowfoots	
Anemone canadensis	Canada anemone
A. virginiana	thimbleweed
Ranunculus spp.	buttercup
Thalictrum dasycarpum	[illegible]
Roses	
Fragaria [illegible]	wild [illegible]
Potentilla [illegible]	silverweed
Rosa palustris	swamp rose
Spiraea alba	meadowsweet
Umbels	
Cicuta maculata	water hemlock
Daucus carota	wild carrot
Sanicula marilandica	black snakeroot
Zizia aurea	[illegible]
Milkweeds	
Apocynum sibiricum	sessile Indian hemp
Asclepias incarnata	swamp milkweed
A. tuberosa	butterfly weed
A. syriaca	common milkweed
Lilies	
Asparagus officinalis	asparagus
Hemerocallis fulva	orange daylily
Polygonatum pubescens	solomon seal
Other Species	
Alisma plantago-aquatica	water plantain
Barbarea vulgaris	yellow rocket

AN ISLAND BIOGEOGRAPHICAL ANALYSIS OF THE FLORA OF SOUTHWESTERN MICHIGAN FENS

Michael A. Hoffhines 1/
Kalamazoo College
Kalamazoo, Michigan 49001
and
Daniel C. Nepstad 2/
Fernwood, Inc.
1720 Range Line Road
Niles, Michigan 49120

Abstract. The theory of island biogeography as presented by MacArthur and Wilson (1967) states that biotic diversity is directly proportional to area, where diversity is measured in number of species present. The relation is commonly of the form:

$$S = c\,A^{z}$$

where S equals the number of species present and A the island area. The c parameter is the population density determined by those 2 parameters, and z is a parameter that generally falls between 0.20 and 0.35 for oceanic islands (MacArthur and Wilson 1967). Attempts have been made to generalize this relation to include mainland habitat islands (MacArthur 1972). In this study, a number of fens in southcentral and southwestern Michigan are surveyed to determine to what extent the flora of these fens fits the theory of island biogeography. The relation is significant for linear, semi - log, and log - log models, with z-values falling within the range commonly encountered on habitat islands.

Introduction

MacArthur and Wilson's (1967) theory of island biogeography has been supported by the work of Diamond (1973) and others (Vuilleumier 1970, MacArthur 1972, Simpson 1974). The theory strives to isolate the important aspects of islands that determine the number of species present in order that a predictive understanding of speciation and many other things might be obtained. For a number of studies (Diamond 1973, Simpson, 1974, Diamond, Gilpin and Mayr 1976), 2 parameters suffice to determine the species diversity of the island, where species diversity is measured by the number of species present. They form the basis for MacArthur and Wilson's theory.

The 2 parameters of islands that most consistently predict diversity are: 1) area of the island and 2) distance from the mainland (or another island) that serves as floral and faunal sources for the island in question (Pielou 1975). MacArthur and Wilson (1967) state that island diversity is related inversely to distance and directly to island size. This follows since increasing distance lowers the immigration rate of new species, whereas extinction rate is independent of it (Pielou 1975). Increasing area, however, increases immigration rate while lowering extinction by supporting larger populations (Pielou 1975).

Closely allied with this explanation of insular species diversity is the notion that for every island there is an optimal (i.e., equilibrium) number of species associated with it (Diamond 1968, 1976). This view has been termed the equilibrium theory of island biogeography and was first proposed by Preston (1962) and later by McArthur and Wilson (1963). The basic premise is that the biota of any island is in dynamic equilibrium between immigration of species new to the island and local extinction of those already present (Simberloff 1976). Although Simberloff (1976) argues against the paradigmatic elevation of the equilibrium theory, many observations suggest that a dynamic equilibrium is an important component of island speciation. The work of Diamond (1969) with Channel Island bird species and Simberloff and Wilson (1969) with mangrove islands are 2 of the more frequently cited studies.

Attempts to generalize the theory of island

1/ Current address: Department of Zoology, Michigan State University, East Lansing, Michigan 48824

2/ Current address: Department of Botany, Michigan State University, East Lansing, Michigan 48824

biogeography to mainland habitat islands recently have become widespread (MacArthur 1972, Pickett 1978, Diamond 1976). A number of obvious mainland habitat islands have been studied with gratifying results. Vuilleumier (1970) found that the number of bird species on paramo (mountaintop) islands correlated significantly with area of the habitat island. Johnson (1975) studies the bird species of the Great Basin mountaintops with similar results.

These and other studies commonly lead to a relation of the form

$$S = c A^z$$

where S equals the number of species present and A the area of the island. A constant of proportionality, c, depends upon the taxon and biogeographic region, and the population density determined by those 2 parameters. The dimensionless parameter, z, typically has a value in the range of 0.20-0.35 for oceanic islands and a range of 0.12-0.17 for continental habitat islands or sample areas within islands (MacArthur and Wilson 1967, Diamond 1976).

When the species-area relation above is represented by a graph with the logarithm of the area on the abscissa and the logarithm of the number of species on the ordinate, z can be seen as the rate of change in the log species with a change in the log-area.

The present study examined the species-area relation for 10 ferns in south-central and south western Michigan under assumed equilibrium conditions. The procedure of Vuilleumier (1970), which involved linear regression of avifaunal data with respect to 3 models, was employed. The 3 models were: 1) linear (untrasformed data), 2) semi-log (long transformed independent variable), and 3) log-log (log transformed data).

The term fen was originally used to describe the estuarine vegetation of the British Isles (Foos 1971). Anderson (1943) was the first American author to use the term. Curtis (1959) recognized a fen community in his *Vegetation of Wisconsin.* Curtis described a fen as a grassland on a wet and springy site, with an internal flow of water rich in calcium and magnesium sulfates as well.

Foos (1971) found that the majority of species indicative of fens occupied regions north of the glacial boundary. Foos inferred from this that the majority of fens are similarly restricted to these regions. Curtis (1959) claimed that fens were limited in their distribution in Wisconsin by the presence of dolomitic limestone from which the alkaline waters characteristic of fens issued. Dolomitic limestone may be responsible for the distribution of fens in Michigan as well.

In the present study, fens were not defined directly in terms of their edaphic properties. Rather, a fen was defined in terms of the vegetation present. The study sites were defined to be fens as they were found to be most similar in terms of flora to the community Curtis (1959) described as a fen. Two measures of similarity were employed and the results were presented as a test of community type for the study sites.

Since a fen may represent an isolated community by virtue of the degree of specificity of fen flora for particular physical parameters, they are potentially well-suited for a study of insularity in a continental region. In addition, the renewed interest in wetlands, as demonstrated by a legislative move to initiate wetland inventories at the federal level by the U. S. Fish and Wildlife Service (Golet and Larson 1974), may make it worthwhile to study the mechanics of species diversity in a wetland community in order to determine a strategy for conservation of wetland areas. The theory of island biogeography may provide a basis for such an endeavor (Kushlan 1979).

Materials and Methods

Ten sites located in 4 counties of southcentral and southwestern Michigan were chosen for the study. In those sites where a recognized name was known, it was used here. If no recognized name was known, one was assigned to the site that would give an indication of its location. The 10 study sites, their names, and their locations are listed below:

1) Asylum Lake Fen. Kalamazoo Co., City of Kalamazoo, T2S, R11W, Sec 30 W½.
2) Brunke Fen. Berrien Co., Bertrand Township, T8S, R18W, Sec 2 N½.
3) Dayton Fen. Berrien Co., Bertrand Township, T8S, R18W, Sec 16 E½.
4) Hampton Lake Fen. Kalamazoo Co., City of Portage, T3S, R11W, Sec 30 E½.
5) Helmer Brook Fen. Calhoun Co., City of Battle Creek T1S, R8W, Sec 33 S½.
6) McCoy Creek Fen. Berrien Co., Buchanan Township, T7S, R18W, Sec 34 SE¼.
7) Priest Lake Fen. Cass Co., Silver Creek Township, T5S, R16W, Sec 11 S½, Sec 14 N½.
8) Rowe Lake Fen. Berrien Co., Pipestone Township, T5S, R17W, Sec 2 E½.

9) Sugarloaf Lake Fen. Kalamazoo Co., Schoolcraft Township, T4S, R11W, Sec 5 NW¼.

10) Whitman Lake Fen. Kalamazoo Co., Charleston Township, T2S, R9W, Sec 13.

The floristic survey of all study sites was conducted during October 1979, June 1980, and July 1980. The method of cruising was employed for the survey. A species list for each site was compiled through field identification and identification of collected specimens.

Following compilation of species lists for the study sites, a check of the community type was conducted to insure that each site was indeed a fen according to our definition. The test employed is a direct application of the work of Curtis (1959) and follows the methodology of Read (1979) (personal communication). Every specimen identified in the survey was assigned to a particular modality, if one existed. This assignment follows Curtis' (1959) evaluation of Wisconsin plant communities in which plant species x is a modal for a community y if x is present in y more frequently than in any other plant community.

An unidentified community A, then is said to be of type Z if, and only if, both of the following conditions are met: the ratio of species of modality z found in community A to the total number of species found in community A when expressed as a percent is greater for Z than any other community W. That is,

$$\frac{\text{No. of species found in A of modality Z}}{\text{No. of species found in A}} \times 100 > \frac{\text{No. of species found in A of modality W}}{\text{No. of species found in A}} \times 100$$

Secondly, the percent of the modals for community X represented in community A must be greater than the percent of the modals from any other community W. This may be formalized in the following manner:

$$\frac{\text{No. of species found in A of modality Z}}{\text{No. of modals for Z}} \times 100 > \frac{\text{No. of species found in A of modality W}}{\text{No. of modals for W}} \times 100.$$

These 2 modes of comparison will be referred to as "percent of list" and "percent of modals", respectively. For our purposes, then, a fen is defined to be a plant community in which fen modal species surpass all other represented community modals taken one at a time and expressed both as percent of the list and percent of the modals.

Determination of area for the study sites involved the use of infrared aerial photographs. Aerial photographs used were those of the South-central and Southwestern Michigan Planning Commissions. The photographs were in the form of 5" x 8" negatives. Therefore, an overhead projector was used to enlarge the photo and facilitate location of the study sites. Projecting the image onto a sheet of paper made it then possible to outline the boundary of the site. Once this had been done, the area (ha) of the individual study site was calculated using a planimeter.

Analysis of data was done with a PDP-10. Curve fitting and analysis of regression data involved the use of the STATPACK program available through Western Michigan University.

In this study 3 models following the work of Vuilleumier (1970) were tested to determine a possible relation between the number of species and the area. In all models, area was taken as the independent variable. From Vuilleumier (1970), the 3 models are: 1) linear (untransformed data), 2) semi-log (log-transformed independent variable), and 3) log-log (log-transformed data). The multiple correlation coefficient (r^2) was the statistic used to estimate how much variance in the predicted values of the dependent variable is due to the regression (Vuilleumier 1970, Snedecor and Cochran 1968).

Results

Floristic Survey. The floristic survey of the study sites revealed a total of 169 species. A composite listing shows that over one-half of the species found are contained in 5 families. These are *Compositae* (23.7%), *Cyperaceae* (4.7%), *Gramineae* (6.5%), *Rosaceae* (6.5%), and *Scrophulariaceae* (8.9%).

Of the communities recognized by Curtis (1959), 23 had modals found on at least 1 site. The most prominent among these were the alder thicket, bog, fen, northern sedge meadow, mesic prairie, and wet-mesic prairie. Table 1 lists these communities and gives a percent of list and percent of modals figure for each.

Of the 169 specie found during the floristic survey, 4 species were present on all 10 of the study sites. Three of these belong to the family *Compositae.* They are *Eupatorium perfoliatum* (common boneset), *Solidago patula* (swamp goldenrod), and *S. riddellii* (Riddell's goldenrod). The fourth species found on all sites was *Dryopteris thelypteris pubescens* (marsh shield fern), a member of the family *Polypodiaceae.* All but 1 of these 4, *Solidago patula,* is a modal species for the fen community.

Table 1. The major fen-related communities represented by at least 5 modal species found in the floristic survey of the study sites

Community	No. of Modals	Percent of List	Percent of Modals
Alder Thicket	11	6.5	44.0
Fen	23	13.6	62.2
Mesic Prairie	8	4.7	20.0
Northern Sedge Meadow	5	4.0	20.8
Open Bog	8	4.7	26.7
Wet Prairie	10	5.9	43.5
Wet-Mesic Prairie	14	8.2	36.8

In addition, only 3 weedy species (Curtis 1959) were encountered. These were *Centaurea maculosa* (sweet sultan), *Lythrum salicaria* (purple loosestrife), and *Melilotus alba* (white sweet clover).

The number of species found on the sites individually ranged from 39 in the case of the Asylum Lake fen to 74 species found at the Hampton Lake fen. Table 2 lists the number of species found at each study site.

Table 2. The number of species found at each of the 10 study sites during the months of October, 1979, June, 1980, and July, 1980

Study Site	Number of Species
Asylum Lake fen	39
Brunke fen	58
Dayton fen	42
Hampton Lake fen	74
Helmer Brook fen	71
McCoy Creek fen	61
Priest Lake fen	52
Rowe Lake fen	60
Sugarloaf Lake fen	46
Whitman Lake fen	58

Test of Community Type. All 10 of the study sites proved to be of the community type Curtis (1959) referred to as a fen, according to the methodology of this study. For each site the percent of list and percent of modals figure is greater for the fen community than any other plant community recognized by Curtis.

Determination of Area. The smallest study site was the Dayton fen which contained 0.05 ha (Table 3). The largest study site was Hampton Lake fen consisting of 2.0 ha. This represents a change of 40 times over the 10 sites considered in this study.

Table 3. Calculated area for each study site

Site	Area (ha)
Dayton fen	0.05
Sugarloaf Lake fen	0.13
Asylum Lake fen	0.28
Priest Lake fen	0.39
Brunke fen	0.57
Rowe Lake fen	1.20
McCoy Creek Fen	1.40
Helmer Brook fen	1.50
Whitman Lake fen	1.90
Hampton Lake fen	2.00

Regression Analysis. A plot of the untransformed data with area (ha) as the independent variable and number of species as the dependent variable shows that a positive correlation exists between the two. The existence of this relation is statistically significant for each of the models examined in this study. Each of the three models proposed shows an r^2 greater than 0.7 (Table 4). The probability that no correlation exists is 0.005 for all models. Figures 1, 2, and 3 summarize the 3 models considered herein with respect to the floristic survey and area determination of the study sites. Each of the 3 models considered accounts for a significant amount of the variation. However, the standard error is too high to make a statistically significan distinction between them.

Table 4. Results of regression analysis for the 3 models used in this study

Model	Regression Coefficient	Term Constant	r^2	$P < 0.005$
1. Linear	13.3	43.6	.73	.0016
2. Semi-log	17.9	60.4	.71	.0022
3. Log-log	0.144	1.8	.72	.0018

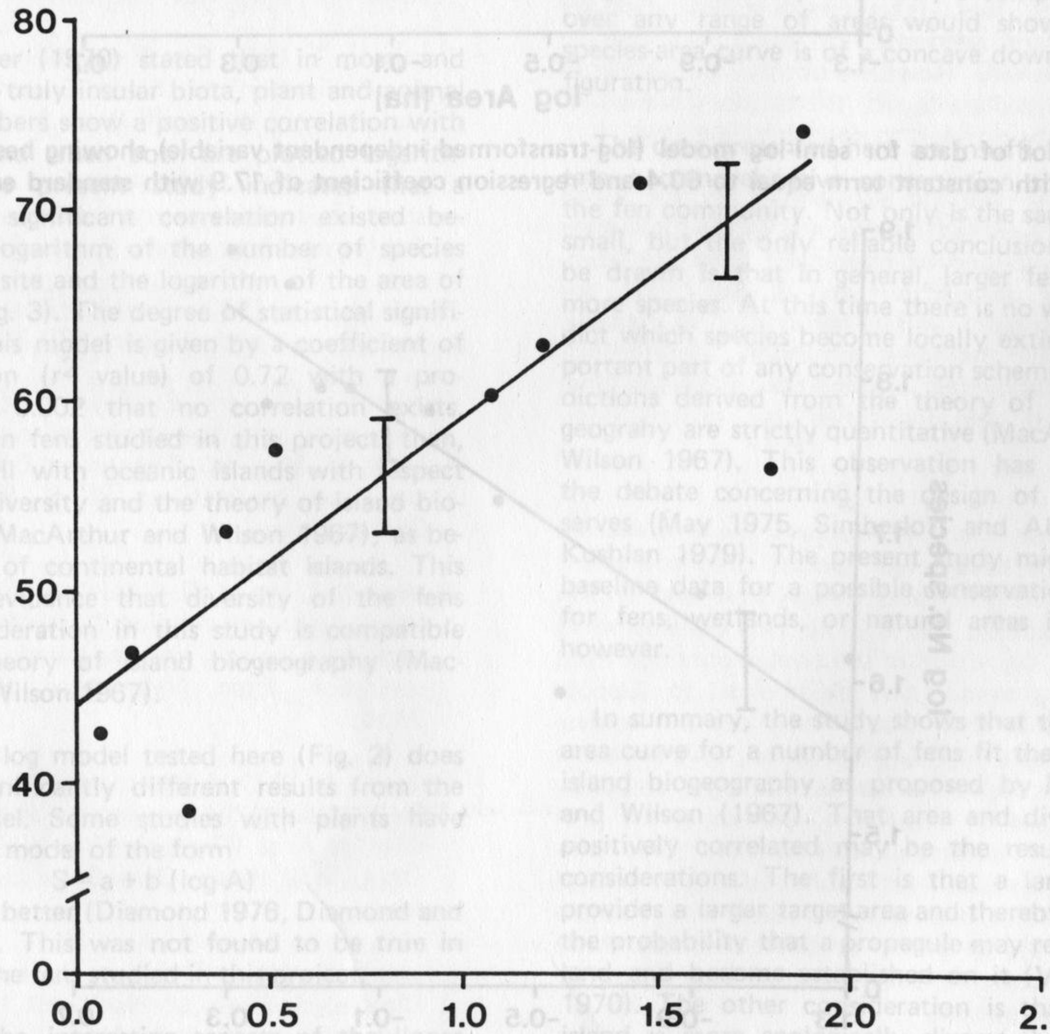


Fig. 1 Plot of data for linear model (untransformed data) showing best fit curve, with constant term equal to 43.6 and regression coefficient of 13.3 with a standard error of 2.8.

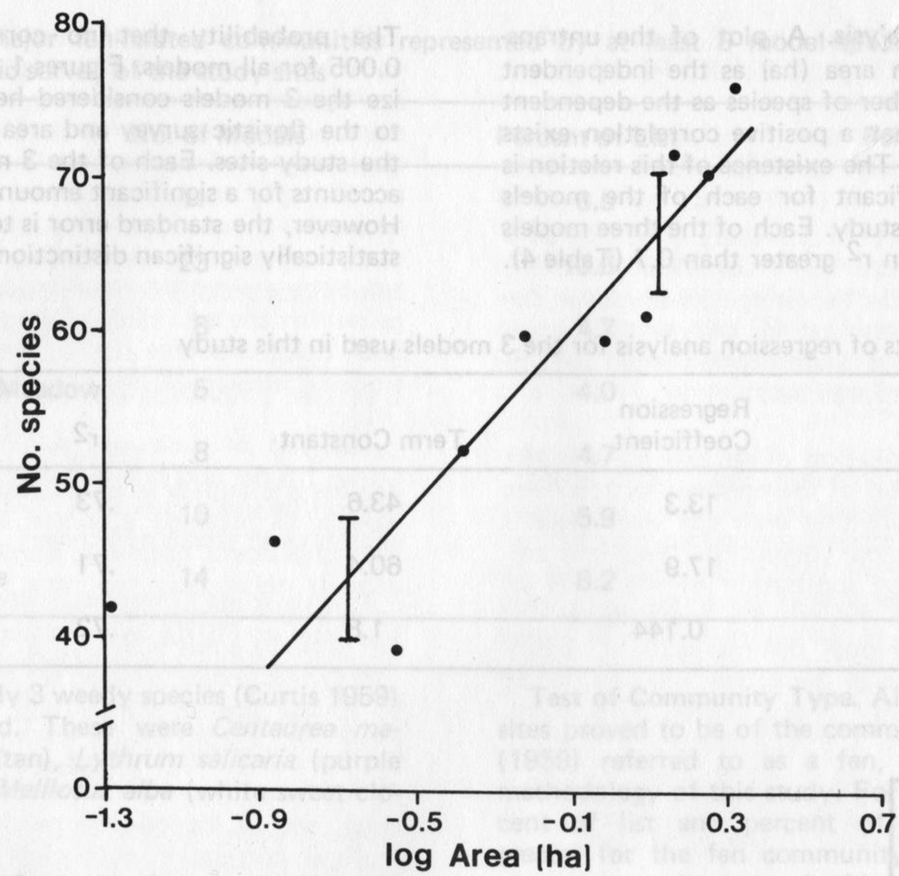


Fig. 2. Plot of data for semi-log model (log-transformed independent variable) showing best fit curve, with constant term equal to 60.4 and regression coefficient of 17.9 with standard error of 4.0.

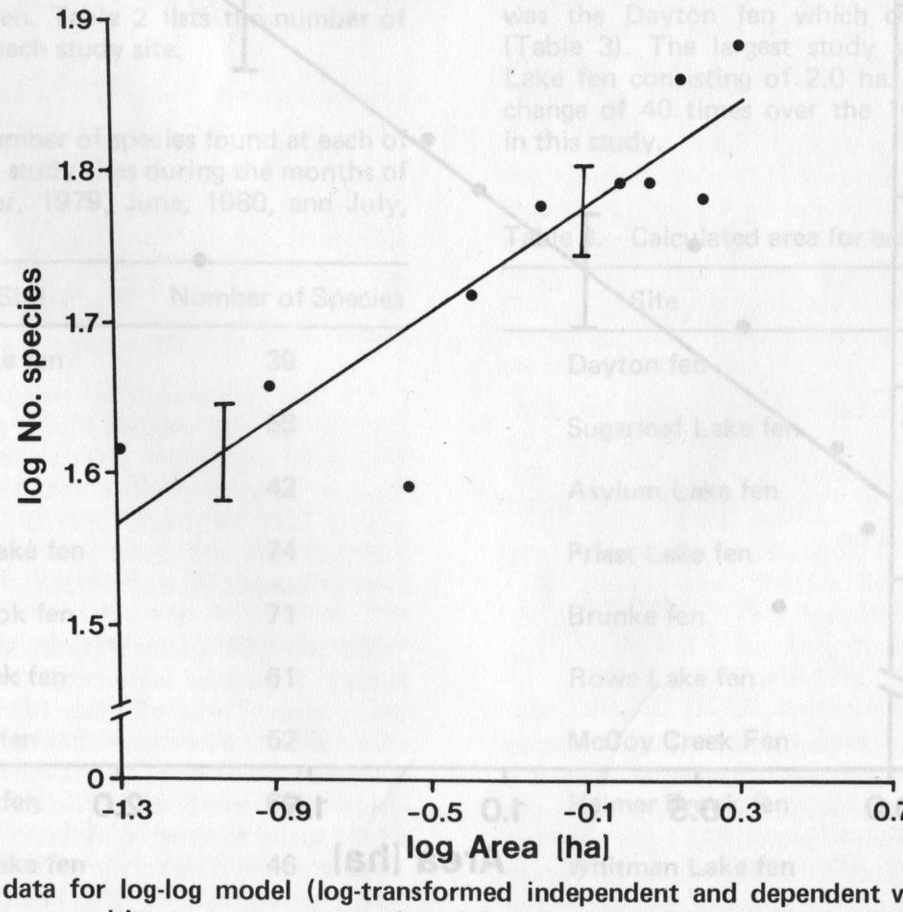


Fig. 3. Plot of data for log-log model (log-transformed independent and dependent variable) showing best fit curve, with constant term equal to 1.8 and regression coefficient of 0.14 and a standard error of 0.031.

Discussion

Curtis (1959) stated that a high correlation existed between Wisconsin fens and wet prairies. Taking the percent of modals found as a measure of correlation, the floristic survey of the study sites shows that 43.5% of wet prairie modals were found, 18.7% fewer than the percent of fen modals found. The percent of modals figures for the mesic, wet-mesic and northern sedge meadow communities are similar, indicating that a relation does exist between these communities and the fen community. However, the relation may not be as strong as cited by Curtis (1959), but rather a weaker relation of the degree found by Foos (1971) may be a more accurate description. This study is more supportive of a relation of this latter type, since no single prairie or meadow community is strongly represented. What can be said is that a general relation exists between the wetland communities studied here, if species presence is used as the measure of such a relation.

Vuilleumier (1970) stated that in most, and probably all truly insular biota, plant and animal species numbers show a positive correlation with area of island when both are plotted logarithmically. The present study indicated that a statistically significant correlation existed between the logarithm of the number of species found on a site and the logarithm of the area of that site (Fig. 3). The degree of statistical significance for this model is given by a coefficient of determination (r^2 value) of 0.72 with a probability of 0.002 that no correlation exists. The Michigan fens studied in this project, then, compare well with oceanic islands with respect to species diversity and the theory of island biogeography (MacArthur and Wilson 1967), as being typical of continental habitat islands. This is further evidence that diversity of the fens under consideration in this study is compatible with the theory of island biogeography (MacArthur and Wilson 1967).

The semi-log model tested here (Fig. 2) does not give significantly different results from the log-log model. Some studies with plants have found that a model of the form

$$S = a + b\ (\log A)$$

fits the data better (Diamond 1976, Diamond and Mayr 1976). This was not found to be true in the case of the fens studied in this project.

One of the interesting aspects of the linear model is its non-zero constant term. That is, the linear model predicts that a little over 43 species of plants would be found on a fen consisting of a point, i.e., zero area. Since the floristic survey took place over time, this could be interpreted to mean that 43 species migrated into and out of a single point within the survey time period. Given the long life of plants and their general lack of mobility however, this possibility seems remote in light of the fact that the survey took place in less than a year. Another interpretation of this model is that only over the range of area considered is the fen species-area curve linear.

This latter interpretation seems more plausible as it seems reasonable to assume that no species should be present on an island of zero area. There is another reason for believing that the species-area relation for fens is not strictly linear. There are only a finite number of species that define a fen and, therefore, only a finite number of species that can be found on a fen of any size. But the linear model predicts that any number of species can be found on a fen of sufficient size. For all of these reasons, then, we suspect that although the species-area relation for the fens studied over this range of areas may be linear, a complete model over any range of areas would show that the species-area curve is of a concave downward configuration.

The data presented here are insufficient to dictate a comprehensive conservation strategy for the fen community. Not only is the sample space small, but the only reliable conclusion that can be drawn is that in general, larger fens contain more species. At this time there is no way to predict which species become locally extinct, an important part of any conservation scheme. The predictions derived from the theory of island biogeograhy are strictly quantitative (MacArthur and Wilson 1967). This observation has intensified the debate concerning the design of nature reserves (May 1975, Simberloff and Abele 1976, Kushlan 1979). The present study might supply baseline data for a possible conservation scheme for fens, wetlands, or natural areas in general, however.

In summary, the study shows that the species-area curve for a number of fens fit the theory of island biogeography as proposed by MacArthur and Wilson (1967). That area and diversity are positively correlated may be the result of two considerations. The first is that a larger island provides a larger target area and thereby increases the probability that a propagule may reach the island and become established on it (Vuilleumier 1970). The other consideration is that a larger island is more ecologically diverse thus increasing the probability that the recipient island is ecologically suitable enough for the propagule to survive and reproduce (Vuilleumier op. cit.). In these respects the fens studies resemble oceanic islands in a continental sea. In continental islands, however, the dispersal barriers presented to their species consist of unsuitable or marginally suitable habitats, rather than the sea. Terrestrial habitats present less stringent dispersal barriers to fen species than does open water to colonizing island species, as it may be possible for a particular propagule to survive for a short while in an unsuitable or marginal habitat before dispersing again. Hence, the possibility of a propagule reaching a particular island is increased as the propagule may 'rest' (Vuilleumier 1970).

The method of dispersion outlined above may be termed 'stepping-stone' dispersion. Such dispersion is frequently encountered on archipelagoes and is evidenced by the lack of a significant correlation between the number of species present and the distance from propagule source (Simpson 1974). To the extent that fen species employ the 'stepping-stone' mode of dispersion, distance from propagule source may or may not play an important role in determining species diversity on fens. It is probable that distance between fens accounts for some variation in species diversity. However, until all possible propagule sources are found, the species-distance relation will be difficult to determine directly.

Since the floristic survey yielded species of 23 different modalities, the study sites themselves may be described as marginal habitat, or 'stepping-stones' (MacArthur and Wilson 1967), for the non-fen communities represented in the sites. Diversity of the sites is partially determined, then, by the degree to which they act as marginal habitat, or 'stepping-stones' for related communities.

The present study supports the observation that islands have fewer species than equivalent areas of the mainland (MacArthur and Wilson 1967, Diamond, 1976). The fens considered in this study, by virtue of the z-value obtained from the log-log model may be inferred to support more species than would their oceanic equivalents. In light of this observation, it is probable that at least some fen species employ a 'stepping-stone' mode of dispersion, increasing the probability of successful colonization. This possibility is discussed for habitat islands in general by MacArthur and Wilson (1967) and Vuilleumier (1970). It is also probable that the study sites are acting as 'stepping-stones' for other related communities.

The fen communities studied may be considered as mainland habitat islands. Species diversity has been shown to correlate to a significant degree with the size of the fen. The present study did not consider distance between fens as a source of variation in species diversity, although distance probably exerts some effect on species diversity of fens. In terms of the species-area relation, the fens studies are in agreement with the MacArthur and Wilson (1967) theory of island biogeography.

Acknowledgements

In acknowledging those who aided in the preparation and completion of this project, we thank Margaret Kohring and Michael Champagne for their help with theoretical and taxonomic problems. We also extend our appreciation to Dr. Richard Brewer for his time spent discussing island biogeography, and his suggestions of a number of sites for study.

Literature Cited

Anderson, W. A. 1943. A fen in northwestern Iowa. Am. Midl. Nat. 29:787-791.

Curtis, J. T. 1959. The Vegetation of Wisconsin, an Ordination of Plant Communities. The University of Wisconsin Press, Madison.

Diamond, J. M. 1969. Avifaunal equilibria and species turnover rates on the Channel Islands of California. Proc. Nat. Acad. Sci. 64:57-63.

________. 1973. Distributional ecology of New Guinea birds. Science 179:759-769.

Diamond, J. M. and E. Mayr. 1976. Island biogeography and the design of nature reserves. In R. M. May, ed., Theoretical Ecology, Principles and applications. W. B. Saunders Co., Philadelphia.

Diamond, J. M., M. E. Gilpin and E. Mayr. 1976. Species-distance relation for birds of the Solomon Archipelago, and the paradox of the great speciators. Proc. Natl. Acad. Sci. 73:2160-2164.

Foos, K. A. 1971. A floristic and phytogeographical analysis of the fen element at the Resthaven Wildlife Area (Castaleja Prairie), Erie County, Ohio. M.S. thesis, Ohio State University, Columbus.

Gleason, H. 1974. The New Britton and Brown Illustrated Flora of Northeast United States and Adjacent Canada. Vols. I, II, III. Hatner Press, New York.

Golet, F. C. and J. S. Larson. 1974. Classification of freshwater wetlands in the glaciated northeast. U. S. Fish and Wildlife Serv. Resource Publ. 116. Wash., D.C.

Johnson, N. D. 1974. Controls of a number of bird species on montane islands in the Great Basin. Evolution 29:546-567.

Kushland, J. A. 1979. Design and management of continental wildlife reserves: lessons from the everglades. Biol. Conserv. 15:281-291.

MacArthur, R. H. and E. O. Wilson. 1963. An equilibrium theory of insular zoogeography. Evolution 17:373-387.

MacArthur, R. H. and E. O. Wilson. 1967. The Theory of Island Biogeography. Princeton University Press, Princeton, New Jersey.

MacArthur, R. H. 1972 Geographical Ecology, Patterns in the Distribution of Species. Harper and Row, New York.

May, R. M. 1975. Island biogeography and the design of nature reserves. Science 254:177-178.

Pickett, S. T. A. 1978. Patch dynamics and the design of nature reserves. Biol. Conserv. 13:27-37.

Pielou, E. C. 1975. Ecological Diversity. J. Wiley and Sons, New York.

Preston, F. W. 1962. The canonical distribution of commoness and rarity: Part I. Ecology 43:185-215.

Read, R. 1979. Personal Communication.

Simberloff, D. S. and E. O. Wilson. 1969. Experimental zoogeography of islands: the colonization of empty islands. Ecology 50:278-289.

Simberloff, D. S. 1976. Species turnover and equilibrium island biogeography. Science 194:572-578.

Simberloff, D. S. and L. G. Abele. 1976. Island biogeography theory and conservation practice. Science 191:285-286.

Simberloff, D. S. 1978. Islands and their species. The Nature Conservancy News. pp. 4-10.

Simpson, B. B. 1974. Glacial migrations of plants: island biogeographical evidence. Science 185:698-700.

Snedecor, G. W. and W. G. Cochran. 1967. Statistical Methods, 6th Ed. Iowa State University Press, Ames.

Swink, Floyd and Gerould Wilhelm. 1979. Plants of the Chicago Region. Rev. Ed. The Morton Arboretum Press, Lisle, Illinois.

Vuilleumier, Francois. 1970. Insular biogeography in continental regions. I. The northern Andes of South America. Am. Nat. 104:373-388.

east. U. S. Fish and Wildlife Serv. Resource Publ. 116. Wash. D.C.

Johnson, N. D. 1974. Controls of numbes of bird species on montane islands in the Great Basin. Evolution 29:546-567.

Kushland, J. A. 1979. Design and management of continental wildlife reserves: lessons from the everglades. Biol. Conserv. 15:281-291.

MacArthur, R. H. and E. O. Wilson. 1963. An equilibrium theory of insular zoogeography. Evolution 17:373-387.

MacArthur, R. H. and E. O. Wilson. 1967. The Theory of Island Biogeography. Princeton University Press, Princeton, New Jersey.

MacArthur, R. H. 1972 Geographical Ecology, Patterns in the Distribution of Species. Harper and Row, New York.

May, R. M. 1975. Island biogeography and the design of nature reserves. Science 254:177-178.

Pickett, S. T. A. 1978. Patch dynamics and the design of nature reserves. Biol. Conserv. 13:27-37.

Pielou, E. C. 1975. Ecological Diversity. J. Wiley and Sons, New York.

Preston, F. W. 1962. The canonical distribution of commoness and rarity: Part I. Ecology 43:185-215.

Reed, R. 1979. Personal Communication.

Simberloff, D. S. and E. O. Wilson. 1969. Experimental zoogeography of islands: the colonization of empty islands. Ecology 50:278-289.

Simberloff, D. S. 1976. Species turnover and equilibrium island biogeography. Science 194:572-575.

Simberloff, D. S. and L. G. Abele. 1976. Island biogeography theory and conservation practice. Science 191:285-286.

Simberloff, D. S. 1978. Islands and their species. The Nature Conservancy News, pp. 4-10.

Simpson, B. B. 1974. Glacial migrations of plants: island biogeographical evidence. Science 185:698-700.

Snedecor, G. W. and W. G. Cochran. 1967. Statistical Methods. 6th Ed. Iowa State University Press, Ames.

Swink, Floyd and Gerould Wilhelm. 1979. Plants of the Chicago Region. Rev. Ed. The Morton Arboretum Press, Lisle, Illinois.

Vuilleumier, Francois. 1970. Insular biogeography in continental regions. I. The northern Andes of South America. Am. Nat. 104:373-388.

THE SIGNIFICANCE OF ASYMBIOTIC DINITROGEN FIXATION IN GRASSLANDS

Lawrence A. Kapusta
Botany Department
Miami University
Oxford, Ohio 45056

Abstract. Field and laboratory measurements of the N_2 fixation capacity of an Oklahoma tallgrass prairie and an Ohio prairie preserve indicate that asymbiotic bacteria and heterocystic cyanobacteria provide the principal source of biologically-fixed N to these systems. Estimates of N_2-fixation rates for these and other temperate grasslands range from <1-5 kg N/ha/year with approximately 10 kg N/ha/year added by precipitation. Generally, temperate grasslands do not support major populations of rhizobial-legume or actinorhizal associations. The environment factors most crucial to the growth and activity of the asymbionts are available energy (light or organic metabolites), adequate moisture, suitable temperature, and pO_2. Clearly, native grasslands operate on a much less luxuriant N economy than our experiences with agricultural systems would lead us to believe. Biological-N_2 fixation was discounted in the IBP assessments of the N budget. In light of the current information we now must reevaluate the dynamics of the N cycle in grasslands.

Introduction

Primary production for arid and semi-arid grasslands is determined primarily by the availability of water in early spring and summer and secondarily by the availability of mineral N during periods of adequate moisture supply. For the Pawnee site in Colorado, Dodd and Laurenroth (1979) demonstrated increases in net primary production of 1.3-2.7 x with the maintenance of N at 50 kg/ha, 2.0-4.6 x when water was maintained at 0.0 to - 0.8 bars, and 5.0-13.0 x when the high levels of N and water were combined. Additional responses including shifts in community structure and species dominance attest to the dynamic balance of grasslands fostered by the typical moisture and nutrient conditions (Dodd and Laurenroth 1979). Presumably in the more mesic grasslands, N takes on increasing importance.

Soil N content is governed by a truly holistic suite of biotic and abiotic forces. Legg (1975) described the various transformations among organic and inorganic forms of N for grasslands. He and others (Woodmansee et al. 1978) have suggested that soil N may require several thousands of years to achieve equilibrium, if in fact equilibrium is ever realized. Nevertheless, relatively constant (predictable) levels of primary production suggest a condition approaching equilibrium.

The balance sheet for the N cycle in a closed system contains 3 sources of N: 1) inorganic (NH_4^+ and NO_x) from dust and precipitation, 2) symbiotic biological N_2 fixation, and 3) asymbiotic biological N_2 fixation. Losses may occur *via* denitrification, volatilization, and leaching.

Summarizing several studies, Woodmansee (1979) reported the ranges of annual N influx from non-biological sources from as low as 0.2 g/m^2 in arid sites to as high as 1.0 g/m^2 in the tallgrass prairie at the Osage site in northeastern Oklahoma. The bulk of this N occurs as NH_4^+ and NO_3^- in rainfall.

In the several IBP reposts from the grassland biome studies (Breymeyer and Van Dyne 1979, French 1979, Coupland 1979) the contribution of biologically fixed N has been dismissed summarily as being insignificant when considered as part of the total budget of the soil N pool. Presently, this position appears to be accepted widely. In this paper I would like to challenge this prevailing position for the following reasons. First, none of the reports contain data on the rates of biological-N_2 fixation. Second, our impression of "significant" rates of N_2 fixation too often are judged against rates of N_2 fixation by domesticated legumes and the N requirements of agricultural systems. Finally, rates of N_2 fixation in a tallgrass prairie in Oklahoma and a relic, hilltop prairie in southern Ohio suggest that asymbiotic N_2 fixation represents a significant influx of N for these sites.

Biological Dinitrogen Fixation

The increasing costs of fossil fuels used in the synthesis of chemical fertilizers has stimulated a renewed interest in biological-N_2 fixation especially in forage and grain legumes (Newton et al. 1977, Evans and Barber 1977, Burris 1978). The development of high yield forage crops, as with high yield cereal grains has led to an increased dependency on N, with requirements as high as 1000-2000 kg N/ha/year to achieve maximum productivity (Gibson 1976). Domesticated legumes approach the levels of N influx required by high yield crops with reports of 50-60 kg N/ha/year (alfalfa and clover) (Mishustin and Shil'nikova 1971).

Native grasslands and rangelands operate on a much less luxuriant N economy than our experiences with agricultural systems would lead us to expect. Estimates of N_2 fixation of temperate grasslands range from <1-5 kg N/ha/year (Paul et al. 1971, Steyn and Delwiche 1970, Balandreau and Dommergues 1973, Vlassak et al. 1973, Kapustka and Rice 1976). The ability of the prairie to maintain high productivity with the relatively low rates of N_2 fixation focuses on the highly efficient recovery of mineralized N. This efficiency may be enhanced by the suppression of nitrification due to the release of inhibitors from the rhizomes of the climax grass species (Rice and Pancholy 1972, 1973, 1974).

The principal diazotrophs of the temperate grasslands do not appear to be rhizobial-legume or actinorhizal symbionts, but asymbiotic bacteria, and where light is available at the soil surface, heterocystic syanobacteria (Harris and Dart 1972, Kapustka and Rice 1976, 1978a, 1978b). The contribution of N by asymbiotic forms in an Oklahoma prairie in 1974 was 3.5 kg N/ha/year which was up to 14x greater than the calculated maximum symbiotic contribution (Kapustka and Rice, 1978b). DuBois (1980) measured the N_2 fixation by *Nostoc* colonies in an Ohio prairie preserve (Lynx Prairie, Adams Co., Ohio) at rates as high as 0.19 kg N/ha/day. At the same site for the period 29 March 1980 through 24 July 1980, the cyanobacterial N_2 fixation has totaled 3.0 kg N/ha while the heterotrophic diazotrophs have fixed an additional 3.2 kg N/ha (DuBois pers. comm.).

Heterocystic cyanobacteria. Cyanobacteria are considered to be primary colonizers serving to bind the soil, maintain soil moisture and contribute combined nitrogen to the developing communities (Shields and Durrell 1964, Fogg 1973). The generic identity of the colonies is dependent upon the microenvironment. Wet virgin soils tend to support *Nostoc, Anabaena,* and *Calothirix*. Dry virgin soils are often colonized by *Fischerella, Nostoc, Tolypothrix,* and *Scytonema. Cylindrospermum* and *Anabaena* are common in cultivated soils (Stewart 1974).

Dinitrogen fixation by cyanobacteria in soil habitats has been studied in Sweden (Granhall 1970), Arizona (Cameron and Fuller 1960, Mayland et al. 1968, MacGregor and Johnson 1971), California (Steyn and Delwiche 1970), Oklahoma (Kapustka and Rice 1976), Colorado (Eskew and Ting 1978), Ohio (DuBois 1980), and other temperate regions (Henriksson 1971) with values ranging from 1-2 kg N/ha/year (Stewart et al. 1978) to 39 kg N/ha/year (Day et al. 1975).

The environmental factors which appear to determine the magnitude of cyanobacterial activity are light, moisture, temperature, and pH. Although many cyanobacteria can exist heterotrophically, their most significant growth and N contribution occurs during photoautotrophic conditions. Optimal light for dinitrogen fixation appears to be approximately 200 uE/m^2/sec (Rychert and Skujins, 1974). Optimal pH is around neutrality. Optimum temperatures range from 19°C (Rychert and Skujins 1974) to 30°C (Steyn and Delwiche 1970, Stewart 1974). Optimal water conditions for N_2ase activity is at or near soil water holding capacity. Steyn and Delwiche (1970) reported -0.3 bars optimal for blue-green algal-lichen crusts with little or no N_2ase activity at -12 bars. DuBois and Kapustka (in review) demonstrated a linear decline in N_2ase activity of approximately 10% for each1 bar drop in water potential. The combination of environmental factors favorable for N_2ase in drier climates occur in the spring and/or fall seasons.

Heterotrophic diazotrophs. Asymbiotic, heterotrophic diazotrophs include several aerobic forms in the Azotobacteraceae, facultative anaerobes in the Enterobacteraceae and strict anaerobes in the genus *Clostridium*. The regulation of metabolic activity of the asymbionts is complex and presumably finely tuned to physical, chemical and biochemical stimuli. Soils contain varied microhabitats with respect to oxygen levels, water potentials, and chemical constituents across relatively steep gradients.

A variety of experimental techniques have demonstrated O_2 gradients ranging from near ambient concentrations to anaerobic conditions across distances as little as 1 mm providing optimal niches for all heterotrophic diazotrophs (Greenwood and Goodman 1964a, 1964b, 1967, Rice, Paul and Wetter 1967, Rice and Paul 1971).

Laboratory data from glucose amended soil cores indicate that heterotrophs may achieve maximum growth/N_2 fixation activity within 48 - 72 hours and decline to a quiescent state within 96 to 120 hours (Fig. 1).

Respiration of soil bacteria decreases rapidly below -3 bars and essentially ceases at -20 bars (Wilson and Griffin 1975). $N_2(C_2H_2)$ase activity in glucose amended soil cores shows a similar response to water potential (Fig. 2).

Investigations of asymbiotic dinitrogen fixation associated with root systems of temperate grassland species have demonstrated a wide range of response. Estimated rates of N additional by rhizosphere associations range from <1-18 kg N/ha/year for temperate upland species (Harris and Dart 1973, Tjepkema 1975 and Burris 1976, Nelson et al. 1976, Barber and Evans 1976, Evans and Barber 1977).

Rovira (1969) and Christiansen et al. (1970) have conclusively demonstrated that many higher plants selectively exude organic chemicals from their roots. In turn the array of chemicals promote the growth of certain microorganisms and may restrict the growth of others (Katznelson et al. 1948, Rovira 1961, Hale et al. 1978). Manifestations of this exudation perhaps are responsible for the initiation of symbiotic relationships in legumes (Rao et al. 1973, Dart 1975). Dobereiner and colleagues have demonstrated an association between the tropical grass *Paspalum notatum* and the N_2-fixing *Azotobacter paspali* effective in providing substantial quantities of N to the host plant (Dobereiner and Campelo 1971, Dobereiner, Day and Dart 1972a, 1972b, Day, Neves and Dobereiner 1975). On the other end of the spectrum, bacteria associated with the root systems of the annual grass *Aristida oligantha* have been shown to inhibit the growth of N_2-fixing bacteria (Leuck and Rice 1976). This latter situation appears to explain the relatively low levels of N_2-fixation measured in an *A. oligantha*-dominated site (Kapustka and Rice 1976, 1978a). Several other studies have demonstrated inhibition of N_2-fixation by phenolics released from dicotyledonous and graminaceous species (Rice 1974, Kapustka and Rice 1976). Thus with respect to N_2-fixing micro-organisms, the exudates from higher plants effect a range of plant-microbial interaction from endophytic association to antagonistic exclusion.

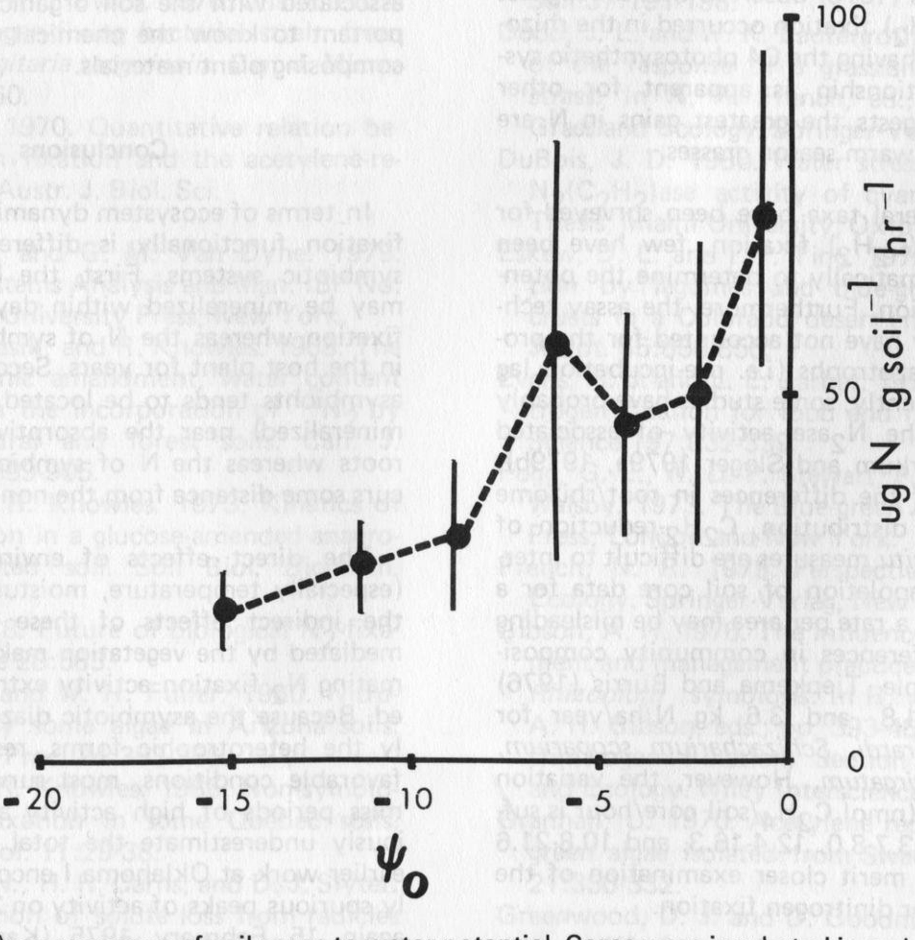


Fig. 1. $N_2(C_2H_2)$ase response of soil cores to water potential. Cores were incubated in a glucose-amended N-free medium supplemented with PEG-400 as the osmoticum.

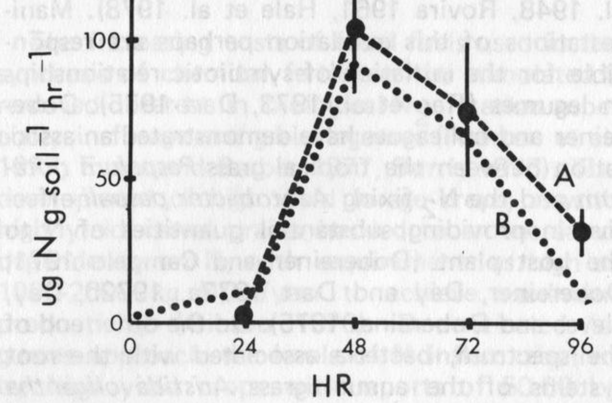


Fig. 2. Typical time course responses of $N_2(C_2H_2)$ase activity of glucose-amended soil cores. A: cores with no detectable activity in 1st 24-hr period, mean ∓ standard error. B: cores showing activity in 1st 24-hr, only the mean shown.

The factor most limiting to free-living diazotrophs is a suitable carbon source. Thus it is not surprising that a number of environmental parmeters that influence the rate of photosynthesis appear to influence rhizosphere N_2ase activity (Bergersen 1970, Balandreau et al. 1977). Tjepkema and Burris (1976) observed that the highest rates of $N_2(C_2H_2)$ fixation occurred in the rhizospheres of taxa having the C4 photosynthetic system. This relationship is apparent for other studies and suggests the greatest gains in N are likely found for warm season grasses.

Although several taxa have been surveyed for rhizosphere $N_2(C_2H_2)$ fixation, few have been examined systematically to determine the potential for N addition. Furthermore, the assay techniques generally have not accounted for the proliferation of diazotrophs (i.e. pre-incubation lag phase). Consequently, some studies have probably overestimated the N_2ase activity of associated species (van Berkum and Sloger 1979a, 1979b). Also because of the differences in root/rhizome abundance and distribution, C_2H_2-reduction of soil cores on *in situ* measures are difficult to interpret. And extrapolation of soil core data for a given species to a rate per area may be misleading because of differences in community composition. For example, Tjepkema and Burris (1976) reported 0.7, 1.8, and 3.6 kg N/ha/year for *Andropogon gerardi*, *Schizacharium scoparium*, and *Panicum virgatum*. However, the variation among samples (nmol C_2H_4/soil core/hour is sufficiently large (3.7-8.0, 12.4-16.3, and 10.8-21.6 respectively) to merit closer examination of the true potential for dinitrogen fixation.

Diazotroph activity associated with decomposition is regulated by many of the same microenvironmental factors as discussed above, namely temperature, soil moisture, pH, and suitable metaboilic substrate. Several investigators have examined the influence of substrate added to soils. Chang and Knowles (1965), Rice et al. (1967), Brouzes et al. (1969, 1973), and O'Toole and Knowles (1973) credited anaerobes for the marked increases in N_2ase activity which occur following the addition of carbohydrates to soil. In part this may result from a drop in pO_2 as metabolism of aerobes increases. Rapid short-lived bursts of microbial activity which occur normally in field situations provide comparable conditions.

Although metabolic substrate may become available to diazotrophs during the periods of high activity, the presence of associated decomposition products can be significant. In a study of N_2ase activity in old field succession Kapustka and Rice (1978) inferred that allelochmics from several pioneer weed species were reducing the potential N_2-fixing capability. The early weed sere had nearly 65% as much organic carbon as the prairie soil. However, compared to the prairie soil the weed stage supported only 28% as much N_2ase activity in fresh soil and 35% as much N_2ase activity in glucose amended soil. Consequently in determining asymbiotic N_2 fixation associated with the soil organic matter, it is important to know the chemical nature of the decomposing plant materials.

Conclusions

In terms of ecosystem dynamics asymbiotic N_2 fixation functionally is different from that of symbiotic systems. First, the N of asymbionts may be mineralized within days or weeks after fixation whereas the N of symbionts may reside in the host plant for years. Second, the N of the asymbionts tends to be located (and presumably mineralized) near the absorptive regions of the roots whereas the N of symbionts generally occurs some distance from the non-host plants.

The direct effects of environmental factors (especially temperature, moisture, and light) and the indirect effects of these same parameters mediated by the vegetation make the task of estimating N_2 fixation activity extremely complicated. Because the asymbiotic diazotrophs, especially the heterotrophic forms, respond rapidly to favorable conditions, most surveys are likely to miss periods of high activity and therefore seriously underestimate the total N influx. In my earlier work at Oklahoma I encountered seemingly spurious peaks of activity on 25 May 1974 and again 15 February 1975 (Kapustka and Rice 1976). Activity at the rate of the 25 May sampling for a period of 1 week would equal the N contribution of the remainder of the year at the typically low rates.

Despite these difficulties, the data for asymbiotic N_2 fixation accumulated in systematic sampling efforts from several sites reveal a significant N influx that approaches or exceeds the quantity delivered from atmospheric sources. Asymbiotic diazotrophs provide up to 50% or more of the total N influx of the tallgrass prairies studied to date. Since this component was discounted in earlier assessments of the N budget we now must reevaluate the dynamics of the N cycle in grasslands.

Literature Cited

Balandreau, J. and Y. Dommergues. 1973. Assaying nitrogenase (C_2H_2) activity in the field. Bull. Ecol. Res. Comm. (Stockholm) 17:247-254.

Balandreau, J. P., C.R. Millier, P. Weinhard, P. Ducerf and Y. R. Dommergues. 1977. A modeling approach of acetylene reducing activity of plant rhizosphere diazotroph systems. In Newton et al., eds., Recent Development in Nitrogen Fixation. Academic Press, New York.

Barber, L. E. and H. J. Evans. 1976. Characterization of a nitrogen-fixing bacterial strain from the roots of *Digitaria sanguinalis*. Can. J. Microbiol. 22:254-260.

Bergersen, F. J. 1970. Quantitative relation between nitrogen fixation and the acetylene-reduction assay. Austr. J. Biol. Sci. 23:1015-1025.

Breymeyer, A. I. and G. M. Van Dyne. 1979. Grasslands, Systems Analysis and Man. IBP No. 19. Cambridge University Press, New York.

Brouzes, R., J. Lasik, and R. Knowles. 1969. The effect of organic amendment, water content and oxygen on the incorporation of $^{15}N_2$ by some agricultural and forest soils. Can. J. Microbiol. 15:899-905.

Brouzes, R. and R. Knowles. 1973. Kinetics of nitrogen fixation in a glucose-amended anaerobically incubated soil. Soil Biol. Biochem. 5:223-229.

Burris, R. H. 1978. Future of biological N_2-fixation. Bioscience 28:563.

Cameron, R. E. and W. H. Fuller. 1960. Nitrogen fixation by some algae in Arizona soils. Soil Sci. Amer. Proc. 24:353-356.

Chang, P-C. and R. Knowles. 1965. Non-symbiotic nitrogen fixation in some Quebec soils. Can. J. Microbiol. 11:29-38.

Christiansen, M. N., H. R. Carns, and D. J. Slyter. 1970. Stimulation of solute loss from radicles of *Gossypium hirsutum*. Plant Physiol. 46:53-56.

Coupland, R. T. 1979. Grassland Ecosystems of the World: Analysis of Grasslands and Their Uses. Cambridge University Press, New York.

Dart, P. J. 1975. Legume root nodule initiation and development. In J. G. Torrey and D. T. Clarkson, eds., The Development and Function of Roots. Academic Press, New York.

Day, J. M., M. C. P. Neves, and J. Dobereiner. 1975. Nitrogenase activity on the roots of tropical forage grasses. Soil Biol. Biochem. 7:107-112.

Day, J., D. Harris, P. J. Dart, and P. van Berkum. 1975. The Broadbalk experiment. An investigation of nitrogen gains from non-symbiotic nitrogen fixation. In W. D. P. Steward, ed., Nitrogen Fixation by Free-living Microorganisms. Cambridge University Press, New York.

Dobereiner, J. and A. B. Campelo. 1971. Non-symbiotic nitrogen fixing bacteria in tropical soils. Plant and Soil Special Volume:457-470.

Dobereiner, J., J. M. Day, and P. J. Dart. 1972a. Nitrogenase activity and oxygen sensitivity of the *Paspalum notatum-Azotobacter paspali* association. J. Gen. Microbiol. 71:103-116.

Dobereiner, J., J. M. Day and P. J. Dart. 1972b. Nitrogenase activitiy in the rhizosphere of sugar cane and other tropical grasses. Plant and Soil 37:191-196.

Dodd, J. L. and W. K. Laurenroth. 1979. Analysis of the response of a grassland ecosystem to stress. In N. R. French, ed., Perspectives in Grassland Ecology. Springer-Verlag, New York.

DuBois, J. D. 1980. Water stress effects on the $N_2(C_2H_2)$ase activity of cyanobacteria. M.S. Thesis, Miami University, Oxford, Ohio.

Eskew, D. L. and I. P. Ting. 1978. Nitrogen fixation by legumes and blue-green algal-lichen crusts in a Colorado desert environment. Am. J. Bot. 65:850-856.

Evans, H. J. and L. E. Barber. 1977. Biological nitrogen fixation for food and fiber production. Science 197:332-339.

Fogg, G. E., W. D. P. Stewart, P. Fay, and A. E. Walsby. 1973. The Blue-green Algae. Academic Press, London and New York.

French, N. R. 1979. Perspectives in Grassland Ecology. Springer-Verlag, New York.

Gibson, A. H. 1976. The influence of the environment and management practices on the legume-*Rhizobium* symbiosis. In R. W. F. Hardy and A. H. Gibson, eds., pp. 393-450, A Treatise on Dinitrogen Fixation. Section IV. Agronomy and Ecology. Wiley Interscience, New York.

Granhall, U. 1970. Acetylene reduction by blue-green algae isolated from Swedish soils. Oikos 21:330-332.

Greenwood, D. J. and D. Goodman. 1964a. Oxygen diffusion and aerobic respiration in soil spheres. J. Sci. Food Agric. 15:579-588.

Greenwood, D. J. and D. Goodman. 1964 b. Effects of shape on oxygen diffusion and aerobic respiration in soil aggregates. J. Sci. Food Agric. 15:781-790.
Greenwood, D. J. and D. Goodman. 1967. Direct measures of the distribution of oxygen in soil aggregates and on columns of fine soil crumbs. J. Sci. Food Agric. 18:182-196.
Hale, M. G., L. D. Moore, and G. J. Griffin. 1978. Root exudates and exudation. In Y. R. Dommergues and S. V. Krupa, eds., Interactions Between Non-pathogenic Soil Microorganisms and Plants. Elsevier Scientific Publ. Co., Amsterdam.
Harris, D. and P. J. Dart. 1973. Nitrogenase activity in the rhizosphere of *Stachys sylvatica* and some other dicotyledonous plants. Soil Biol. Biochem. 5:277-279.
Hendriksson, E. 1971. Algal nitrogen fixation in temperate regions. In T. A. Lie and E. G. Mulder, eds., Biological Nitrogen Fixation in Natural and Agricultural Habitats. Special Vol. Plant and Soil.
Kapustka, L. A. and E. L. Rice. 1976. Acetylene reduction (N_2-fixation) in soil and old field succession in central Oklahoma. Soil Biol. Biochem. 8:497-503.
Kapustka, L. A. and E. L. Rice. 1978a. Acetylene reduction (N_2-fixation) of glucose-amended soils from central Oklahoma old field succession plots. Southwest. Natur. 23:389-396.
Kapustka, L. A. and E. L. Rice. 1978b. Symbiotic and asymbiotic N_2-fixation) in a tall grass prairie. Soil Biol. Biochem. 10:553-554.
Katznelson, H., A. G. Lochead, and M. I. Timonin. 1948. Soil microorganisms and the rhizosphere. Bot. Rev. 14:543-587.
Legg, J. O. 1974. Influence of plants on nitrogen transformations in soils. Proc. Fourth Midwest Prairie Conf., pp. 221-227, M. K. Wali, ed. University of North Dakota, Grand Forks.
Leuck, E. E. and E. L. Rice. 1976. Effect of rhizosphere bacteria of *Aristida oligantha* on *Rhizobium* and *Azotobacter.* Bot. Gaz. 137:160-164.
Line, M. A. and M. W. Loutit. 1971. Non-symbiotic nitrogen-fixing organisms from some New Zealand soils. J. Gen. Microbiol. 66:309-318.
MacGregor, A. N. and D. E. Johnson. 1971. Capacity of desert algal crusts to fix atmospheric nitrogen. Soil Sci. Soc. Amer. Proc. 35:843-844.
Mayland, H. F., T. H. McIntosh, and W. H. Fuller. 1966. Fixation of isotopic nitrogen on a semiarid soil by algal crust organisms. Soil Sci. Soc. Amer. Proc. 30:56-60.
Mishustin, E. N. and V. K. Shil'nikova. 1971. Biological Fixation of Atmospheric Nitrogen. Macmillan Press, New York.
Nelson, A. D., L. E. Barber, J. D. Tjepkema, S. A. Russel, R. Powelson, R. J. Sidler, and H. J. Evans. 1976. Nitrogen fixation associated with grasses in Oregon. Can. J. Microbiol. 22:523-530.
Newton, W., J. R. Postgate, and C. Rodriguez-Barrueco. 1977. Recent Developments in Nitrogen Fixation. Academic Press, New York.
O'Toole, P. O. and R. Knowles. 1973. Efficiency of acetlyene reduction (nitrogen fixation) in soil: effect of type and concentration of available carbohydrate. Soil Biol. Biochem. 5:789-797.
Paul, E. A., R. J. K. Meyers, and W. A. Rice. 1971. Nitrogen fixation in grassland and associated cultivated ecosystems. In T. A. Lie and E. G. Mulder, eds., pp. 295-507, Biological Nitrogen Fixation in Natural and Agricultural Habitats. Special Vol. Plant and Soil.
Rao, V. R., N. S. S. Rao, and K. G. Mukerji. 1973. Inhibtion of rhizobium *in vitro* by non-nodulating legume roots and root extracts. Plant and Soil 39:449-452.
Rice, E. L. 1974. Allelopathy. Academic Press, New York.
Rice, E. L and S. K. Pancholy. 1972. Inhibition of nitrification by climax ecosytems. Amer. J. Bot. 59:1033-1040.
Rice, E. L. and S. K. Pancholy. 1973. Inhibition of nitrification by climax ecosystems. II. Additional evidence and possible role of tannins. Amer. J. Bot. 60:691-702.
Rice, E. L. and S. K. Pancholy. 1974. Inhibition of nitrification by climax ecosystems. III. Inhibitors other than tannins. Amer. J. Bot. 61:1095-1103.
Rice, W. A. and E. A. Paul. 1971. The acetylene reduction assay for measuring nitrogen fixation in water logged soil. Can. J. Microbiol. 17:1049-1056.
Rovira, A. D. and J. R. Harris. 1961. Plant root excretions in reulation to the rhizosphere effect. V. The exudation of B-group vitamins. Plant and Soil 14:199-214.
Rovira, A. D. 1969. Plant root exudates. Bot. Rev. 35:35-57.
Rychert, R. C. and J. Skujins. 1974. Nitrogen fixation by blue-green algae-lichen crusts in the Great Basin Desert. Soil Sci. Soc. Amer. Proc. 38:768-771.
Shields, L. M. and L. W. Durrell. 1964. Algae in relation to soil fertility. Bot. Rev. 30:92-128.
Steyn, P. L. and C. C. Delwiche. 1970. Nitrogen fixation by non-symbiotic microorganisms in some California soils. Envir. Sci. Tech. 4:1122-1128.
Stewart, W. D. P. 1974. Blue-green algae. In A. Quispel, ed., The Biology of Nitrogen Fixation. North-Holland Publ. Co., Amsterdam and Oxford.

Stewart, W. D. P., M. J. Sampaio, A. O. Isichei, and R. Sylvester-Bradley. 1978. Nitrogen fixation by soil algae of the temperate and tropical soils. In J. Dobereiner, R. H. Burris, and A. Hollander, eds., Limitations and Potentials for Biological Nitrogen Fixation in the Tropics. Plenum Press, New York.

Tjepkema, J. D. 1975. Nitrogenase activity in the rhizosphere of *Panicum virgatum*. Soil Biol. Biochem. 7:179-180.

Tjepkema, J. D. and R. H. Burris. 1976. Nitrogenase activity associated with some Wisconsin prairie grasses. Plant and Soil 45:81-94.

van Berkum, P. and C. Sloger. 1979a. Nitrogenase activity by excised grass roots. Pl. Physiol. Suppl. 63:85 (abstract).

van Berkum, P. and C. Sloger. 1979b. Comparing immediate acetylene reduction by grasses to legumes. Pl. Physiol. Suppl. 65:86 (abstract).

Vlassak, K., E. A. Paul, and R. E. Harris. 1973. Assessment of biological nitrogen fixation in grassland and associated sites. Plant and Soil 38:637-649.

Wilson, J. M. and D. M. Griffin. 1975. Water potential and and the respiration of microorganisms in the soil. Soil Biol. Biochem. 7:199-204.

Woodmansee, R. G., J. L. Dodd, R. A. Bowman, F. E. Clark, and C. E. Dickinson. 1978. Nitrogen budget for a shortgrass prairie ecosystem. Oecologia 34:363-376.

Woodmansee, R. G. 1979. Factors influencing input and output of nitrogen in grasslands. In N. R. French, ed., Perspectives in Grassland Ecology. Springer-Verlag, New York.

Harris, D. and P. J. Dart. 1973. Nitrogenase activity in the rhizosphere of *Stachys sylvatica* and some other dicotyledonous plants. Soil Biol. Biochem. 5:277-279.

Hendriksson, E. 1971. Algal nitrogen fixation in temperate regions. In T. A. Lie and E. G. Mulder, eds., Biological Nitrogen Fixation in Natural and Agricultural Habitats. Special Vol. Plant and Soil.

Kapustka, L. A. and E. L. Rice. 1976. Acetylene reduction (N_2-fixation) in soil and old field succession in central Oklahoma. Soil Biol. Biochem. 8:497-503.

Kapustka, L. A. and E. L. Rice. 1978a. Acetylene reduction (N_2-fixation) of glucose-amended soils from central Oklahoma old field succession plots. Southwest. Natur. 23:389-396.

Kapustka, L. A. and E. L. Rice. 1978b. Symbiotic and asymbiotic N_2-fixation) in a tall grass prairie. Soil Biol. Biochem. 10:553-554.

Katznelson, H., A. G. Lochhead, and M. I. Timonin. 1948. Soil microorganisms and the rhizosphere. Bot. Rev. 14:543-587.

Legg, J. O. 1974. Influence of plants on nitrogen transformations in soils. Proc. Fourth Midwest Prairie Conf., pp. 221-227. M. K. Wali, ed. University of North Dakota, Grand Forks.

Leuck, E. E. and E. L. Rice. 1976. Effect of rhizosphere bacteria of *Aristida oligantha* on *Rhizobium* and *Azotobacter*. Bot. Gaz. 137:160-164.

Line, M. A. and M. W. Loutit. 1971. Non-symbiotic nitrogen-fixing organisms from some New Zealand soils. J. Gen. Microbiol. 66:309-318.

MacGregor, A. N. and D. E. Johnson. 1971. Capacity of desert algal crusts to fix atmospheric nitrogen. Soil Sci. Soc. Amer. Proc. 35:843-844.

Mayland, H. F., T. H. McIntosh, and W. H. Fuller. 1966. Fixation of isotopic nitrogen on a semiarid soil by algal crust organisms. Soil Sci. Soc. Amer. Proc. 30:56-60.

Mishustin, E. N. and V. K. Shil'nikova. 1971. Biological Fixation of Atmospheric Nitrogen. Macmillan Press, New York.

Paul, E. A., R. J. K. Myers, and W. A. Rice. 1971. Nitrogen fixation in grassland and associated cultivated ecosystems. In T. A. Lie and E. G. Mulder, eds., pp. 495-507, Biological Nitrogen Fixation in Natural and Agricultural Habitats. Special Vol. Plant and Soil.

Rao, V. R., N. S. S. Rao, and K. G. Mukerji. 1973. Inhibition of rhizobium *in vitro* by non-nodulating legume roots and root extracts. Plant and Soil 39:449-452.

Rice, E. L. 1974. Allelopathy. Academic Press, New York.

Rice, E. L. and S. K. Pancholy. 1972. Inhibition of nitrification by climax ecosystems. Amer. J. Bot. 59:1033-1040.

Rice, E. L. and S. K. Pancholy. 1973. Inhibition of nitrification by climax ecosystems. II. Additional evidence and possible role of tannins. Amer. J. Bot. 60:691-702.

Rice, E. L. and S. K. Pancholy. 1974. Inhibition of nitrification by climax ecosystems. III. Inhibitors other than tannins. Amer. J. Bot. 61:1095-1103.

Rice, W. A. and E. A. Paul. 1971. The acetylene reduction assay for measuring nitrogen fixation in water logged soil. Can. J. Microbiol. 17:1049-1056.

Rovira, A. D. and J. R. Harris. 1961. Plant root excretions in relation to the rhizosphere effect. V. The exudation of B-group vitamins. Plant and Soil 14:199-214.

Rovira, A. D. 1969. Plant root exudates. Bot. Rev. 35:35-57.

Rychert, R. C. and J. Skujins. 1974. Nitrogen fixation by blue-green algae-lichen crusts in the Great Basin Desert. Soil Sci. Soc. Amer. Proc. 38:768-771.

Shields, L. M. and L. W. Durrell. 1964. Algae in relation to soil fertility. Bot. Rev. 30:92-128.

Steyn, P. L. and C. C. Delwiche. 1970. Nitrogen fixation by non-symbiotic microorganisms in some California soils. Envir. Sci. Tech. 4:1122-1128.

Stewart, W. D. P. 1974. Blue-green algae. In A. Quispel, ed., The Biology of Nitrogen Fixation. North-Holand Publ. Co., Amsterdam and Oxford.

SEASONAL VARIATION IN C3 AND C4 BIOMASS AT THE ORDWAY PRAIRIE AND SELECTIVITY BY BISON AND CATTLE

Larry L. Tieszen, David J. Ode
and Paul W. Barnes
Department of Biology
Augustana College
Sioux Falls, South Dakota 57197
and
Paul M. Bultsma
S. H. Ordway Jr., Memorial Prairie
Star Route, Box 17
Leola, South Dakota 57456

Abstract. The Samuel H. Ordway, Jr. Memorial Prairie, near Leola, South Dakota is a Mixed Prairie Preserve owned and managed by the Nature Conservancy. Twenty-seven of the 305 species photosynthesize by the C_4 system. This includes 36% of the grasses. Communities dominated by C_4 grasses are distributed on drier and potentially warmer sites. They also occupy sites which are poorer in mineral nutrients or which are high in salt content. Carbon isotope studies have been used to evaluate the biomass contribution by each photosynthetic type and the selectivity of grasses by grazing bison and cattle. Biomass early in the season (April-June) is nearly all derived from C_3 sources. Although maximum biomass is attained by late June or early July, most of the carbon added at this time and during midsummer is provided by C_4 plants. By October the biomass again consists of C_3-derived carbon. Thus, this system is characterized by carbon from C_3 plants most active in spring and fall and from C_4 plants most active in mid-summer.

Introduction

The Samuel H. Ordway, Jr. Memorial Prairie is a 3076-ha (approx. 12 sq mi) contiguous preserve owned and managed by the Nature Conservancy and located in north-central South Dakota, U.S.A. (45° 43′N, 99°W), on the eastern edge of the Coteau du Missouri, 9 miles west of Leola, S.D. The topography consists of undulating and rolling hills at an elevation of 587 to 614 m above sea level (Christensen 1977) with deep loamy soils developed on glacial till. Numerous wetland basins and temporary to permanent aquatic systems are present. The vegetation is a northern Mixed Prairie type (Weaver and Albertson 1956, Weaver 1968) dominated by the grass genera *Stipa, Agropyron, Andropogon* and *Boutelous* together with the forb genera *Astragulus, Anemone, Aster, Artemisia* and *Solidago.* This is also recognized as Mixed Prairie by Kuchler (1964) and is immediately west of his Tallgrass Transition.

Since the acquisition of the Ordway Prairie, we have undertaken a number of studies in an attempt to provide the data base and understanding for an appropriate management system. The objectives for this preserve are to maintain a natural prairie system and to manage it to enhance the diversity of native species and communities. One of the interesting features of the system is the co-dominance of cool season (C_3) and warm season (C_4) grasses. Fifty-three, or 17% (Ode and Tieszen 1980) of the 305 species (Hertz 1976) documented on the preserve are grasses (Table 1). Thirty-four of these species are C_3, including 10 introduced species, of which *Bromus* and *Poa* pose serious management problems. Only 8 forbs photosynthesize by the C_4 pathway. Eighty-one percent of all Ordway species are native to North America while 19% are introductions.

In this paper we will summarize some of the results of our 1977 research efforts at Ordway. Our overall objectives are to: 1) better understand the vegetation units at Ordway, their distributions, and their productivities, 2) establish the seasonality (phenology) of production by community and photosynthetic type, and 3) determine the seasonality of species and habitat utilization of various herbivores.

Table I. Number of species documented for the Ordway Prairie by growth form and photosynthetic type. (Compiled from Hertz 1976 and Ode and Tieszen 1980)

	Photosynthetic Type				
	C_4		C_3		
Source	Forbs	Grasses	Forbs	Grasses	Total
Introduced	5	4	38	10	57
Native	3	15	206	24	248
Total	8	19	244	34	305

Methods

Community diversity. A 259-ha exclosure (not grazed for 2 years) lying in sections 26 and 35 of Township (R. 69 W., T. 126 N.) was selected as a study site. We subjectively defined 14 community types which encompassed the variation at this site. Three stands in each type were sampled (four l-m^2 quadrats/stand) for species present, percent cover, canopy structure, above ground production, and a group of environmental and soil variables. A modified Bray and Curtis ordination (Clark 1977) was used to spatially orient all stands and species along abstract axes which were correlated with environmental variables.

Seasonality of production. Two communities were studies more intensively to document seasonal patterns of primary production. An upland community of a 5 - 15^o west-facing slope along a ridge top was selected to represent the various upland communities. This upland community was dominated by a mixture of C_4 *(Muhlenbergia cuspidata* (Torr) Rydb., *Andropogon scoparius* Michx. = *Schizachyrium scoparium* (Michx.) Nash, *Bouteloua gracilis* (HBK.) Lag.) and C_3 *(Stipa comata* Trin. & Rupr., *Carex filifolia* Nutt., and *Carex elecharis* Bailey) species. In the classification scheme of Dix and Smeins (1967), this upland community would be closely aligned with their "high prairie" designation. Maximum cover was 115% with C_4 species accounting for 43%. One-half of the 10 grasses with the highest cover were C_4; however, even in this community only 7 of the 47 species were C_4.

The lowland community, on a 5 - 10^o south-facing slope along the base of a ridge, was dominated by the C_3 grasses, *Agropyron smithii* Rydb. and *Stipa viridula* Trin. Only 2 C_4 species *Bouteloua gracilis* and *Calamovilfa longifolia* (Hook.) Scribn., were present, and were minor constituents with 4.6% cover in a total coverage of 137%. This lowland community would be associated with the "mid prairie" of Dix and Smeins (1967).

Standing vegetation was normally clipped at 15-day intervals from 30 April to 8 October in 1977 at 10 m intervals along 2 transects through each plant community. At each sample date, 5 samples from each community were collected by clipping one 0.1 m x 1.0 m strip radially from each point, with 10 strips per sample. Each sample was quartered, sorted into 3 components: green, 1977 dead, and litter, dried for 24 hrs at 98^{o}C, and weighed.

C_3 and C_4 determinations and $\delta^{13}C$ analysis. Leaf anatomy of 305 vascular species was determined by microscopic examination of hand-sectioned fresh and herbarium specimens. On the basis of the "maximum lateral cell count" and "maximum cell distant count" as described by Hattersley and Watson (1957), plant species were categorized as C_3 or C_4.

One of the characteristics which distinguishes C_3 from C_4 plants is the fractionation against the stable heavy isotope, $\delta^{13}C$. This provides a label for the organic material derived from each of the photosynthetic types. Dried green subsamples from each biomass collection were finely ground. Three samples from each community were analyzed for their $\delta^{13}C$ value for each sample date. Results are reported in terms of $\delta^{13}C$ (o/oo) relative to the PDB carbonate standard where:

$$^{13}C = \left[\frac{\text{R Sample}}{\text{R Standard}} - 1\right] \times 1000.$$

Known C_3 and C_4 plants from Ordway were analyzed to obtain mean values for $\delta^{13}C$ for each photosynthetic type. These mean values (C_3 = -26.7, CV = -0.27; C_4 = -12.9, CV = -0.50) were used to estimate the percent composition by photosynthetic types of the biomass samples from each community (Ode and Tieszen 1980). We could therefore determine the quantitative proportion of the biomass at any time derived from cool season (C_3) or warm season (C_4) plants.

Vegetation Selectivity. Our principal interest is in determining quantitative utilization with a technique described by Tieszen et al. (1979). The isotopic ratio in feces is a direct function of the ratio in the vegetation which is consumed (assuming comparable digestibilities of C_3 and C_4 plants.) We collected 7 fresh fecal samples from free-ranging bison each month between February and November and from cattle between June and October. Subsamples were analyzed for isotopic composition in a VG Micromass 602E isotope ratio mass spectrometer at Augustana College.

Results

Community diversity and production. Detailed descriptions of the species composition and structure of each of the 14 communities are available in Barnes and Tieszen (1978) and will be presented elsewhere. It is apparent from Table 2 that the communities range widely in species richness and diversity. Both richness and diversity are much greater in the communities inhabiting the hill slopes and hill tops where 30 to 40 species commonly occur. The ordination showed 7 significant clusters of communities (at the 40% level). The axes of the ordination (Table 3) were correlated quite highly with soil nutrient and moisture variables.

Table 2. Plant communities identified at Ordway, species richness, species diversity, above ground net primary production and percent C_4 vegetation.

Community Number	Community Name	Richness Rank	Number of species	H 1/	Production 2/ 1977, g/m^2	Percent C_4 Biomass 3/	Percent C_4 Species
18	Midgrass south-facing slope	1	40	2.73	74.8	42	13
11	Midgrass north-facing slope	2	35	4.49	146.5	26	17
12	Invading wolfberry patch	3	34	2.52	139.0	2	12
17	Upland shortgrass community	4	32	2.10	68.4	28	9
22	Western wheatgrass community	5	31	1.64	215.4	6	10
23	Needlegrass community	6	28	1.35	183.7	12	14
20	Foxtail barley community	7	26	1.68	215.9	0	4
21	Prairie cordgrass community	8	24	1.61	268.5	49	17
19	Tallgrass lowland community	9	23	1.34	238.0	49	13
13	Central lowland depression	10	19	1.83	213.7	0	11
15	*Rumex* community	11	16	1.78	244.1	0	0
14	*Carex* ring about depression	12	16	1.27	467.6	0	0
24	*Sagittaria* shoreline community	13	8	0.97	185.1	0	0
25	*Alisma* shoreline community	14	3	0.33	180.9	0	0

1/ Shannon's index of diversity.
2/ 1977 production (g/m^2) = 1977 green + 1977 dead.
3/ Known samples of C_3 species gave an average ratio of -26.7; Known samples of C_4 gave an average ratio of -12.9. A sample below -26.7 was thus called 100% C_3 and a sample above -12.9 was called 100% C_4; intermediate values were interpolated.

Table 3. Highest correlation of ordination axes and environmental variables

Axis	Environmental Variable	r
X	Relative soil moisture content	-0.865
Y	Phosphorous (P)	-0.470
	Nitrogen (N)	-0.496
Z	Potassium (K)	-0.633

Aboveground production varied by a factor of 7 (Table 2) and was highest in communities occupying lowland sites. Production was inversely related to the presence of C_4 species. No community consisted of more than 50% of C_4 derived biomass.

The ordination suggests a strong relationship between the abundance of C_4 vegetation and soil and moisture variables. C_4 vegetation is most abundant on sites of low moisture and low nutrients status. The relationships between C_4 presence and contribution to community production are presented in Table 2. C_4 species are uncommon in low lying sites and their contribution to production here is low. The exceptions are communities of *Spartina* or *Distichlis,* communities also characterized by salt accumulation, and tallgrass lowland communities.

Seasonality of production. Aboveground biomass resulting from primary production in the upland and lowland sites was present on April 30, the first sampling date (Fig. 1). Positive changes in live biomass were measured through June 30 for the upland community and through June 16 for the lowland community with peaks of 149 (SE = $\pm$ 12) g/m^2 and 183 (SE = $\pm$ 8) g/m^2 respectively. The maximum standing crop of current production (including current dead) was also greater (student t:p = 0.05) in the lowland community [around 201 (SE = $\pm$ 9) g/m^2] than in the upland [around 157 (SE = $\pm$ 13) g/m^2]. After this early season maximum, biomass in both communities decreased continuously through the last sampling period on October 8. At this time the amount of live material present was around 10% of the seasonal maximum.

Biomass samples from each community were analyzed for δ^{13}C. In both the lowland and upland communities (Fig. 2) the early season samples possessed the lowest values (-26.6% and -25.3%, respectively). An ANOVA indicated that both communities possessed similar but defined seasonal trends in δ^{13}C and that the communities differed in magnitude. The lowland community increased slightly to -24.5% around midsummer and decreased nearly to spring values by October 8. Changes in the upland community were more dramatic, increasing to around -20.0% by June 15. After August it also became more negative and approached the spring value by October 8. Based on δ^{13}C values of known C_3 (-26.7) and C_4 (-12.9) plants from the Ordway Prairie, we calculated the contributions by each photosynthetic system to the biomass of each community (Fig. 3). For both the upland and lowland communities, the peak contribution by the C_4 photosynthetic system occurred after the peak of total green biomass. On August 16 in the upland community C_4 plants attained a maximum contribution of 50% of the total green standing vegetation. On June 30, the peak production date for the upland community, C_4 plants contributed 39.7% of the total green biomass. Similarily, in the lowland community, the peak C_4 contribution occurred July 15 with only 19.9% of the green biomass attributed to the C_4 photosynthetic system. On the lowland community's peak production date, June 16, C_4 plants contributed only 16.7% of the total green vegetation. On October 8, C_4 plants contributed only 12% of the carbon to the live compartment in the upland community and less than 8% in the lowland community.

Vegetation selectivity. The δ^{13}C values for bison and cattle fecal samples collected at monthly intervals were used to calculate the percent composition by C_3 and C_4 derived carbon. Cattle could not be maintained on the prairie during the winter months but bison were sampled February through November. Based upon preliminary data, which have not been subjected to statistical analysis, Fig. 4 shows the seasonal fluctuation in feces composition for bison and cattle grazing the study area.

The data indicate that during the fall, winter and spring (the months of September through June) the C_4 component of bison feces remained less than 10% and that the fecal material collected during July and August contained an increased proportion of C_4 material reaching a peak of 37% in July. The data for cattle feces indicated a similar seasonal trend.

Discussion

It is clear that the large enclosure studied in this project consists of a large diversity of community types which are arranged along the topographic and related environmental gradients. Cool season (C_3) species dominate these communities both in terms of floristic composition and biomass contribution. The δ^{13}C values presented in Table 2, in fact, are biased toward C_4 values, since the determinations were made at "peak" season (July and August), the time which coincides with the maximum photosynthetic and productive activity of these species.

The distribution of C_4 plants at Ordway appears to fall within 3 categories: 1) weedy successional species of disturbed soil, 2) single dominant species of lowland or alkali areas, 3) codominants of diverse but dry upland communities. Seven of the 8 C_4 dicotyledonous species are weedy (Van Bruggen 1976) or fugitive species

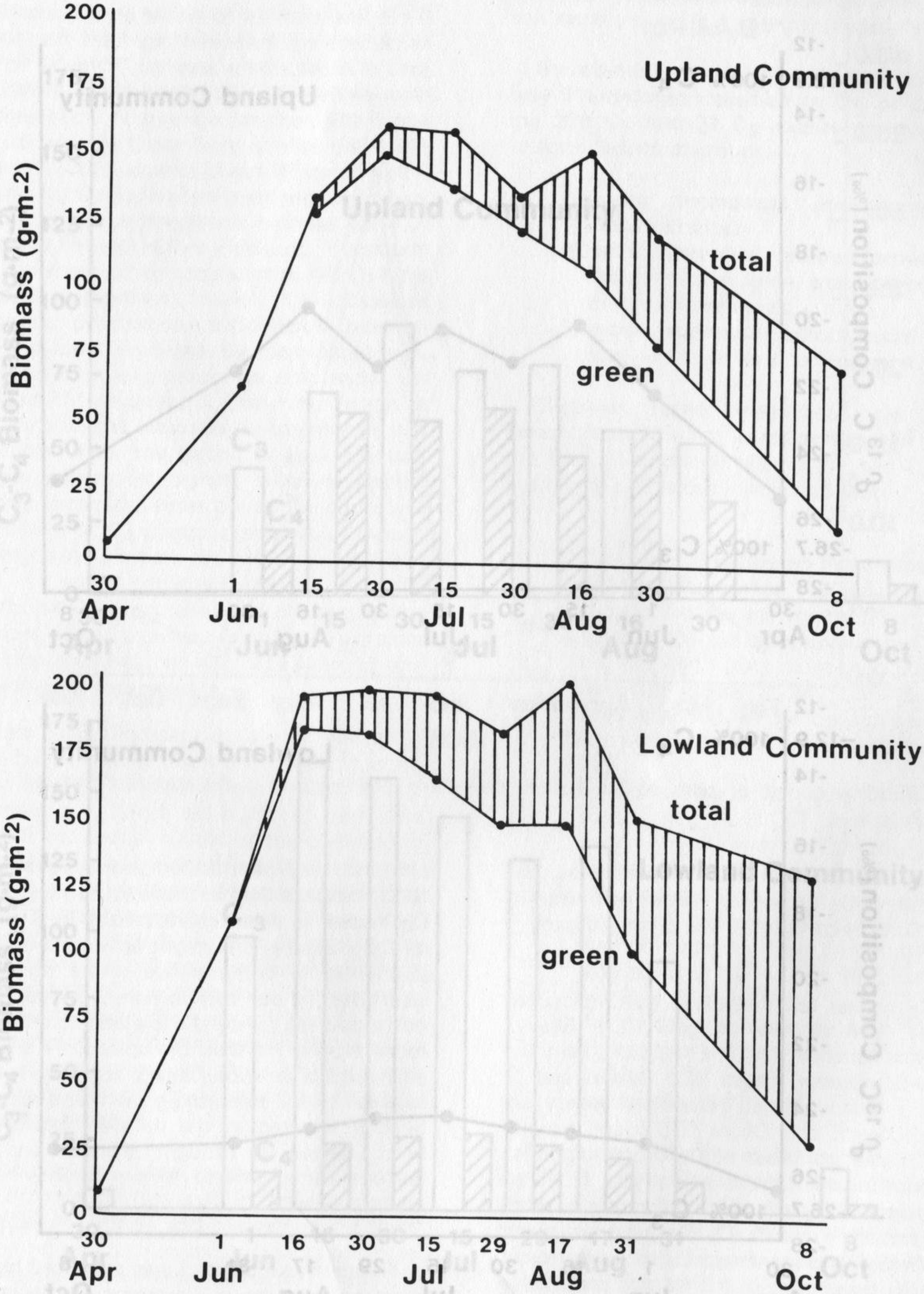


Fig. 1. Seasonal course of biomass in an upland community and in a lowland community (Ode and Tieszen 1980).

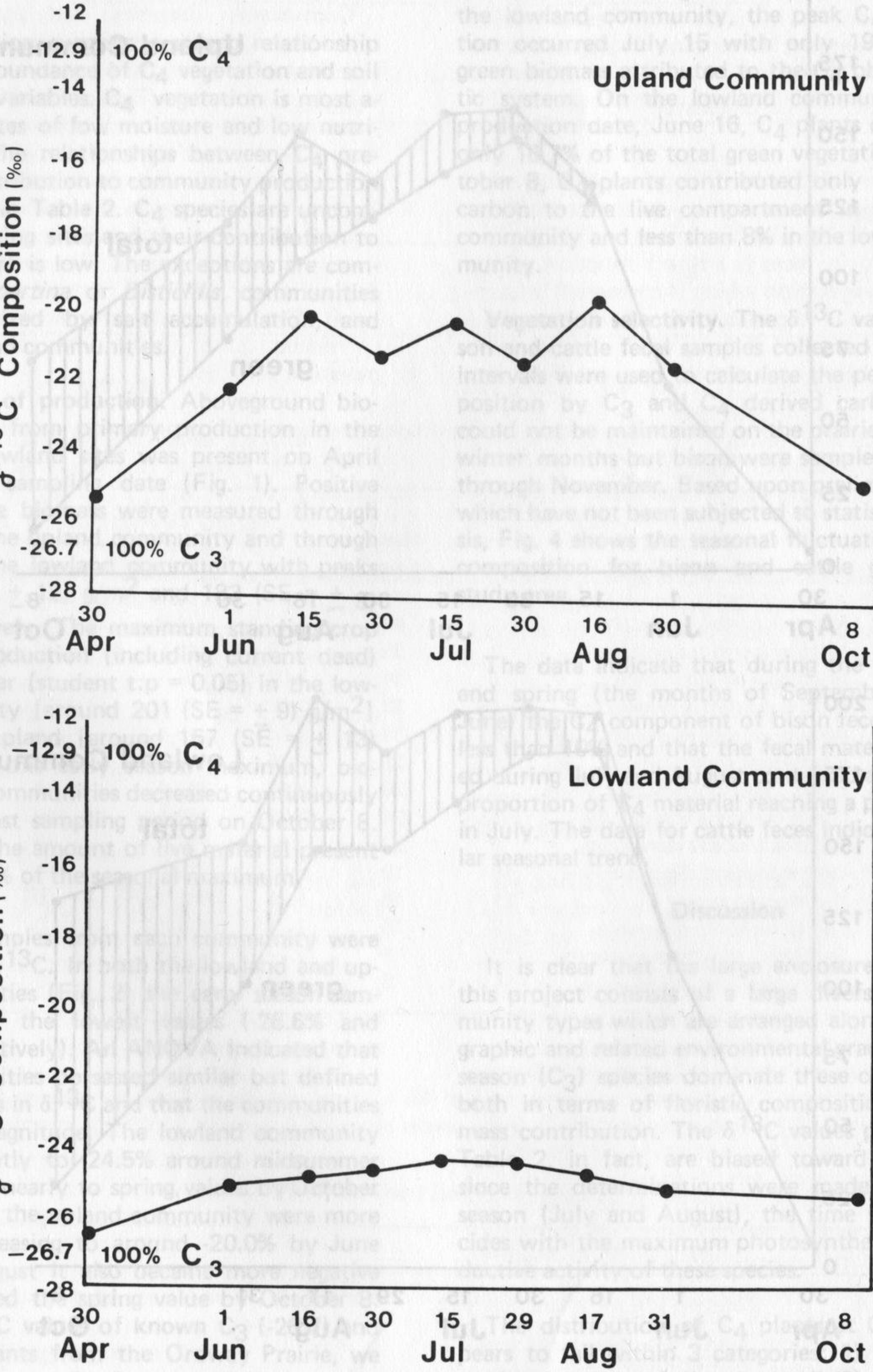


Fig. 2. Seasonal course of $\delta^{13}C$ values of green biomass in 2 communities (Ode and Tieszen 1980).

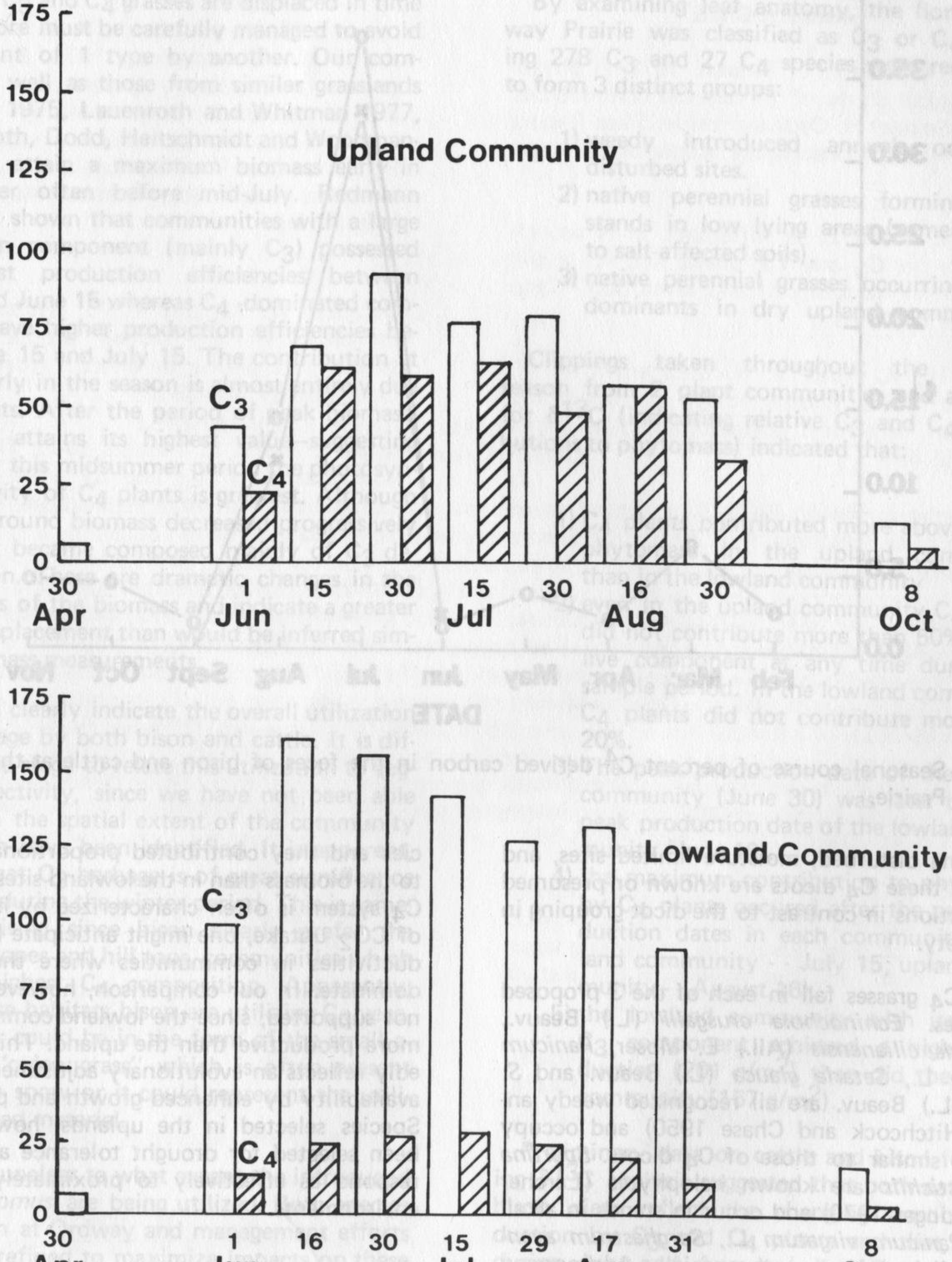


Fig. 3. Seasonal course of C^3 and C^4 biomass in an upland and a lowland community (adapted from Ode and Tieszen 1980).

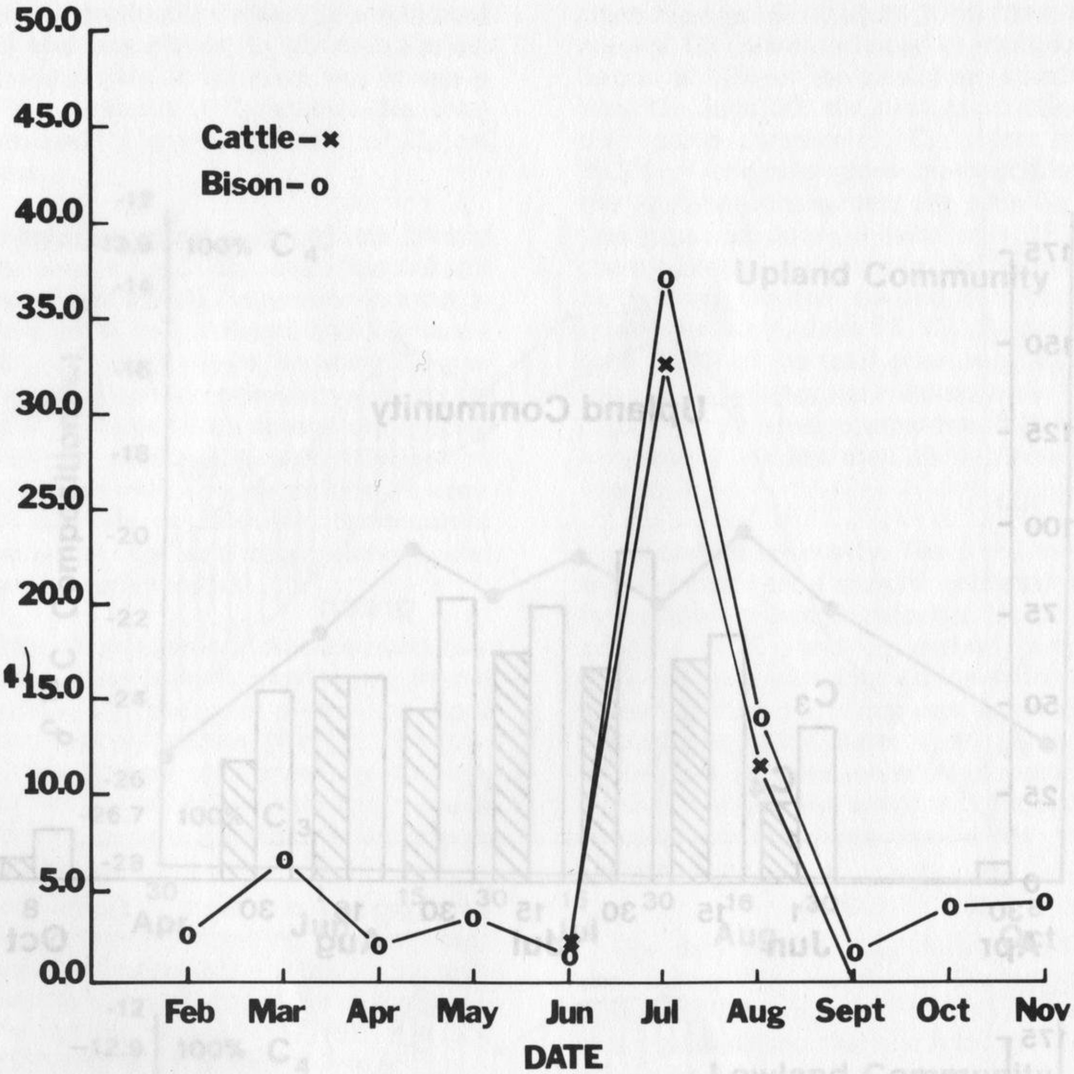


Fig. 4. Seasonal course of percent C^4 derived carbon in the feces of bison and cattle at the Ordway Prairie.

occupying disturbed, moisture limited sites, and most of these C_4 dicots are known or presumed introductions in contrast to the dicot grouping in its entirety.

The C_4 grasses fall in each of the 3 proposed categories. *Echinochola crusgalli* (L.) Beauv., *Eragrostis cilianensis* (All.) E. Moser, *Panicum capillare* L., *Setaria glauca* (L.) Beauv. and *S. viridis* (L.) Beauv. are all recognized weedy annuals (Hitchcock and Chase 1950) and occupy habitats similar to those of C_4 dicots. *Spartina* and *Distichlis* are known halophytes (Larcher 1975), Ungar 1970) and occur in stands in alkali areas. *Panicum virgatum* L., *Sorghastrum avenaceum* (Michx.) Nash, and especially *Andropogon gerardi* Vit. grow in fairly dense and productive stands in lowland swales. The remainder of the C_4 grasses occupy xeric sites in diverse upland communities.

Our upland community possessed more C_4 species and they contributed proportionately more to the biomass than in the lowland sites. Since the C_4 system is often characterized by higher rates of CO_2 uptake, one might anticipate higher productivities in communities where these species dominate. In our comparison, however, this was not supported, since the lowland community was more productive than the upland. This undoubtedly reflects an evolutionary adjustment to water availability by enhanced growth and production. Species selected in the uplands, however, have been selected for drought tolerance and did not respond as effectively to proximately favorable environments.

Another relationship was suggested by the ordination. As the soil-nutrient status improved, there was an increase in C_3 composition, an increase in production, and a decrease in diversity. This may reflect a lower requirement for nutrients by C_4 species (Brown 1978). On the basis of nutrient differences and digestibility differences. Caswell et al. (1973) even suggest that herbivores avoid C_4 species, an avoidance which should also result in C_4 plants increasing under a grazing system.

The seasonal progression of biomass and $\delta^{13}C$ values support the hypothesis that the productive periods of C_3 and C_4 grasses are displaced in time and therefore must be carefully managed to avoid displacement of 1 type by another. Our community as well as those from similar grasslands (Redmann 1975, Lauenroth and Whitman 1977, Lauethenroth, Dodd, Heitschmidt and Woodmansee 1975), attain a maximum biomass early in the summer often before mid-July. Redmann (1975) has shown that communities with a large cool season component (mainly C_3) possessed the highest production efficiencies between May 15 and June 15 whereas C_4-dominated communities have higher production efficiencies between June 15 and July 15. The contribution at Ordway early in the season is almost entirely due to C_3 plants. After the period of peak biomass, C_4 carbon attains its highest value—suggesting that during this midsummer period the photosynthetic activity of C_4 plants is greatest. Although live aboveground biomass decreased progressively into fall, it became composed mainly of C_3 derived carbon. These are dramatic changes in the $\delta^{13}C$ values of the biomass and indicate a greater seasonal displacement than would be inferred simply by biomass measurements.

The data clearly indicate the overall utilization of C_3 herbage by both bison and cattle. It is difficult at this stage to relate this utilization to vegetation selectivity, since we have not been able to establish the spatial extent of the community types which have been identified. It is apparent, however, that C_3 herbage is of great significance at Ordway during the winter period. This is somewhat surprising since bison clearly prefer the snow-free slopes and hill tops, communities which have the highest C_4 composition. Apparently, even in these habitats bison are utilizing C_3 vegetation. This could be in the form of the small amount of "green grass" which is often present beneath the snow or it could represent the utilization of dead material.

It is also unclear to what extent the introduced *Poa* and *Bromus* are being utilized. Both species are common at Ordway and management efforts need to be refined to maximize impacts on these species and minimize effects on native C_3 and C_4 species.

Summary

An ordination of 48 selected stands representing 14 subjectively defined plant communities revealed 7 clusters at the 40% similarity level. The distribution of these 48 stands was highly correlated with relative soil moisture and several soil nutrients (N,P,K). Stands with a relatively high C_4 compenent occurred on sites with low soil moisture and low nutrient status.

By examining leaf anatomy, the flora of Orway Prairie was classified as C_3 or C_4 revealing 278 C_3 and 27 C_4 species were recognized to form 3 distinct groups:

1) weedy introduced annuals occupying disturbed sites.
2) native perennial grasses forming dense stands in low lying areas (some specific to salt-affected soils).
3) native perennial grasses occurring as codominants in dry upland communities.

Clippings taken throughout the growing season from 2 plant communities and analyzed for $\delta^{13}C$ (indicating relative C_3 and C_4 contributions to phytomass) indicated that:

1) C_4 plants contributed more aboveground phytomass in the upland community than in the lowland community
2) even in the upland community C_4 plants did not contribute more than 50% of the live component at any time during the sample period. In the lowland community C_4 plants did not contribute more than 20%.
3) The peak production date of the upland community (June 30) was later than the peak production date of the lowland community (June 16).
4) the maximum contribution to phytomass by C_4 plants occured after the peak production dates in each community (lowland community - - July 15; upland community - - August 16).
5) the lowland community with its higher C_3 component achieved a higher production (201 g/m^2) than did the upland community (157 g/m^2).

Preliminary data on cattle and bison feces using $\delta^{13}C$ analysis suggested that both cattle and bison diets reflect the changing seasonal production by C_3 and C_4 plants and that, except during July and August (when C_4 production is maximal), bison diets within the study pasture consisted predominantely (〉90%) of C_3 plants.

Acknowledgements

This project was supported by the Nature Conservancy, the Augustana Research and Art-ist Fund, the NSF (DEB78-19552), and a William and Flora Hewlett Foundation Grant of Research Corp. We thank the Nature Conservancy for assistance throughout the project, Juan Lerman for isotopic analysis, and Julie Posz and Jean Stevermer for typing.

Literature Cited

Barnes, P. W. and L. L. Tieszen. 1978. A phytosociological study of 14 selected communities at the Samuel H. Ordway Prairie. Data Report to the Nature Conservancy, Augustana College. 42 pp.

Brown, R. H. 1978. A difference in N use efficiency in C_3 and C_4 plants and its implications in adaptation and evolution. Crop Science 18:93-98.

Caswell, H., R. Reed, S. N. Stephensen, P. A. Wermer; 1973. Photosynthetic pathways and selective herbivory: a hypothesis. Am. Nat. 107:465-481.

Clark, Susan J. Vetter. 1977. The Vegetation of Rocky Flats, Colorado. M.S. Thesis, University of Colorado, Boulder.

Christensen, C. M. 1977. Geology and water resources of McPherson, Edmunds, and Faulk Counties, South Dakota Part 1: Geology. Bull. No. 26 South Dakota Geological Survey, Vermillion, South Dakota:

Dix, R. L. and F. E. Smeins. 1967. The prairie, meadow and marsh vegetation of Nelson County North Dakota. Can. J. Bot. 45:21-58.

Hattersley, P. W. and L. Watson. 1975. Anatomical parameters for predicting photosynthetic pathways of grass leaves: the 'maximum lateral cell count' and the 'maximum cell distant count'. Phytomorphology 25:325-333.

Hertz, B. L. 1976. The vascular flora at Ordway Prairie, McPherson County, South Dakota. M.S. Thesis, South Dakota State University, Brookings.

Hitchcock, A. A. and A. Chase. 1950. Manual of the Grasses of the United States. Misc. Publ. 200, U. S. Government Printing Office, Washington, D.C.

Kuchler, A. W. 1964. Potential natural vegetation of the conterminous, United States. Special Publ. No. 36. Am. Geog. Soc., New York.

Larcher, W. 1975. Physiological Plant Ecology. Springer-Verlag, New York.

Lauenroth, W. K., J. L. Dodd, R. K. Heirschmidt, and R. G. Woodmansee. 1975. Biomass Dynamics and primary production in mixed prairie grasslands in southeastern Montana: Baseline data for air pollution studies. Proc. Ft. Union Coal Field Symposium, pp. 559-578, Montana Acad. Sci., Eastern Montana College, Billings.

Lauenroth, W. K., and W. C. Whitman. 1977. Dynamics of dry matter production in a mixed-grass prairie in western North Dakota. Oecologia 27:339-351.

Ode, D. J. and L. L. Tieszen. 1980. The seasonal contribution of C_3 and C_4 plant species to primary production in a mixed prairie. Ecology (in press).

Redmann, R. E. 1975. Production ecology of grassland plant communities in western North Dakota. Ecol. Monogr. 45:83-106.

Tieszen, L. L., D. Hein, S. A. Qvortrup, J. H. Troughton and S. K. Imbamba. 1979. Use of $\delta^{13}C$ values to determine vegetation selectivity in East African herbivores. Oecologia 37: 351-359.

Ungar, I. A. 1970. Species-soil relationships on sulfate dominated soils of South Dakota. Am. Mid. Nat. 83:343-357.

Van Bruggen, T. 1976. The Vascular Plants of South Dakota. The Iowa State University Press, Ames.

Weaver, J. E. 1968. Prairie Plants and Their Environment. University of Nebraska Press, Lincoln.

Weaver, J. E. and F. W. Albertson. 1956. Grasslands of the Great Plains. Johnson Publishing Co., Lincoln, Nebraska.

SESSION IV. Landscaping and Restoration with Prairie Plants.
Paul Nelson, Presiding

The large-scale changes in the prairie landscape provide a rationale for developing programs of rehabilitation, and the application of self-sustaining populations of native plants and animals in land use. Kramer's lead paper addresses these quesions, making effective use of prairie grasses in the stabilization process on an industrial site. Otto discussed use of native plants in home lawns, and with this increase in diversity a concomitant increase in animal species also occurs. Three papers, by Anderson and Birkenholz, Drake, and Kuenstler, Henry and Sanders, deal with prairie grasses used in strip-mine reclamation, which attest to varying degrees of success. Establishment of bryophyte populations in mine spoils is discussed by Rastorfer, as early colonizers in the restoration process. Prairie restoration on public lands including military reservations is evaluated by Dale and Smith, Reed, and Evans. The paper by Boyd also is timely, dealing with restoration effects by students in a college environment. Woehler and Martin document annual changes in soil fungi populations in restored prairie. In these presentations, the benefits of aesthetic enhancement, soil protection, and improving diversity offer compelling recommendations for using native species in land reclamation programs.

ist Fund, the NSF (DEB78-19552), and a William and Flora Hewlett Foundation Grant of Research Corp. We thank the Nature Conservancy for assistance throughout the project, Juan Lerman for isotopic analysis, and Julie Posz and Jean Stevermer for typing.

Literature Cited

Barnes, P. W. and L. L. Tieszen. 1978. A phytosociological study of 14 selected communities at the Samuel H. Ordway Prairie. Data Report to the Nature Conservancy, Augustana College. 42 pp.

Brown, R. H. 1978. A difference in N use efficiency in C_3 and C_4 plants and its implications in adaptation and evolution. Crop Science 18:93-98.

Caswell, H., R. Reed, S. N. Stephenson, P. A. Werner. 1973. Photosynthetic pathways and selective herbivory: [illegible] 107:461-481.

[illegible]

[illegible] County North Dakota. Can. J. Bot. 45:21-58.

Hattersley, P. W. and L. Watson. 1975. Anatomical parameters for predicting photosynthetic pathways of grass leaves: the 'maximum lateral cell count' and the 'maximum cell distant count'. Phytomorphology 25:325-333.

Hertz, B. L. 1976. The vascular flora at Ordway Prairie, McPherson County, South Dakota. M.S. Thesis, South Dakota State University, Brookings.

Hitchcock, A. A. and A. Chase. 1950. Manual of the Grasses of the United States. Misc. Publ. 200, U. S. Government Printing Office, Washington, D.C.

Kuchler, A. W. 1964. Potential natural vegetation of the conterminous United States. Special Publ. No. 36. Am. Geog. Soc., New York.

Larcher, W. 1975. Physiological Plant Ecology. Springer-Verlag, New York.

Lauenroth, W. K., J. L. Dodd, R. K. Heitschmidt, and R. G. Woodmansee. 1975. Biomass Dynamics and primary production in mixed prairie grasslands in southeastern Montana: Baseline data for air pollution studies. Proc. Ft. Union Coal Field Symposium, pp. 559-578, Montana Acad. Sci., Eastern Montana College, Billings.

Lauenroth, W. K., and W. C. Whitman. 1977. Dynamics of dry matter production in a mixed-grass prairie in western North Dakota. Oecologia 27:339-351.

Ode, D. J. and L. L. Tieszen. 1980. The seasonal contribution of C_3 and C_4 plant species to [illegible]

[illegible]

[illegible] 351-359.

Ungar, I. A. 1970. Species-soil relationships on sulfate dominated soils of South Dakota. Am. Mid. Nat. 83:343-357.

Van Bruggen, T. 1976. The Vascular Plants of South Dakota. The Iowa State University Press, Ames.

Weaver, J. E. 1968. Prairie Plants and Their Environment. University of Nebraska Press, Lincoln.

Weaver, J. E. and F. W. Albertson. 1956. Grasslands of the Great Plains. Johnson Publishing Co., Lincoln, Nebraska.

PRAIRIE STUDIES AT CATERPILLAR TRACTOR CO. PEORIA PROVING GROUND

G. L. Kramer
100 N. E. Adams St.
Peoria, Illinois 61629

Abstract. This slide presentation will discuss Caterpillar Tractor Company's use of native plants for both landscaping and erosion control. Prairie remnants found on Company property will also be included in the presentation.

Introduction

Caterpillar Proving Ground is a 2550-acre facility located several miles north of East Peoria, Illinois. This site is used to test and evaluate earth moving equipment before, during and even after machines have been put into production. Many tests simulate and supplement construction applications. However, the majority of tests involve moving vast amounts of earth. This type disturbance creates many severe erosion problems. These problems were left unchecked until the late 1960's when a conservation program was started. A very important part of this program is the recycling of test areas. This accomplishes 2 things. First, better test data are obtained because soil parameters are closely controlled; this provides more consistent and uniform tests. Second, the amount of land designated for test fields, slopes, and roads was reduced to approximately 300 acres in the center of the Proving Ground allowing the remaining "Buffer Zone" to be made as ecologically sound as possible.

Prairie Restoration and Maintenance

Once bare areas are now green. Gullies or washes were filled, slopes seeded, and culverts installed to carry runoff water to the bottom of ravines. Ditches were check-dammed and the side slopes sodded.

All of the initial seeding was with smooth brome, perennial rye, tall fescue, and sometimes crown vetch. Later, as an interest in prairie developed in the area, most of the seeding was converted to a seed mixture of prairie grasses. Partially responsible for this interest is a 20-acre remnant located on the property. Thirty-eight native plants have been identified, and the list is incomplete. Many visitors, students, science clubs, academy of science have toured this prairie — some collecting seeds for other projects in the Peoria area.

The first attempt at establishing a prairie at the Proving Ground was on a 5-acre fill that once was a badly eroded gulley. Because of limited knowledge and experience only grass seed was sown. This was a 6-species mixture consisting of big bluestem, little bluestem, Indian grass, switch grass, side-oats gramma, and wheat grass. This mixture was applied with a hydro-seeder and, because of the bare sub soil condition, fertilizer at the rate of 400 lbs/acre was applied. In the first 2 or 3 years, switch grass was the only grass visible (without very close inspection) but after 5 years all 6 species could be found, and in more abundance each succeeding year.

The same 6-species mixture was used on several more areas with similar results. The slopes around the main retention lake were seeded and caused concern because nothing seemed to appear the first year! Worry was premature because soon prairie was coming on strong, this time with side-oats taking the lead with more and more little bluestem subsequently appearing.

As indicated earlier, most prairie planting at the Proving Ground is for erosion control but after observing some prairie landscape at other company facilities, 10 acres along the Proving Ground entrance road, previously mowed, were sown. This time a mixture of forbs was added to the grass seed. Black-eyed susan and Indian grass were the predominant species in this area in the first 3 years.

The first burn at the Proving Ground was conducted in spring of 1979. The older prairie burned vigorously while the more recently developed areas had lighter, more sparse fire. In a few days, however, all looked plush!

It will be a continuing practice to use prairie planting in erosion work, and to increase the prairie landscape for aesthetic beauty and reduction of maintenance costs.

Finally, it should be mentioned that because of the conservation program, 2 impressive things are occurring: much more wildlife is being attracted to the area, and prairie is reestablishing itself in small patches, often in unlikely places.

THROUGH OUR WINDOWS
AN ALTERNATIVE TO LAWNS

Lorrie Otto
Riveredge Nature Center
9701 North Lake Drive
Milwaukee, Wisconsin 53217

Abstract. Lawns appear to be our sacred cows, unscathed by fashion or environmental concerns. Nature centers in the Milwaukee area encourage natural landscaping with year round activities and opportunities, including examples of restored prairies. Home yards have only fragments of prairies but those can 'pack a wallop'. Perhaps this intimate and constant association with such diverse beauty might be the strongest influence in weaning the public from the devastation and monotony of lawns.

At the 1970 Prairie Conference there were 2 young women participants. Both wore finger-tip length dresses with hair flowing to their mid-backs. By 1972, the women at the conference in Kansas were in clunky, square-toed boots whose tops were covered with long skirts. Now, just a few years later in Missouri, the knee is hidden but the feet are exposed on the highest of heels with a minimum of strapping to hold a sole in place. During this decade, women's fashions have taken illogical swings which have been dictated by a few fashion designers living far from prairie states. Meanwhile, the fashion of lawns has remained with us. Even the Japanese have been unable to intervene here! Our neat, plastic, poisoned land-scapes defy reason and environmental concern.

Earth Day movies continue to depict environ-mental horrors such as toxic waste dumps, strip-mining, clearcutting, agricultural monocultures, pesticide and herbicide planes managing both forests and crop lands while diminishing the di-versity of life and dispersing toxic chemicals over the earth. Yet, nowhere do we see exposes of the one great monoculture which we could really do something about. Lawns appear to be our sacred cows.

Experts warn that our next crisis will be one of water which will make the energy crisis pale by comparison; yet we are doing little to assure that water returns properly to clean aquifers. Part of the problem would be alleviated if houses were surrounded by prairie plants with their network of roots and animal life extending many feet down into the compacted soil. If we could cur-tail run-off, not only would we stop converting our streams into storm sewers, but also water would be without chemical pollutants. Lawns contribute to the large amount of pesticides which are found in urban streams. This contam-ination is often 2 - 4 times greater than that dis-covered in rural streams.

Noise is the environmental pollutant the public is most intolerant of, yet we suffer the noise of power mowers in even the wealthiest of communities. The 50 million powered mowers in our country not only directly destroy habitat for birds and butterflies, but they also anni-hilate life in other places where metals, minerals and fossil fuels are mined for their manufacture. Fuel is used to transport and operate them. The land they mow is treated with petroleum-based products. These fertilizers, pesticides and herbi-cides have in turn consumed enormous quanti-ties of heat energy in their processing. And all of these activities pollute the air we breathe. We not only strip the soil our own nests, but we destroy the options and supporting habitats of plants and animals on which human life depends.

Wouldn't it be marvelous if environmentalists had the power that fashion designers have! Landscapers, the few who do have environmental educations, have had small success, and conser-vation organizations are still too small and too late for many of our problems. We are working so hard but we are scarcely making ripples. Dur-ing the last 10 years, the nature centers in the Milwaukee area have been trying to break the lawn habit. Among the alternatives we have suggested is prairie restoration. The problems of acceptance have been the tyranny of the tidy minds. For example, in Madison, Wisconsin there is an ordinance which allows neighbors to pass judgment on a yard even before it is planted! The Schlitz-Audubon Nature Center has a 'Wild Ones' natural landscaping club. All of the nature centers have demonstration prairie restorations, the oldest being at the Wehr Nature Center. These instructions are often joined by the University of Wisconsin Extension in promoting natural landscaping classes. This is an annual event at the Riveredge Nature Center. Plant sales are offered by David Kopitzke of the Little Valley Farm nursery. Lectures are also provided. Both Audubon and Riveredge sponsor public tours in wealthy suburbia where some of the *front* lawns have become natural, tousled and often colorful. So far, no one has done a proper prairie restoration. They have either taken the easy way of using some prairie species in their unmowed lawn grasses or they have planted small, contrived islands like pieces of a church altar in a museum. In between the model islands are expanses of mowed grass whose purpose is to tie the yard visually to the neighbor's lawn. It would seem that the emphasis is still on how it looks to passing traffic or to the neighbors. Perhaps it is time to examine how that vegetation appears to the family in residence — to a family whose house is only a shelter in the center of a quiet, undisturbed environment.

A natural yard can be tidied during the dormant season. Woodland vegetation can be thinned and trimmed, paths widened, and, if a meadowed-lawn, it can be mowed in the late winter, or occasionally burned if it is a restored prairie. That sounds like a lazy man's dream but it can only come after considerable intelligent and patient preparation. It is never the reason that I, one of the leading proponents of this critical environmental choice, would ever suggest for abolishing a lawn. True, after the plantings are established, the tending of a naturally growing yard need only be done when the mood strikes one and then the kind of care it requires can hardly be called 'work'. Such manipulation is part of the relaxed joy accompanying this kind of landscaping. At the other end is the pleasure conservationists experience in preserving gene pools. For some others, it is a collection of living antiques, highlighted by historical accuracy and record, as well as the unusual patterns being made available for assimilation into suburbia.

One of the unexpected bonuses of my yard is looking out of the window and seeing photographers and artists coming to enjoy it. Nancy Burket was sketching there this spring. She was working on illustrations for the Emily Dickinson book, *Acts of Light.*

From my dining room window, I can see both kinds of purple cone flowers growing side by side. They are growing in clay so solid that it could be thrown on a potter's wheel. Six years after seeding, 1 of the 3 plants of *Echinacea pallida* flowered. This year, there are 2 long blooming stems which stretch around in the air like a charmer's snake, as they position their buds for the best exposure to the sun. One plant is resting — not blooming this year — while the third one has 4 flowering stalks with at least 2 buds on each stem. In the meantime, the deeper purple *Echinacea purpurea* all bloomed the second year after seeding. One has as many as 9 flowering stalks this summer. They all stand shorter than the pale purple cone flower and will begin to blossom 3 weeks later. Unlike the pallidas, they will hold their ray color until frost. They also make a much more impressive statement in the snow.

After 9 years of waiting, the compass plant, *Silphium laciniatum,* and the white baptisia, *Baptisia leucantha,* finally burst into bloom. What a glorious surprise in early July! Until my yard was growing naturally, I did not realize how many butterflies were still surviving in our section of the state. By watching through my window each day, I have been able to make a list. Also I did not know that there were wasps which sustained themselves on nectar as they hunted insects for their carnivorous young. They are partial to the swamp milkweed, *Asclepias incarnata* growing in the storm-water swale. There is a moth whose wings make so much noise that it alerts me to its presence each year when the wild bergamont, *Monarda fistulosa,* blooms. One rarely sees a day-flying moth. This one looks like an elongated bumble bee with a little fan for a tail. I expected bees as pollinators but was surprised to see so many different kinds. Also there are hover flies which often work 2 at a time on black-eyed Susans. There are flowers with long, thin rays; others are greenish-yellow as they open. Some have high peaked centers. Last year, 1 Susan plant bore flowers which had petals at the base of each ray. The cup plant, *Silphium perfoliatum,* is a dramatic green sculpture against my kitchen window. It also allows a close-up view of honey bees clustered on a single flower or of insects and birds drinking from the cup encircling the large, square stem. At the end of the season, goldfinches, juncos and chick-adees remove the seeds from the spent and dried stalks.

Some of us eagerly await the time when having a natural yard will be a cachet and the current repetitious suburban schmaltz will be phased out. As we encourage people to find alternatives to lawns, the emphasis should be on the aesthetic reward we receive when we live immersed in the kind of beauty which comes to us through our windows and enriches and fulfills our everyday lives. This could be the driving force which would eradicate those deadly-dull mowed lawns.

judgments [illegible]
The Schlitz-Audubon Nature Center has a 'Wild Ones' natural landscaping club. All of the nature centers have demonstration prairie restorations, the oldest being at the Wehr Nature Center. These instructions are often joined by the University of Wisconsin Extension in promoting natural landscaping classes. This is an annual event at the Riveredge Nature Center. Plant sales are offered by David Kopitzke of the Little Valley Farm nursery. Lectures are also provided. Both Audubon and Riveredge sponsor public tours in wealthy suburbia where some of the front lawns have become natural, tousled and often colorful. So far, no one has done a proper prairie restoration. They have either taken the easy way of using some prairie species in their unmowed lawn grasses or they have planted small, contrived islands like pieces of a church altar in a museum. In between the model islands are expanses of mowed grass whose purpose is to tie the yard visually to the neighbor's lawn. It would seem that the emphasis is still on how it looks to passing traffic or to the neighbors. Perhaps it is time to examine how that vegetation appears to the family in residence — to a family whose house is only a shelter in the center of a quiet, uncluttered environment.

A natural yard can be tidied during the dormant season. Woodland vegetation can be thinned and trimmed, paths widened, and, if a meadowed-lawn, it can be mowed in the late winter, or occasionally burned if it is a restored prairie. That sounds like a lazy man's dream but it can only come after considerable, intelligent and patient preparation. It is never the reason that I, one of the leading proponents of this critical environmental choice, would ever suggest for abolishing a lawn. True, after the plantings are established, the tending of a naturally growing yard need only be done when the mood strikes one and then the kind of care it requires can hardly be called 'work'. Such manipulation is part of the relaxed joy accompanying this kind of landscaping. At the other end is the pleasure conservationists experience in preserving gene pools. For some others, it is a collection of living antiques, highlighted by historical accuracy and record, as well as the unusual patterns being made available for assimilation into suburbia.

One of the unexpected bonuses of my yard is looking out of the window and seeing photographers and artists coming to enjoy it. Nancy Burkat was sketching there this spring. She was working on illustrations for the Emily Dickinson book, *Acts of Light*.

[illegible] could be thrown on a potter's wheel. Six years after seeding, 1 of the 3 plants of *Echinacea pallida* flowered. This year, there are 2 long blooming stems which stretch around in the air like a charmer's snake, as they position their buds for the best exposure to the sun. One plant is resting — not blooming this year — while the third one has 4 flowering stalks with at least 2 buds on each stem. In the meantime, the deeper purple *Echinacea purpurea* all bloomed the second year after seeding. One has as many as 9 flowering stalks this summer. They all stand shorter than the pale purple cone flower and will begin to blossom 3 weeks later. Unlike the pallidas, they will hold their ray color until frost. They also make a much more impressive statement in the snow.

After 9 years of waiting, the compass plant, *Silphium laciniatum*, and the white baptisia, *Baptisia leucantha*, finally burst into bloom. What a glorious surprise in early July! Until my yard was growing naturally, I did not realize how many butterflies were still surviving in our section of the state. By watching through my window each day, I have been able to make a list. Also I did not know that there were wasps which sustained themselves on nectar as they hunted insects for their carnivorous young. They are partial to the swamp milkweed, *Asclepias incarnata* growing in the storm-water swale. There is a moth whose wings make so much noise that it alerts me to its presence each year when the wild bergamont, *Monarda fistulosa*, blooms. One rarely sees a day-flying moth. This one looks like an elongated bumble bee with a little fan for a tail. I expected bees as pollinators but was surprised to see so many different kinds. Also there are hover flies which often work 2 at a time on black-eyed Susans. There are flowers with long, thin rays; others are greenish-yellow as they open. Some have high peaked centers. Last year, 1 Susan plant bore flowers which had petals at the base of each ray. The cup plant, *Silphium perfoliatum*, is a dramatic green sculpture against my kitchen window. It also allows a close-up view of honey bees clustered on a single flower or of insects and birds drinking from the cup encircling the large, square stem. At the end of the season, goldfinches, juncos and chick-a-dees remove the seeds from the spent and dried stalks.

Some of us eagerly await the time when having a natural yard will be a cachet and the current repetitious suburban schmaltz will be phased out. As we encourage people to find alternatives

GROWTH AND ESTABLISHMENT OF PRAIRIE GRASSES AND DOMESTIC FORAGE ON STRIP-MINE SOILS

Roger C. Anderson
and
Dale E. Birkenholz
Department of Biological Sciences
Illinois State University
Normal, Illinois 61761

Abstract. Growth and establishment of big bluestem and Indian grass was compared with that of orchard grass and alfalfa on strip-mine soils in Fulton County, Illinois. The study site was graded to a 3% slope and 1 ha (2.4 acres) was seeded at a rate of 72.3 kg/ha (64.5 lbs/acre) with prairie grasses during May, 1978. The conditions encountered in this study were not conducive to the establishment of prairie grasses. At the end of the summer an average of 17.0 seedlings/m^2 was recroded; however, only 1.0 prairie grass seedlings/m^2 remained the following spring. Initial establishment of both orchard grass and alfalfa was satisfactory but no orchard grass seedlings survived beyond late summer, 1978. Alfalfa, in contrast yielded 4830 kg/ha (4,314 lbs/acre) of forage during the second growing season. Treated sewage supernatant was applied through grated pipe to the prairie plantings during the second growing season, but reached only 10 to 15 m below the pipe. This area produced 18820 kg/ha (16,779 lbs/acre) by September 10, but most of the biomass was annual forbs, 16720 kg/ha (14,090 lbs/acre). Middle and lower slopes received no supernatant and produced 2630 kg/ha (2,349 lbs/acre).

Introduction

Several workers, including Greene and Curtis (1953), Anderson and Cottam (1970), Schulenberg (1970), Schwarzmeier (1972), Zimmerman and Schwarzmeier (1978), and others have reported on native prairie restoration in the Midwest. Despite the general concensus among prairie biologists that prairie grasses might be ideally suited for revegetating strip-mine spoils, few studies, including one by Schramm and Kalvin (1978), have provided documentation of the success of prairie plantings on such sites. The purpose of this study was to compare the establishment and growth of native prairie with domestic forage species, orchard grass *(Dactylis glomerata)* and alfalfa *(Medicago sativa)* on strip-mine soils.

The 2.6 ha (6.5 acre) study site is located 6 miles west of Canton, Fulton County, Illinois, on property owned by the Metropolitan Sanitary District (MSD) of Greater Chicago. The site contains recontoured strip-mile soil composed of unconsolidated material mixed with small rocks. A mixture of brome grass *(Bromus inermis)* and alfalfa was established on the recontoured strip-mine soils 15 to 20 years ago. However, no detectable soil profile development had occurred on the site. As part of erosion control work, the area was graded to a 3% slope facing north in the fall of 1977.

Following grading, annual rye *(Secale cereale)* was planted to provide winter cover. The rye was disked in the spring of 1978 and 1 ha (2.4 acres) was seeded to native prairie grass and about 1 acre to an orchard grass-alfalfa mix. The domestic forage site was seeded to alfalfa and orchard grass on May 26, 1978, at a rate of 22.4 and 8.3 kg/ha (20 and 8 lbs/acre), respectively. The prairie grass seed was purchased from Dr. Peter Schramm at Knox College, Galesburg, Illinois. Eighty-four percent of the seed was collected in the fall of 1976 and the remainder in 1977. The seed was moist-stratified at 30-35°F, air-dried, and sown May 24, 1978 at the rate of 72.3 kg/ha (64.5 lbs/acre). The seed consisted of about 60% Indian grass *(Sorghastrum nutans)* and 40% big bluestem *(Andropogon gerardi)*. It was hand-broadcasted, lightly harrowed, with a cover crop of oats drilled over the seeding at the rate of 34.2 kg/ha (30 lbs/acre).

A top dressing of fertilizer granules at rates of 112 kg/ha (100 lbs/acre) of P_2O_5 and 224 kg/ha 9200 lbs/acre) of K_2O was applied to the prairie plants and domestic forage in July of 1978. Because of the sparse cover on the prairie site during the fall of 1978, a cover crop of annual rye 22.4 kg/ha (20 lbs/acre) was seeded. However, Canada geese consumed most of the crop as it grew and an additional cover crop of oats was planted in the spring of 1979. The Metropolitan Sanitary District transports treated sewage sludge containing about 5% stabilized solids by barge down the Illinois River to Liverpool, Illinois. The sludge is then pumped 17 km (10.7 mi) to surge ponds on the strip-mine site. About 80% of the solids settle and the supernatant contains less than 1% dissolved solids. The treated sludge and supernatant are used by the District to fertilize crop fields. Gated pipe was installed at the top of the study site slope in May, 1979 and MDS supernatant applied to the prairie grass plantings on the upper portion of the slope during the growing season of 1979.

Methods

To determine germination of prairie grass seed, tests were conducted in Petri dishes and in greenhouse flats. Twenty-five randomly-selected seeds were placed in each of 11 Petri dishes lined with 2 layers of filter paper. Seeds were maintained at room temperature and germination counts made daily for 30 days. In the greenhouse 119 Indian grass and 83 big bluestem seeds were placed on the surface of 2.5 cm of potting soil in a flat and covered with 0.6 to 1.2 cm of soil. Observations were continued for 48 days.

Growth of the field plantings was monitored by counting individual plants in 1-m^2 quadrats, estimating cover using a point sampling procedure, and making clip quadrats to estimate aboveground biomass. To determine plant density, quadrats were located at the intersections of grid lines located about 15 m apart. Plant cover was estimated at 8 m intervals along established contour lines. The point sampling procedure was used only on the prairie grass site.

Biomass samples were taken only on the forage site in 1978, on September 7. In 1979 samples were taken 3 times. Two samples were made prior to cutting of the site for hay and a third was made on September 10 near the end of the growing season. Biomass on the prairie site was collected only once, September 10, 1979, and separated into 2 subsamples: 1) quadrats harvested near the top of the slope where the vegetation received supernatant, and 2) quadrats harvested on the middle and lower slope positions where supernatant was not applied. All biomass samples were oven-dried at 70°C for 48 hours and weighed. The soil was sampled for nutrient content on April 10, 1978 before the site was planted, August 7, 1978 after application of commercial fertilizer, and on August 10, 1979 after application of supernatant (prairie site only).

Soil samples were analyzed by the Wisconsin State Soil Testing Laboratory at Madison, for pH, available P, K, Ca, Mg, and ammoniacal and nitrate nitrogen.

Results and Discussion

Twenty percent of the seeds sown in Petri dishes germinated, mostly within 20 days. Similar results for the length of time required for germination were reported by Nuzzo (1978). In the greenhouse study 24.7% of the randomly selected seeds germinated; germination for Indian grass was 37.8% and for big bluestem 6.0%. Comparing only germinated seeds, 9.7% were big bluestem and 90.3% Indian grass. These values compared favorably with the percentage of big bluestem (11.6%) and Indian grass (88.4%) seedlings established by the end of the first growing season in the field (Table 1). Our germination study results are similar to those reported by other workers (Robocker et al. 1953, Halinar 1978).

Changes in the density of the grasses are given in Table 1. Near the end of the first growing season (1978), the mean density of prairie grass seedlings was 17.0/m^2. However, many plants were shallowly rooted and probably were lost due to soil erosion during the winter. The average density measured in May 1979 was 1.0 plant/m^2. By August 1979 the number of grasses had increased to 4.2/m^2. Because individual clumps of grass stems were counted as single plants, some of the numerical increase between May and August may have been due to tillering rather than establishment of new plants by late germination. Schramm and Kalven (1976) reported that a seeding rate of 22.2 kg/ha on a strip-mine site yielded seedling densities ranging from 9/m^2 on dry sites to 24/m^2 in seepage areas. However, supplemental water was provided during summer drought. Establishment of orchard grass plants was initially very good with 31.3/m^2 recorded on July 5, 1978. However, densities declined during the summer and by September 7, 1979 no plants remained (Table 1). Seasonal densities of all species on the prairie and domestic forage sites during July of the first study year are shown in Table 2. Densities of alfalfa (58.6/m^2) and orchard grass (31.3/m^2) were higher than those of prairie grasses at this time. The density of weedy species was sparse; competition was never a serious problem during the first year on either the prairie or domestic forage sites.

Table 1. Changes in grass densities (individuals/m^2) in 1978 and 1979

Sampling Date	Prairie Site Total	Prairie Site SE	n	Domestic Forage Site (Orchard grass) Total	SE	n
July 5, 1978	11.7	2.3	30	31.3	4.8	17
August 7, 1978	10.0	2.3	39	6.0	1.3	26
Sept. 7, 1978	17.0	3.0	36 1/	0.0	0.0	0
May 29, 1979	1.0	0.4	45	0.0	0.0	0
August 10, 1979	4.2	1.4	40 1/	0.0	0.0	0

1/ Percent composition on last sampling dates was 88.4% and 11.6% for Indian grass and big bluestem, respectively, in 1978, and 93.5% and 2.4% in 1979, with switch grass representing 4.3% of the total in the latter year.

Table 2. Plant density (individuals/m^2 - July 5, 1978)

Species	Prairie Site	Domestic Forage Site
Prairie grasses	11.7	-
Orchard grass *(Dactyli glomerata)*	-	31.3
Alfalfa *(Medicago sativa)*	-	58.6
Oats (cover crop) *(Avena sativa)*	49.7	34.1
Annual rye *(Secale cereale)*	27.7	5.2
Yellow sweet clover *(Melilotus officianalis)*	3.9	-
Whorled milkweed *(Asclepias verticillata)*	0.03	1.2
Velvet leaf *(Abutilon theophrasti)*	0.3	0.4
Unknown	0.3	0.1
Smartweed *(Polygonum aviculare)*	0.1	0.2
Birdfoot trefoil *(Lotus corniculatus)*	-	0.2
Lamb's quarter *(Chenopodium album)*	-	0.2
Kentucky bluegrass *(Poa pratensis)*	-	0.1
Daisy fleabane *(Erigeron strigosus)*	-	0.1
Smartweed *(Polygonum pennsylvanicum)*	-	0.1
Peppergrass *(Lepedium virginianum)*	0.1	0.1
Wild parsnip *(Pastinaca sativa)*	-	0.1
Common milkweed *(Asclepias syriaca)*	0.03	
Total	93.7	131.9

By the end of the first year visual estimates of cover on the prairie and forage site were about 5 and 30%, respectively. Cover increased substantially during the second year on the prairie site, but most of the increase was due to non-prairie species, (Table 3). In September of, 1979, yellow sweet clover *(Melilotus officinalis)* measured 28.1% cover, burning bush *(Kochia scoparia)* 14.1%, and all prairie species combined provided 16.9% cover. Bare ground occupied 39.5 and 31.3% of the prairie site on August 10 and September 9, respectively. Although no prairie switchgrass *(Panicum virgatum)* was knowingly included in the seed mixture, a few plants became established in 1978. This species does very well on strip-mine soils compared to Indian grass and big bluestem, and we estimated a density of 0.2 plants/m^2 on August 10 and a cover of 4.7% on September 9, 1979.

The upper slope of the prairie site where supernatnant was applied produced 18,820 kg/ha compared to 2630 kg/ha for untreated lower slopes (Table 4). The accumulated domestic forage yield was 4830 kg/ha which included 3 spearate harvests during the year. The standing crop on the domestic forage site was 525 kg/ha on September 7, 1978. Prairie grasses responded well to supernatant application but so did the weeds. The 1979 production estimate for weedy species was 16720 kg/ha. These included giant foxtail, common ragweed, velvet leaf, fall panicum and others. For comparison, production on undisturbed, non-burned prairie sites in Oklahoma averaged 4800 kg/ha (Risser 1976).

Sample variances (S^2) for biomass estimates were high, especially for the middle and lower slope where some quadrats were nearly devoid of vegetation. The standard error ($S/\sqrt{n}$) when expressed as a percent of the mean should be less than 20% to obtain a reasonable estimate of biomass (personal communication with Dr. Paul Risser, Department of Botany, University of Oklahoma, Norman). With the exception of the middle and lower slope data, the samples are close to this 20% value.

Soils on the site are silty clay loams. Textural analysis of samples from upper and lower slopes consisted of 9-10% sand, 51-55% silt and 36-39% clay. The soil lacked structure, became compacted at the surgace with drying, and eroded quite easily. Lack of structure and the high clay content decreased water infiltration and percolation so that during summer dry periods little moisture was available for plant growth. Nutrient status of the soil before and after treatment indicated low availability, especially of phosphorus and nitrogen. Soil pH was high.

Levels of nitrogen, phosphorus, and potassium reported for August 10, 1979 were higher than those of April 10, 1978. This increase in nitrogen, phosphorus and potassium reflects application of commercial fertilizer during July of 1978 and supernatant during the 1979 growing season. Between April 1978 and August 1979 total nigrogen, NH_4^+ and NO_3^-, increased from 5.0 to 19.5 ppm, consisting mostly of the latter. The ammonium ion is the prevalent form of nitrogen in the supernatant but apparently is converted readily to nitrate in the soil. The sample reported for August 10, 1979 was collected where supernatant was applied. Analysis of a soil sample collected further down slope (13 m below the pipe) showed increases in phosphorus and potassium between April, 1978 and August, 1979 reflecting the commercial fertilizer application. There was little change in nitrogen.

Our results indicate that prairie grasses may not be a panacea for strip-mine restoration. Initial establishment of prairie grasses was good, 17.0/m^2, however, this density was achieved with a high seeding rate. Using data from Ode (1968) on the number of seeds of big bluestem and Indian grass per pound (90,000 and 360,000 lbs respectively), and our germination rates (6% for big bluestem and 37.8% for Indian grass), and a density of 17.0 seedlings/m^2 (2.0 big bluestem and 15.0 Indian grass), the number of live seeds required to successfully establish a seedling would be 7.0 for big bluestem and 35.1 for Indian grass.

The results indicate that native grasses are not readily established on strip-mine soils such as those in our study site. A satisfactory stand of grass may require at least 10-15 years for establishment.

Alfalfa produced more cover than did the prairie grasses and yeilded usable forage after 2 years. Alfalfa was cut for hay twice during 1979 and yielded 300 and 700 bales of hay for the first and second cutting, respectively. The hay yield is equivalent to about 6490 kg/ha, assuming an average dry weight of 25 kg/bale. This compares reasonably well with our estimate of 4830 kg/ha for total aboveground production on the forage site (Table 4). Orchard grass did not do as well as the prairie species. The success of this cool season species probably would have been greater if sown earlier in the spring. The prairie grasses might have benefited from earlier planting as well. Native prairie grasses are usually planted in late May or early June and the site worked late in the spring to reduce competition from introduced cool season weeds. Delaying the planting date, however, increases the risk of high seedling mortality on droughty strip-mine soils during summer. Risks of summer droughts could be reduced by the application of supernatant. Our results show that this enhances weed growth, which could be controlled by cutting with a rotary mower.

The use of gated pipe for liquid fertilizer application is not practical with prairie plantings because its use is limited to slopes. Prairie grasses produce little cover during the first year of growth. Thus, there is little vegetation to reduce erosion that can result from the flow of supernatant. Except for an area immediately down slope from the pipe (8-12 cm) there is uneven distribution of the supernatant.

Table 3. Percent cover for the prairie site using point sampling procedure

August 10, 1979 (397 points)	
Prairie grasses[1]	13.7
Other species	53.5
Bare ground	39.5
September 9, 1979 (64 points)	
Yellow sweetclover *(Melilotus officinalis)*	28.1
Burning bush *(Kochia scoparia)*	14.1
Oats (dead stems) *(Avena sativa)*	10.9
Indian grass *(Sorghastrum nutans)*	7.8
Big bluestem *(Andropogon gerardi)*	6.2
Prairie switchgrass *(Panicum virgatum)*	4.7
Giant foxtail *(Setaria faberii)*	4.7
Velvet leaf *(Abutilon theophrasti)*	3.1
Lamb's quarter *(Chenopodium album)*	3.1
Thistle *(Cirsium* spp.)	3.1
Flowering spurge *(Euphorbia corollata)*	3.1
Agrostis spp.	3.1
Fall panicum *(Panicum dichotomiflorum)*	1.6
Ragweed *(Ambrosia artemisiifolia)*	1.6
Unknown	1.6
Bare ground	31.2
Prairie grasses combined	16.9

[1] Percent of sampling points having prairie grasses irrespective of species composition.

Table 4. Above-ground production (kg/ha) in 1979 for prairie and domestic forage sites with standard error as percent of mean in parentheses

Site	Upper Slope[1]	Middle and Lower Slope
Prairie, Sept. 10		
Grasses	2100	380
Other spp.	16720	2250
Total	18820 (20.9%)	2630 (38.6%)
Domestic forage		
May 29	3070 (13.9%)	–
Aug. 9	810 (22.3%)	–
Sept. 10	950 (25.7%)	–
Total	4830	

[1] Only the upper slope of the prairie planting site received supernatant.

Based on our experience we suggest that a late fall planting be tried. A light crop, such as annual rye, should be planted to reduce erosion. This facilitates early establishment of seedlings in spring when moisture is available and the soil is more friable.

Literature Cited

Anderson, M. and G. Cottam. 1970. Vegetation change on the Greene prairie in relation to soil characteristics. Proc. Prairie and Prairie Restoration Conf., pp. 42-45, P. Schramm, ed. Knox College, Galesburg, Illinois.

Cottam, G. and H. C. Wilson. 1966. Community dynamics on an artificial prairie. Ecology 47:88-96.

Halinar, M. 1978. Germination percentages for selected lots of prairie seeds 1977-1978. Proc. Sixth North Am. Prairie Conf., in press, R. L. Stuckey, ed. The Ohio State University, Columbus.

Nuzzo, V. 1978. Propagation and planting of prairie forbs and grasses in southern Wisconsin. Proc. Fifth Midwest Prairie Conf., pp. 182-187, D. Glenn-Lewin and R. Landers, eds. Iowa State University, Ames.

Ode, A. H. 1970. Some aspects of establishing prairie species by direct seeding. Proc. Prairie and Prairie Restoration Cong., pp. 52-60, P. Schramm, ed. Knox College, Galesburg, Illinois.

Risser, P. G. 1976. Oklahoma true prairie. In J. Estes and R. Tyrl, eds., pp. 9-26, The Grass and Grasslands of Oklahoma. Ann. Oklahoma Acad. Sci. No. 6.

Robocker, W. C., J. T. Curtis, and H. L. Ahlgren. 1953. Some factors affecting emergence and establishment of native grass seedlings in Wisconsin. Ecology 34:194-199.

Schramm, P. and L. Kalvin. 1978. The use of prairie in strip-mine restoration. Proc. Fifth Midwest Prairie Conf., pp. 151-153, D. Glenn-Lewin and R. Landers, eds. Iowa State University, Ames.

Schulenberg, R. 1970. Summary of Morton Arboretum prairie restoration work 1963 to 1968. Proc. Prairie and Prairie Restoration Conf., pp. 45-46, P. Schramm, ed. Knox College, Galesburg, Illinois.

Schwarzmeier, J. 1972. Aspects of prairie restoration in early stages. Proc. Second Midwest Prairie Conf., pp. 122-139, J. Zimmerman, ed. University of Wisconsin, Madison.

EROSION CONTROL WITH PRAIRIE GRASSES IN IOWA STRIP-MINE RECLAMATION

Lon D. Drake
Department of Geology
The University of Iowa
Iowa City, Iowa 52242

Abstract. A prairie grass planting was tested for controlling erosion along the edge of a row of crop loess terrace built on acid strip-mine spoils near Oskaloosa, Iowa. Loess thickness was the major variable intended, studied by planting a seem mixture of 5 eastern prairie natives on the wedge of loess tapering from 1-31 inches deep. The stand was weedy in 1976 (planting year) and 1977 and erosion data were collected for the more mature condition in 1978 and 1979. A firmly compacted seedbed proved to be a major factor favoring seedling survival, while loess thickness was almost irrelevant. However, once established, plant height, above ground biomass, canopy cover, and mulch cover were proportional to loess thickness. During the drought year of 1977, the thin loess (1-6 inches) became virtually weed free with only dwarfed prairie grasses surviving. Weediness increased proportional to additional loess thickness but declined each succeeding year. A minimum of 24 inches of loess produced a tall, dense stand of native grasses by the third year. Indian grass dominated and set seedheads on the thin loess, while big bluestem and switchgrass flourished on the thicker loess. Smaller proportions of side oats grama and little bluestem survived throughout the planting but produced few seedheads by 1979. The universal soil loss equation was used to estimate potential erodability (by sheetwash) of the loess along the vegetative gradient. On more than 24 inches of loess, the canopy closure was nearly complete by 1979, but the mulch cover was still not well developed after 4 years. Sheetwash erosion rates under the grasses on thin loess were comparable to those for carefully managed row crops on flat land, whereas under the planting on thick loess, rates diminished to those of native mesic prairie. This use of the equation overestimates rates of erosion by not accounting for a minute understory of bryophytes on the soil surface. It also underestimates erosion rates by ignoring channelized runoff from the adjacent cornfield, protected by the native grass strip. The grasses on the thin loess cover were very shallow-rooted and the dense root mat made the loess more resistant to channelized erosion. This use of native prairie grasses provides an inexpensive, flexible, permanent planting requiring little maintenance other than judicious use of herbicides on adjacent cropland.

Introduction

Coal production in the U.S.A. is commonly expected to expand as a partial solution to our energy problems (Lantzke 1979). In the Midwest, most of this coal is strip-mined and the agricultural value of the overlying landscape is gradually leading to the requirement that the post-mining landscape also be suitable for agriculture. In Iowa, it has been long recognized that a large proportion of unreclaimed strip-mine spoils have a pH of less than 4 (Einspahr et. al. 1955) which is lethal to most plants (Limstrom 1960). One reclamation design, tested in Iowa beginning in 1974, is the loess terrace method (manuscripts by Drake and Ririe now in preparation). In this method, spoils are reshaped into terraces as mining progresses and the terrace flats are covered with 4-6 feet of loess stripped before the advancing highwall (Fig. 1). After reconditioning, the loess can be returned to row crop agriculture. The untillable edges of the loess terraces are subject to erosion and experiments were begun to determine whether prairie grasses could be used to retard this erosion.

Experimental Design

The test plot is located about 4 miles west of Oskaloosa, Iowa and is known locally as the South Hull Site. This area was strip-mined for coal during the 1930's and later acquired by the Iowa Conservation Commission for inclusion in a wildlife refuge. Large tracts of acid spoils at this site have remained barren for 4 decades. Erosion is rapid and a series of markers and stakes indicate that rill and sheetwash losses are within the range of 0.5-2.0 inches per year. In 1974, a rectangular 1¼ acre terrace was built from these spoils and covered with a wedge of loess tapering from 1-31 inches thick. Corn was planted over the entire plot in 1974 and 1975 and erosion of the loess was severe along the exposed edge of the wedge. In 1976 a 20-foot-wide strip of native prairie grasses was planted along this edge to evaluate its potential for erosion

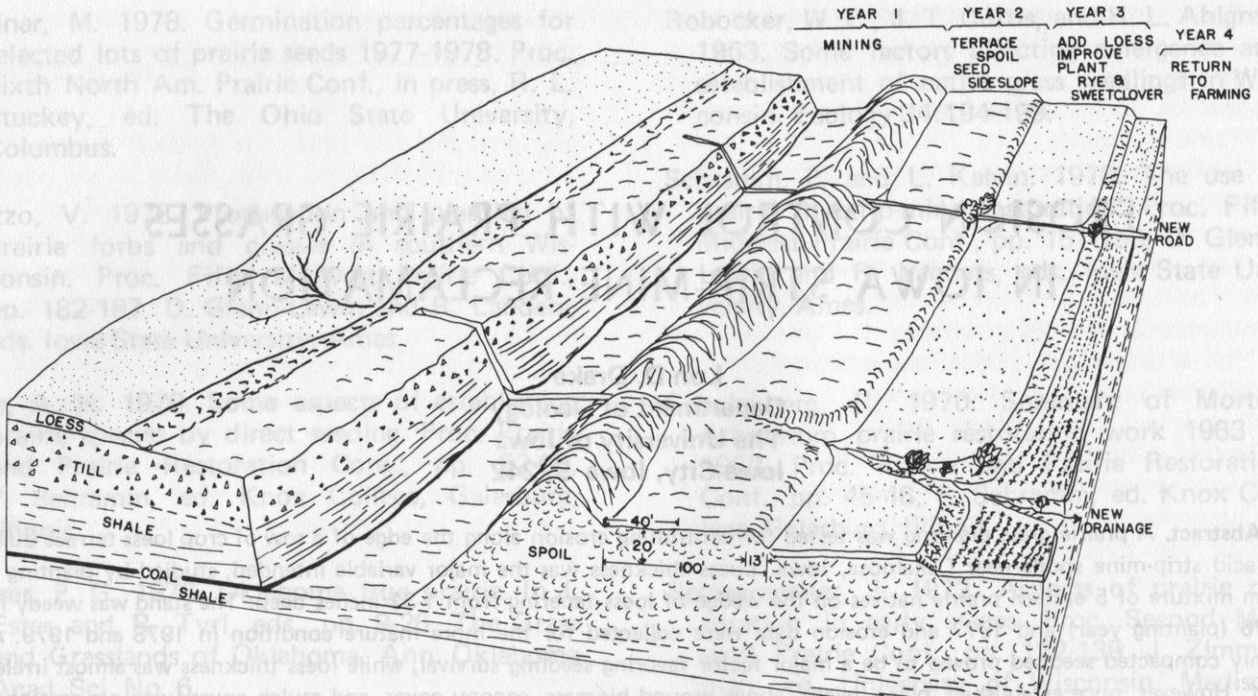


Fig. 1. Loess terrace method.

control. The seeds were commercial named varieties from Stock Seed Farms, Nebraska:

Species	Variety	Lbs. PLS/Acre
Big bluestem	Pawnee	10
Indian grass	Holt	9
Little bluestem	Blaze	8
Sideoats grama	Trailway	5
Switchgrass	Blackwell	5

The grass seeding rate was made especially heavy because 1976 was well into a drought cycle and survival rates were anticipated to be low. The seedbed was mellow and friable following fall plowing and spring discing. Earlier research has indicated that prairie plantings are more likely to flourish in a firm seedbed (Schramm 1968). Conventional soil compaction equipment was lacking, so after broadcasting the seed and working it in lightly with a garden rake, I methodically drove my pickup truck the length of the plot, producing alternating strips of compacted and uncompacted seedbed. Some of the wheel tracks were marked with spray paint for later identification. Maintenance consisted on 1 mowing in August to decapitate weeds.

Growth and Competition

In 1976, the plot was dominated by foxtail and crabgrass. The 2-inch-high natives only became conspicuous after frost. A few crownvetch seedlings appeared along the edge of the thick end of the loess wedge, 'hardseed' sprouts from earlier experiments. The drought continued until mid-August 1977. Conditions were so severe on 1-12 inches of loess that only the native grasses survived and this portion of the test plot became virtually weedfree. Here it could be clearly seen that most of the natives were growing in rows from the compacted wheel tracks of the 1976 seedbed and the planting appeared as though the seed had been drilled instead of broadcast (Fig. 2). A sharp transition took place beyond the 12-inch-thick loess zone. Where more than 12 inches of loess was available, foxtail dominated in 1977 with a scattering of big bluestem seedheads stand-

Fig. 2. Rows of grass on tire-compacted loess.

ing above them. Rainfall in 1978 returned to normal and the foxtail was reduced by competition to an understory in the native grasses on the thicker loess. Scattered clumps of sweetclover appeared in 2-6 inches of loess but otherwise the thin loess remained relatively weedfree. The crownvetch continued to spread into the prairie grasses on the thick loess. These trends continued through 1979. In the thin loess, the native grasses immediately adjacent to the volunteer sweetclover were more robust and of deeper green color than most distant specimens, presumably due to fixed nitrogen becoming available when the biennial sweetclover terminated its life cycle in midsummer. By contrast, on the thick loess, the crown vetch continued to slowly spread in pure stands, totally excluding the native grasses (Fig 3). Foxtail dwindled to a minor component in the thick loess planting in 1979.

Fig. 3. Crownvetch encroaching on prairie grass.

Overall, plant height and above-ground biomass were proportional to loess thickness (Tables 1 and 2). By contrast, the numbers and spacing of the

Table 1. Height of prairie grasses compared to loess thickness

Loess Thickness		Grass Height[1/] 1978		1979	
Inches	(cm)	Inches	(cm)	Inches	(cm)
2	(5.1)	3.4	(8.6)	4.5	(11.4)
3	(7.6)	5.2	(13.2)	5.6	(14.2)
6	(15.2)	6.0	(15.2)	6.7	(17.0)
9	(22.9)	8.8	(22.4)	9.6	(24.4)
12	(30.5)	11.2	(28.4)	11.8	(30.0)
15	(38.1)	17.3	(43.9)	18.8	(47.8)
18	(45.7)	22.5	(57.2)	24.1	(61.2)
21	(53.3)	28.2	(71.6)	35.4	(89.9)
24	(61.0)	32.0	(81.3)	34.7	(95.8)
27	(68.6)	33.2	(84.3)	40.3	(102.4)
30	(76.2)	35.5	(90.2)	41.8	(106.2)

1/ Average height of 3 highest leaves (in natural arched position without dew) on each prairie grass clump within a 1-square yard ($0.84M^2$) quadrat after first frost (excludes native grass seedheads and weeds).

natives was determined during the first growing season and comparable numbers were established on thick and thin loess (Table 3). The harsher environment of the thin loess reduced competition from weeds and may have aided in maintaining their numbers.

All root growth ceased near the loess/spoil contact. The spoils below the loess cover had a pH ranging from 2.8 to 4.8, with a mean value of 3.3 Acids were drawn upwards, by capillary action, into the loess for a few inches and the basal loess was moderately acid. It is known

Table 2. Aboveground biomass compared to loess thickness

Loess Thickness		Aboveground Biomass[1/]			
		1978		1979	
Inches	(cm)	Lbs/Acre	Kg/Ha	Lbs/Acre	Kg/Ha
2	(5.1)	1233	(222)	1675	(302)
3	(7.6)	1310	(236)	1094	(197)
6	(15.2)	1387	(250)	2081	(375)
9	(22.9)	1768	(318)	2372	(427)
12	(30.5)	1924	(346)	2565	(462)
15	(38.1)	2618	(471)	3369	(606)
18	(45.7)	5322	(958)	6098	(1098)
21	(53.3)	6884	(1239)	9321	(1678)
24	(61.0)	7793	(1403)	10948	(1971)
27	(68.6)	8134	(1464)	11247	(2024)
30	(76.2)	8328	(1499)	11318	(2037)

1/ Air-dry weight of all above-ground plant parts (including weeds) from 1 square yard ($0.84 m^2$) quadrats collected after first heavy frost. The 1978 measurements from thicker loess are dominated by foxtail.

that low pH results in loss of cellular components from root tissues and reduces absorption of many cations. Jacobson et al. (1950) observed loss of N, P, K and Ca below pH 5, with severe losses below pH 4. With increased acidity (pH 4 or less) iron and aluminum become available in quantities toxic to most plants (Bondy 1969). Excavations at the test plot, indicate that root tips simply die when entering the acid basal loess, which forces more branching higher in the soil profile.

Sheetwash and Rill Erosion

The immediate effect of vegetation upon rates of soil erosion is the degree to which it reduces raindrop impact and subsequent overland flow. Canopies of tall vegetation, with bare ground between plants, allow raindrops to reaccelerate and permit more erosion than the same biomass distributed on the ground as a mulch. The percentage of prairie canopy closure and percentage of surface mulch cover are shown for the various loess thicknesses in Tables 4 and 5.

The Universal Soil Loss Equation (USLE) can be used in this setting to estimate erosion rates of the loess under the various prairie covers (Wischmeier 1977). The USLE, in its most basic form, is usually expressed as:

$$A = RKLSCP$$

A is computed soil loss per unit area, expressed in the units selected for K and for the period selected for R. in practice, these are selected so that A can be exprssed as tons/acre/.year.

R, the rainfall and runoff factor, is the number of rainfall erosion index units, plus a factor for runoff from snowmelt where significant.

K, the soil erodibility factor, is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, which is defined as a 72.6 foot length of uniform 9% slope continuously in clean-tilled fallow.

L, the slope-length factor, is the ratio of soil loss from the field slope length to that from 72.6-foot length under identical conditions.

S, the slope-steepness factor, is the ratio of soil loss from the field slope gradient to that from a 9% slope under otherwise identical conditions.

C, the cover and management factor, is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow.

P, the support practice factor, is the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to that with straight-row farming up and down the slope.

The test plot was sufficiently uniform that R, K, L, S, and P can be considered constants, so that the vegetation factors comprise the major variable. Values selected for the constants (From Wischmeier and Smith 1978) are:

R = 180

K = 0.37, derived from values for native Fayette silt loams, the source of loess for the test plot

LS = 0.13, a combined factor assuming a 2% slope with a 25-foot average runoff length diagonally across the test plot

P = 0.30, assuming the terrace flats (2% slope) are in continuous cover.

The canopy and mulch effects of vegetation (factor C in the USLE) are not fully additive (Wischmeier and Smith 1978) and the season in which measurements are made has a significant effect upon estimates of erosion losses. On the test plot (without burning), the season with vegetation factors promoting maximum susceptibliity to erosion is early summer when the previous year's growth has partially decayed and the new growth is still low. The minimum susceptibility is in early spring when the previous year's growth has been matted down by winter wind and snow, mulching the surface. The intermediate season, chosen for application of the USLE, is mid-autumn when the canopy of native grasses is fully developed but before much of it is dispersed to ground level forming a mulch. For this condition the interplay between canopy and mulch effects are similar to those for domestic grasses (grains), which has been quantified by Wischmeier and Smith (1978). Their graphs relating canopy and mulch factors were applied to the prairie test plot data (Tables 4,5), producing values for C in the USLE. Summation of all the factors in the USLE estimates long term erosion rates on the prairie planting (Table 6).

Table 3. Number of Plants compared to loess thickness

Loess Thickness		1978		1979	
Inches	(cm)	Plants/acre	Plants/ha	Plants/acre	Plants/ha[1]
2	(5.1)	275880	681699	314600	777377
3	(7.6)	454960	1124206	605000	1494955
6	(15.2)	837320	2069018	924440	2284291
9	(22.9)	938960	2320170	909920	2248412
12	(30.5)	832480	2057058	779240	1925502
15	(38.1)	585640	1447116	677600	1674350
18	(45.7)	430760	1064408	309760	765416
21	(53.3)	227480	562103	159720	394668
24	(61.0)	154880	382708	77440	191354
27	(68.6)	188760	466426	101640	251152
30	(76.2)	150040	370749	91960	227233

1/ Number of individual plants or clumps above-ground, measured within 1 square yard (0.84^2) quadrats. Below the surface, many of these shared a common root system. Measurements were made after first frost.

The canopy cover is essentially complete on 24-27 inches of loess. In general this part of the planting is as tall and dense as any stand of native mesic tallgrass prairie and greater thicknesses of loess cover will not significantly improve resistance to sheetwash and rill erosion.

Table 4. Percent canopy cover including weeds compared to loess thickness

Loess Thickness		Canopy Cover 1/	
Inches	(cm)	1978	1979
2	(5.1)	24	27
3	(7.6)	34	38
6	(15.2)	42	44
9	(22.9)	42	45
12	(30.5)	38	44
15	(38.1)	58	59
18	(45.7)	57	64
21	(53.3)	69	67
24	(61.0)	77	75
27	(68.6)	81	83
30	(76.2)	83	84

1/ Percentage determined by gridding vertical photographs of 1 square yard ($0.84 m^2$) quadrats.

Channelized Erosion

The prairie border on the edge of the loess terrace is also intended to prevent erosion by runoff waters from the adjacent cropland. Perfectly planar agricultural terraces are not feasible and each pass of farm equipment creates a new microtopography. Thus channelization of runoff across the prairie border is inevitable. The USLE was not designed to quantify susceptibility to channelized flow and would underestimate erosion for these conditions. Most organic residues (mulches) become buoyant in channelized flows and are either rafted away or allow runoff to erode beneath them. The root system immediately beneath the soil surface is a major factor determining resistance to erosion by channelized flow. The native tallgrass prairie sods have a reputation for extremely well developed root networks (capable of resisting the westward spread of agriculture in the last century until the advent of the steel plow, as well as permitting the construction of sod houses). Early research (for example, Weaver and Harmon 1935), verified this aspect of prairie folklore. The prairie grasses were selected for erosion control on the loess terraces, because of their sod forming qualities.

The loess terrace sods were sampled at the end of their fourth growing season (autumn 1979), by which time weeds had been reduced to a minor component of the planting. Representative sites along the loess wedge were selected and sod slabs 1-foot square by 2 inches deep were carefully cut out with a sharp, flat-bladed spade, after the above ground biomass had been clipped to the ground level. These slabs were placed in individual trays made of window screening, suspended on chicken wire mesh and sprayed with water to wash the dirt out of the root system. The cleaned root mats were compressed to about half their thickness by the force of the spray, but otherwise retained their shape with little

Table 5. Percent mulch cover compared to loess thickness

Loess Thickness		Mulch Cover 1/	
Inches	(cm)	1978	1979
2	(5.1)	22	32
3	(7.6)	19	36
6	(15.2)	27	43
9	(22.9)	33	48
12	(30.5)	47	66
15	(38.1)	59	80
18	(45.7)	58	77
21	(53.3)	65	86
24	(61.0)	74	90
27	(68.6)	73	92
30	(76.2)	77	94

1/ Percentages determined by gridding vertical photographs of 1 square yard ($0.84 m^2$) quadrats. Photos taken after standing stalks clipped and removed.

Table 6. USLE erosion rates compared to loess thickness and cover and management factor (C).1/

Loess Thickness			Erosion Rate	
-inches	Year	(C)	tons/acre/yr	kg/ha/yr
2	1978	0.46	1.19	437
2	1979	0.46	0.96	353
3	1978	0.47	1.22	448
3	1979	0.30	0.78	286
6	1978	0.34	0.88	323
6	1979	0.23	0.60	220
9	1978	0.28	0.73	268
9	1979	0.20	0.52	191
12	1978	0.24	0.62	228
12	1979	0.14	0.36	132
15	1978	0.14	0.36	132
15	1979	0.08	0.21	77
18	1978	0.14	0.36	132
18	1979	0.08	0.21	77
21	1978	0.10	0.26	95
21	1979	0.06	0.16	59
24	1978	0.08	0.21	77
24	1979	0.05	0.13	48
27	1978	0.07	0.18	66
27	1979	0.04	0.10	37
30	1978	0.07	0.18	66
30	1979	0.04	0.10	37

1/ Other factors in the USLE estimate are constants. See text for explanation.

loss of rootlets. After stones and debris were removed, the mats were air-dried and weighed (Table 7). This table shows that the prairie plantings on the deeper loess were deep rooted, with a tendency for less root mass near the surface than plantings in shallow loess.

Root weight however is not necessarily an adequate indicator of resistance to erosion because a few large roots could have the same weight as a dense network of smaller ones but not be as efficacious in retarding erosion. A 3-dimensional measurement of root density was attempted, by blowing a column of air through the root mat and measuring the restriction of flow. However, these impedence measurements proved to be affected by the degree to which the mat was compressed during washing and were therefore unsatisfactory. A 2-dimensional system of measurement was then utilized, by placing the root mats on an overhead projector and focusing the image on a screen. A light meter was used to measure light transmittance. Optical density standards were prepared by covering the projector plate with known areas of black paper grids. Using a micrometer, the average dry-root thickness was estimated to be approximately 6 mils (0.015 cm). The original sod slab is thus 333 times as thick as an average root $\frac{(2.000 \text{ inches})}{(\ .006 \text{ inches})}$ and since a single root can obscure the transmitted light, the optical density was divided by this value to obtain a rough estimate of the percentage of the slab volume composed of roots (Table 8). This table illustrates that shallow loesses tend to produce shallow root systems in prairie grasses, although the contrast with deeper loess is not as apparent as in Table 7.

This method underestimates root volume by using dried root mats and ignores the fact that roots overlap in the light beam. However, these errors are expected to be consistent between samples and can be ignored for purposes of this comparison.

Discussion

Because the test plot is a narrow strip along the edge of a cornfield, clipping and excavating multiple replications of quadrats could artificially affect the overall erosion potential of the terrace edge. Therefore, each of the data points listed in Tables 1-5 represents information from only a single 1-square-yard quadrat located along

Table 7. Root dry matter in top 2 inches of profile compared to total loess thickness

Loess Thickness		Root Weight	
Inches	(cm)	lbs/acre	kg/ha
2	(5.1)	586	657
3	(7.6)	1012	1135
6	(15.2)	873	980
9	(22.9)	884	992
12	(30.5)	767	860
15	(38.1)	575	645
18	(45.7)	501	562
21	(53.3)	351	394
24	(61.0)	288	323
27	(68.0)	405	454
30	(76.0)	383	430

Table 8. Root volume compared to loess thickness

Loess Thickness		Root Volume 1/
inches	(cm)	percent
2	(5.1)	.29
3	(7.6)	.28
6	(15.2)	.28
9	(22.9)	.26
12	(30.5)	.26
15	(38.1)	.25
18	(45.7)	.26
21	(53.3)	.24
24	(61.0)	.23
27	(68.6)	.24
30	(76.2)	.24

1/ Measured optically in vertical direction; see text for details.

the centerline of the prairie strip. Other variables observed in the field, such as color and health of the plants, suggest that the trends quantified on Tables 1-5 are approximately correct. The sharp improvements in the stand where the loess thickens to 12 inches and 18-21 inches were especially obvious in the field and the plateaus on the quantified data would not have been smoothed out by quadrat replications.

As the test plot matures, self seeding will become a more important factor and species composition may change. Maintenance by burning may favor the native grasses over the invading crownvetch, because the exposed crowns will be more vulnerable to fire. The pattern of invasion suggests crownvetch is using a strategy which includes alleleopathic competition and experiments have been initiated to test this hypothesis. Burning will also affect the canopy vs. mulch balance. However, the long term effects of occasional early spring burnings upon rates of erosion is likely to be minor because short term losses in mulch will be at least partially offset by rejuvenated growth of canopy.

Acknowledgements

The strip-mine reclamation project, including the prairie grass erosion control study, was supported by two electric utility companies and a coal brokerage. Expenses were shared by Iowa Power and Light Company, Iowa Southern Utilities Company, and University Avenue Coal Company.

Literature Cited

Bondy, E. J. 1969. How soil pH affects availability of plant nutrients. Soil Conservation Service. Kansas Technical Note. Agronomy Ka-14.

Einspahr, W. W., A. L. McComb, F. F. Riecken, and W. D. Shrader. 1955. Coal spoil-bank materials as a medium for plant growth. Proc. Iowa Acad. Sci. 62:329-344.

Jacobson, L., R. Overstreet, H. M. King, and R. Handley. 1950. A study of potassium absorption by barley roots. Plant Physiol. 25:639-647.

Lantzke, V. 1979. Expanding world use of coal. Foreign Affairs, 58:351-373.

Limstron, G. A. 1960. Forestation of strip-mined lands. Handbook 166, U. S. Dept. Agri., Wash., D.C.

Schramm, P. 1968. A practical restoration method for tall-grass prairie. Proc. Prairie and Prairie Restoration Conf., p 63, P. Schramm, ed. Knox College, Galesburg, Illinois.

Wischmeier, W. H. 1977. Use and misuse of the universal soil loss equation. In G. R. Foster, ed., Soil Erosion: Prediction and Control.

Wischmeier, W. H. and D. D. Smith. 1978. Predicting rainfall erosion losses - a guide to conservation planning. Handbook 537, U. S. Dept. Agri., Wash. , D.C.

Weaver, J. E. and G. W. Harmon. 1935. Quantity of living plant materials in prairie soils in relation to runoff and soil erosion. Conservation and Surv. Div. Bull. 8, University of Nebraska, Lincoln. 7 pp.

the centerline of the prairie strip. Other variables observed in the field, such as color and health of the plants, suggest that the trends quantified in Tables 1-5 are approximately correct. The sharp improvements in the stand where the loess thickens to 12 inches and 18-21 inches were especially obvious in the field and the plateaus on the quantified data would not have been smoothed out by quadrat replications.

As the test plot matures, self seeding will become a more important factor and species composition may change. Maintenance by burning may favor the native grasses over the invading crownvetch, because the exposed crowns will be more vulnerable to fire. The pattern of invasion suggests crownvetch is using a strategy which includes alleleopathic competition and experiments have been initiated to test this hypothesis. Burning will also affect the canopy vs. mulch balance. However, the long term effects of occasional early spring burnings upon rates of erosion is likely to be minor because short term losses in mulch will be at least partially offset by rejuvenated growth of canopy.

Table 7. Root [illegible] in top 2 inches of profile, compared to loess thickness

Loess Thickness		Root Weight	
inches	(cm)	lbs/acre	kg/ha
2	(5.1)	[illegible]	657
3	(7.6)	1012	1135
6	(15.2)	873	980
9	(22.9)	884	992
12	(30.5)	767	860
15	(38.1)	575	645
18	(45.7)	501	562
21	(53.3)	351	394
24	(61.0)	288	323
27	(68.0)	405	454
30	(76.0)	383	430

Table 8. Root volume compared to loess thickness

Loess Thickness		Root Volume[1]
inches	(cm)	percent
2	(5.1)	.29
3	(7.6)	.28
6	(15.2)	.28
9	(22.9)	.26
12	(30.5)	.26
15	(38.1)	.25
18	(45.7)	.26
21	(53.3)	.24
24	(61.0)	.23
27	(68.6)	.24
30	(76.2)	.24

[1] Measured optically in vertical direction; see text for details.

Acknowledgements

The strip-mine reclamation project, including the prairie grass erosion control study, was supported by two electric utility companies and a coal brokerage. Expenses were shared by Iowa Power and Light Company, Iowa Southern Utilities Company, and University Avenue Coal Company.

Literature Cited

Bondy, E. J. 1969. How soil pH affects availability of plant nutrients. Soil Conservation Service. Kansas Technical Note. Agronomy Ka-14.

Einspahr, W. W., A. L. McComb, F. F. Riecken, and W. D. Shrader. 1955. Coal spoil-bank materials as a medium for plant growth. Proc. Iowa Acad. Sci. 62:329-344.

Jacobson, L., R. Overstreet, H. M. King, and R. Handley. 1950. A study of potassium absorption by barley roots. Plant Physiol. 25:639-647.

Lantzke, V. 1979. Expanding world use of coal. Foreign Affairs, 58:351-373.

Limstron, G. A. 1960. Forestation of strip-mined lands. Handbook 166, U. S. Dept. Agri., Wash., D.C.

ESTABLISHMENT OF BRYOPHYTES ON A RECLAIMED SURFACE MINE SITE AT GOOSE LAKE PRAIRIE STATE PARK, ILLINOIS

James R. Rastorfer
Department of Biological Sciences
Chicago State University
Chicago, Illinois 60628
and
The Land Reclamation Program
Argonne National Laboratory
Argonne, Illinois 60439

Abstract. The location of the site at Goose Lake Prairie State Park provided an impetus to revegetate the reclaimed acid mine soil as a demonstration site with prairie floristic species. Because many bryophytes are pioneer plants and because baseline data were needed, surveys were made (1976-1978) to ascertain the natural establishment of mosses and liverworts on the site. Different habitats were surveyed with respect to types of fine-textured mineral soils, namely, abandoned (cultivated) field soil, old mine soil (spoil), and 2 reclaimed mine soils distinguished by reclamation efforts initiated in 1972-1973 and 1975-1976. Thirty moss species and 1 liverwort species were identified from the site, and 2 additional moss species were found in areas adjacent to the site. Of the 33 bryophyte species recognized, 14 species of mosses are new reports for Grundy County. Comparative distribution patterns indicate that the major pioneer species of mosses on reclaimed mine soil were *Barbula unguiculata, Ceratodon purpureus, Ditrichum pallidum,* and *Funaria hygrometrica.* On the other hand, *Bryum caespiticium* and *Weissia controversa* were considered later seral species rather than the primary invaders. Distribution patterns also indicate that mosses were generally unable to colonize fully exposed bare reclaimed mine soil. However, moss colonization was successful in those areas where the harsh microhabitat conditions were ameliorated by vascular vegetation. Both living and dead higher plants shoots most likely affect the proliferation of mosses by shading the soil surface, which results in increased moisture and decreased temperature at the soil surface in contrast to fully exposed soil. The role of bryophytes in the development of prairie plant communities on reclaimed mine soil is still uncertain. However, existing research data provide support for the following hypotheses: 1) bryophytes should help reduce soil erosion by binding soil particles *via* their rhizoidal systems, and by the relatively high water-holding capacity of their gametophytic shoots; 2) bryophytes might reduce heavy-metal toxicity to certain vascular plants at soil surface, because they have an ability to accumulate these elements; and 3) bryophytes may enhance nitrogen fixation through their associations with blue-green algae and possibly with nitrogen-fixing bacteria.

Introduction

The objective of this study was to determine the establishment of bryophyte species on the land reclamation demonstration site at Goose Lake Prairie State Park. Such a study is important in an early evaluation of reclaimed strip-mined land because many species of mosses and liverworts are pioneer invaders of primary and secondary area and thus, their presence might indicate the suitability of reclaimed mine soil for the successful growth of other native plants. In addition, the study will provide baseline information on bryophyte composition and distribution patterns that can be used in the future to study plant succession on reclaimed strip-mined land.

The Site

History and physical features. The land reclamation demonstration site is located within the southern boundary of Goose Lake Prairie State Park in Grundy County near Morris, Illinois (Fig. 1). About 50 acres (20 ha) of the 110-acre (45-ha) site were affected by strip-mining operations in the early 1940s and subsequently abandoned in 1943. The unreclaimed strip-mined land consisted of mine spoils and final cuts (pits) that formed a mosaic of steep-sided hills (spoil banks) with rounded tops and small lakes (Fig. 2). The portion of the site that had been strip-mined remained abandoned for 29 years, during which exposed surfaces were subjected to severe erosion accompanied by acid runoff. In spite of these severe acid conditions, some natural vegetation occurred (Carter et al. 1973, Green and Zellmer 1975).

The Illinois State Department of Conservation purchased the site in 1972 for additional

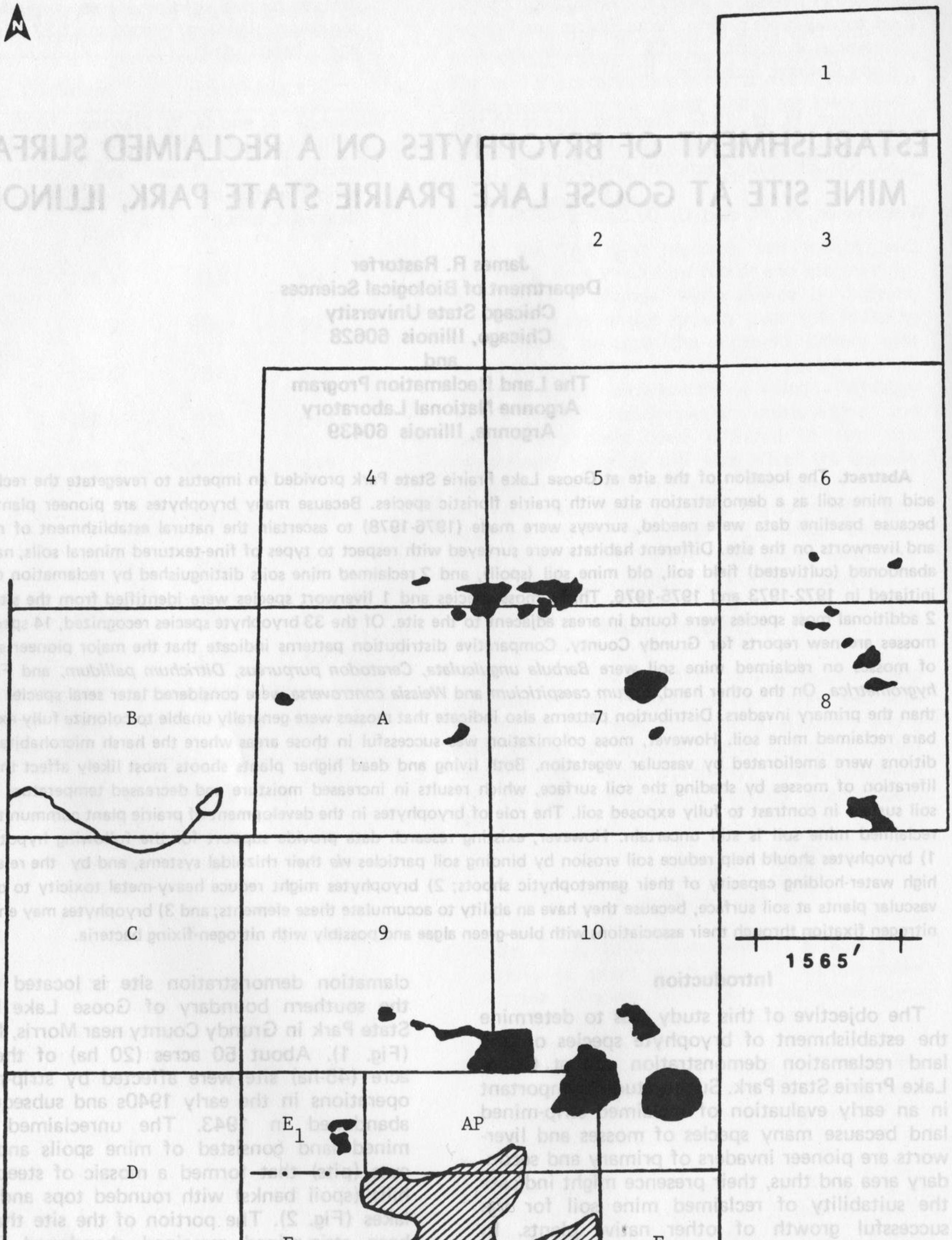


Fig. 1. Land reclamation demonstration site (cross-hatched area) in Goose Lake Prairie State Park. The dark areas represent lakes and ponds. Scale: 1565 ft = 477 m.

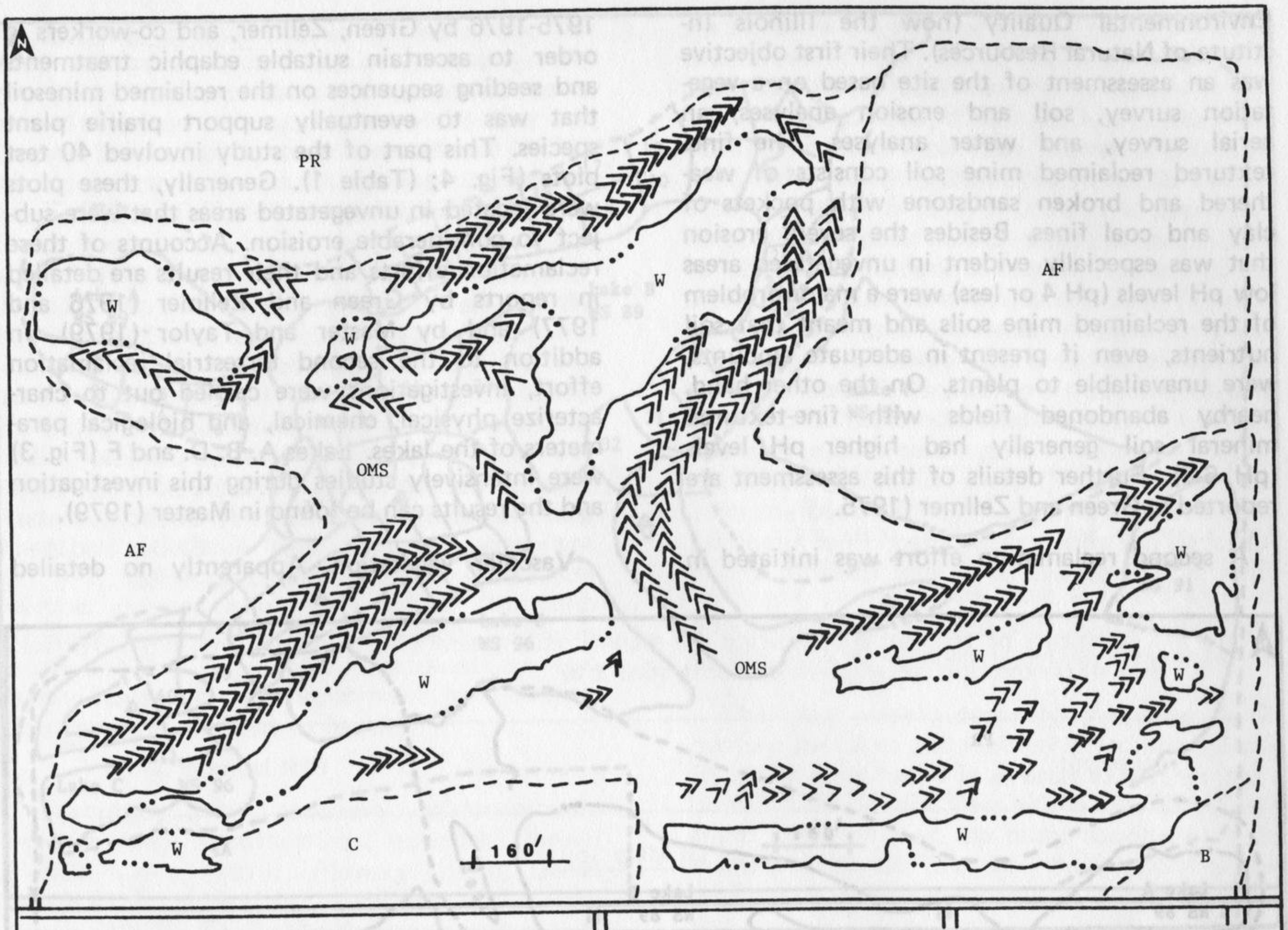


Fig. 2. Topographic map of reclamation site after strip-mining operations ended in 1943, but before the land reclamation effort began in 1972. Key: PR -- mesohydric prairie along the northern boundary of the site; AF -- abandoned agricultural fields that have not been cultivated since 1968: B and C -- small areas that apparently were never cultivated but were disturbed by the stripmining operations; W -- lakes in the final strip-mining pits; and OMS -- remaining areas consisting of old mine spoil (HHH = spoil ridges and slopes). Scale : 160 ft. = 48.8m.

park land, and funded a reclamation effort to develop the approximately 50 acres (20 ha) that had been mined. The reclaimed land was to serve as a demonstration area for reclamation and management procedures that might be used in other regions of Illinois affected by surface mining prior to 1962 (i.e., before reclamation laws were passed to control surface-mining in Illinois). In addition, the reclamation plans included provisions to revegetate the site with selected prairie plant species, and to use the site as an educational and recreational sector of Goose Lake Prairie State Park (Carter et al. 1973, Green and Zellmer 1975).

The initial restoration effort (fall 1972 - summer 1973) consisted of removing existing vegetation, regrading spoils into 'esker' formations and flat areas, as well as filling and reforming lakes (Fig. 3). Topsoil was removed from adjacent areas on the site or from beneath spoil piles and spread over approximately 35 acres (14 ha) of spoil surfaces. This reworked mine soil was limed and seeded with a seed mixture containing 1 forb and 4 grasses. In addition to the terrestrial reclamation operations, the acid lakes (pH3.5+) were neutralized with lime. Lake F was formed subsequent to this reclamation operation (Carter et al. 1973, Green and Zellmer 1975).

Within 2 years, observers recognized that the 1972-1973 reclamation effort was not completely successful, as indicated by large bare and eroded surfaces over much of the reclaimed mine soil, and by the apparent sterility of Lakes A-E. In response to these undesirable conditions, B. B. Green and S. D. Zellmer of Argonne National Laboratory's Land Reclamation Porgram undertook an investigation of the site in early 1975 in cooperation with the Illinois State Department of Conservation and the Illinois Institute for

Environmental Quality (now the Illinois Institute of Natural Resources). Their first objective was an assessment of the site based on a vegetation survey, soil and erosion analyses, an aerial survey, and water analyses. The fine-textured reclaimed mine soil consists of weathered and broken sandstone with pockets of clay and coal fines. Besides the severe erosion that was especially evident in unvegetated areas low pH levels (pH 4 or less) were a major problem of the reclaimed mine soils and meant that soil nutrients, even if present in adequate amounts, were unavailable to plants. On the other hand, nearby abandoned fields with fine-textured mineral soil generally had higher pH levels (pH 6-8). Further details of this assessment are reported in Green and Zellmer (1975.

A second reclamation effort was initiated in 1975-1976 by Green, Zellmer, and co-workers in order to ascertain suitable edaphic treatments and seeding sequences on the reclaimed minesoil that was to eventually support prairie plant species. This part of the study involved 40 test plots (Fig. 4; (Table 1). Generally, these plots were located in unvegetated areas that were subject to considerable eroision. Accounts of these reclamation efforts and their results are detailed in reports by Green and Zellmer (1976 and 1977) and by Master and Taylor (1979). In addition to the second terrestrial reclamation effort, investigations were carried out to characterize physical, chemical, and biological parameters of the lakes. Lakes A, B. D. and F (Fig. 3) were intensively studies during this investigation and the results can be found in Master (1979).

Vascular vegetation. Apparently no detailed

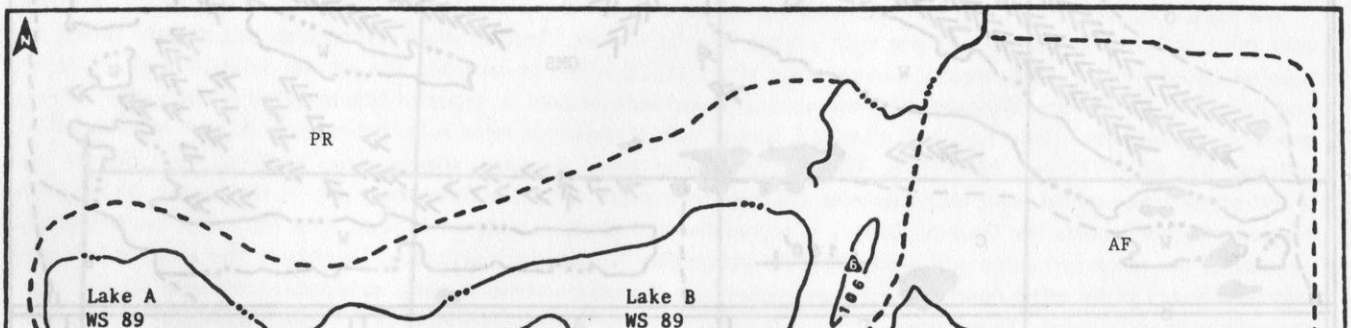


Fig. 3. Topographic map of the land reclamation demonstration site following the 1972-1973 land reclamation effort. Peak relative elevations for the "eskers" (numbered within triangles) and 1) 122; 2) 123; 3) 131; 4) 122; 5) 117; and 6) 106 feet, respectively. Water surfaces (WS) are also in feet, relative elevations. Dotted area above the south shore of Lake A represents a tree-covered slope of an original spoil hill and the area just southwest of Lake F apparently consists of old mine spoil that was reworked during the land reclamation efforts, but was not treated and seeded. The remaining land areas among Lakes A, B, C, D, and E, as well as Area C, consisted of minesoil that had been regraded into "eskers" and flat areas. Lake F was formed subsequent to the first reclamation effort. Rest of key as in Fig. 2. Scale: 160 ft. = 48.8 m.

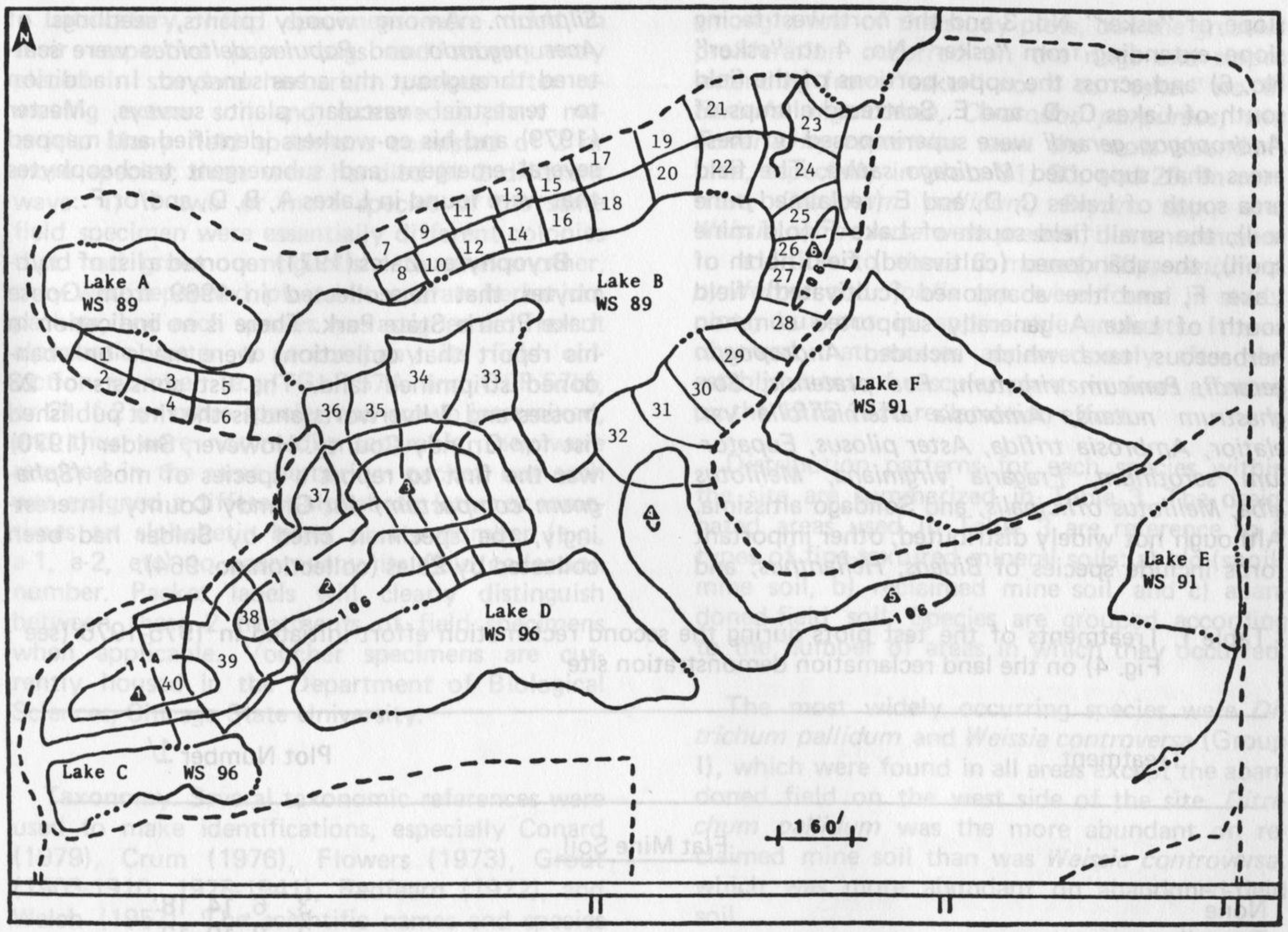


Fig. 4. Topographic map of the land reclamation demonstration site, showing the plots established during the second reclamation effort that began in 19751976. Scale: 160 ft = 48.8 m.

vegetational inventory was taken of the site before the 1972-1973 reclamation effort. However, an invironmental impact statement written before the first reclamation effort began contains a brief description of the vegetation (Carter et al. 1973). Apparently the common trees were species of *Platanus, Populus, Prunus, Rhus* and *Ulmus;* the most abundant herbaceous plants were species of *Festuca, Melitotus, Poa, Solanum,* and *Verbena.*

As mentioned previously, the 1972-1973 reclamation effort included seeding and reworked mine soil. The seed mixture consisted of *Medicago sativa, Andropogon gerardi, Sorghastrum nutans, Avena sativa,* and *Secale cereale.* A vegetational analysis by Green and Zellmer (1975) reported *Medicago sativa* as the dominant species especially on vegetated reclaimed soil, while *Aster* ssp., *Solidago missouriensis* var. *fasciculata, Trifolium pratense,* and *Melilotus alba* were common in old (abandoned) fields. Other species included in this report were *Andropogon gerardi, Bromus* spp., *Populus deltoides,* and *Hymenopappus scabiosaeus.* In addition, two seed applications (as well as edaphic treatments) were made during this second reclamation effort. The seed mixture of the first application (October 1975) consisted of *Festuca rubra, Trifolium hybridum, Trifolium pratense* and *Trifolium repens.* The same species were used in a seed mixture for the second application (April 1976) with the addition of *Festuca arundinacea.*

A terrestrial vascular plant survey was conducted in late August and early September 1978, with some additional field work in the spring and late summer of 1979 (Rastorfer, unpublished data). The 1978 survey focused particularly on species compositions of the abandoned fields and the large area south of Lakes C, D, and E (Fig. 3). The experimental plots (Fig. 4) were not included in this survey. One hundred twenty six higher plants species were identified and, of these, 39 species were considered introduced. Species composition among different morphological groups were as follows: 13 trees, 8 shrubs, 1 woody vine, 23 graminoids, and 81 forbs.

Medicago sativa was the most common plant on "esker" slopes (except for the north-facing slope of "esker" No. 3 and the northwest-facing slope extending from "esker" No. 4 to "esker" No. 6) and across the upper portions of the field south of Lakes C, D, and E. Scattered clumps of *Andropogon gerardi* were superimposed on these areas that supported *Medicago sativa.* The field area south of Lakes C, D, and E (reclaimed mine soil), the small field south of Lake F (old mine spoil), the abandoned (cultivated) field north of Lake F, and the abandoned (cultivated) field south of Lake A generally supported common herbaceous taxa which included *Andropogon gerardi, Panicum virgatum, Poa pratensis, Sorghastrum nutans, Ambrosia artemisiifolia* var. *elatior, Ambrosia trifida, Aster pilosus, Eupatorium serotinum, Fragaria virginiana, Melilotus alba, Melilotus officinalis,* and Solidago altissima. Although not widely distributed, other important forbs include species of *Bidens, Helianthus,* and *Silphium.* Among woody plants, seedlings of *Acer negundo* and *Populus deltoides* were scattered throughout the areas surveyed. In addition to terrestrial vascular plant surveys, Master (1979) and his co-workers identified and mapped several emergent and submergent tracheophytes that were found in Lakes A, B, D, and/or F.

Bryophytes. Zales (1971) reported a list of bryophytes that he collected in 1969 from Goose Lake Prairie State Park. There is no indication in his report that collections were made on abandoned stripmined land. The list consists of 23 mosses and 7 liverworts and is the first published list for Grundy County. However, Snider (1970) was the first to report a species of moss *(Sphagnum compactum)* for Grundy County. Interestingly, the specimen cited by Snider had been collected by Zales (collection no. 964).

Table 1. Treatments of the test plots during the second reclamation effort initiated in 1975-1976 (see Fig. 4) on the land reclamation demonstration site

Treatment	Plot Number 1/
Flat Mine Soil	
None	3, 6, 14, 18
Topsoil	2, 8, 10, 12
Digested sludge	7, 15, 23, 24
Scrubber slag	4, 9, 19, 21
Lime only	1, 5, 17, 20
Digested sludge and lime	11, 13, 16, 22
Slope Mine soil	
Lime only	28, 29, 33, 35
Chemical stablizer and lime	26, 31, 34, 40
Straw mulch and lime	27, 30, 32, 38
Digested sludge and lime	25, 36, 37, 39

1/ Test plots used by the Land Reclamation Program, Argonne National Laboratory (Green and Zellmer 1975, 1976, and 1977; Master and Taylor 1979).

Materials and Methods

Field. The visual surveys and collections of mosses and liverworts that are the subject of this paper were made by walking slowly over the entire site (Fig. 3). The surveys included margins of lakes to the edge of their upper beaches (that is, to the upper limits of water levels and wave actions) and the 40 experimental plots (Fig. 4). Collections were also made in areas adjacent to the site, especially meso-hydric prairie habitats along the northern boundary of the site (Fig. 3). and in park sections E_2 and D (Fig. 1). Park section F along the eastern border of the site was examined, but no bryophytes were found. Surveying these peripheral areas was considered essential in order to assess potential sources of bryophyte disseminules available to the site.

Field-collected specimens were placed in numbered paper bags, and habitat notes were recorded in a field notebook. Furthermore, each collection location was marked, as accurately as possible, on a Mylar overlay of the site map. More than 200 moss and liverwort field specimens (GLP-1 through GLP-288) were collected during 16 field trips to the site.

Laboratory. Field specimens were dried in their respective paper bags and subsequently placed in standard herbarium packets after removing excess soil and extraneous plant materials. Many field specimens consisted of 2 or more species; these were handled in 2 different ways: 1) if two or more species of the same field specimen were essentially different colonies that had grown contiguously to one another, they were separated, placed in separate herbarium packets, and each species was assigned a different alphabetic letter to accompany its field collection number (e.g., GLP-57A and GLP-57b), or 2) if 2 or more species had grown intermixed, and thus were not readily separable, they were retained in the same herbarium packet, but each was assigned a different alphabetic letter or sometimes an alphabetic letter plus a number (e.g., a-1, a-2, etc) to accompany its field collection number. Packet labels will clearly distinguish between these 2 treatments of field specimens when applicable. Voucher specimens are currently housed in the Department of Biological Sciences, Chicago State University.

Taxonomy. Several taxonomic references were used to make identifications, especially Conard (1979), Crum (1976), Flowers (1973), Grout (1903-1910, 1928-1941), Redfearn (1972), and Welch (1957). The scientific names and species authorities follow those of Crum et al. (1973) for the mosses (Musci) and Stotler and Crandall-Stotler (1977) for the liverworts (Hepaticae).

Observations

Taxonomic elements. Thirty-two moss taxa and 1 liverwort taxon are reported for the land reclamation demonstration site and peripheral areas (Table 2). Of the 33 bryophyte species, 14 moss taxa are new recrods for Grundy County. Two mosses, *Entodon cladorrhizans* and *Polytrichum commune,* were found only in areas adjacent to the site (Table 2). Among the remaining taxa, 8 species were common to all 3 areas; 6 species were found on the site and in prairie habitats along the northern boundary of the site. Five species were collected on the site and in park sections on the west side of the site, and 12 species were found only on the site.

Taxon distribution patterns within the site. Specimen locations for collections made in 1976, 1977, and 1978 are shown in Figs. 5, 6, and 7, respectively. Symbols representing specimen locations shown along the southern shore of Lake A (Fig. 5 and 6) were found on a slope consisting of old mine spoil. No mosses or liverworts were found in test plots until the spring of 1978 (Fig. 7). A total of 8 moss taxa was collected among a few of the study plots, but the greatest proliferation occurred on the ridge and slopes extending from "esker" no. 4 to "esker" no. 6. *Barbula unguiculata, Ceratodon purpureus,* and *Funaria hygrometrica* were the most abundant taxa, especially in plots 31, 30, and 29. In contrast, *Ditrichum pallidum, Bryum* spp., and *Weissia controversa* were present, but uncommon. In addition to these 6 mosses, *Physcomitrium pyriforme* and *Pohlia* spp. were found in study plots, but not in appreciable amounts. It was observed that mosses appeared only after the establishment of vascular plants in areas affected by the 1975-1976 reclamation effort.

Distribution patterns for each species within the site are summarized in Table 3. The designated areas used in Table 3 are reference to 3 types of fine-textured mineral soils: a) old (spoil) mine soil, b) reclaimed mine soil, and c) abandoned-field soil. Species are grouped according to the number of areas in which they occurred.

The most widely occurring species were *Ditrichum pallidum* and *Weissia controversa* (Group I), which were found in all areas except the abandoned field on the west side of the site. *Ditrichum pallidum* was the more abundant on reclaimed mine soil than was *Weissia controversa,* which was more abundant on abandoned-field soil.

Group II consists of 4 species that occurred in 4 of the designated areas; however, the distribution pattern and relative abundance of *Brachythecium salebrosum* was quite different from those of *Barbula unguiculata, Ceratodon purpureus,* and *Funaria hygrometrica. Brachythecium salebrosum* was of relatively low abundance and appeared to be associated with more stable habitats, whereas the latter 3 species were more prevalent in disturbed habitats, especially on reclaimed minesoil.

The taxa of Group III were found in 3 of the designated areas. *Rhynchostegium serrulatum* and *Amblystegium varium* had the same distribution patterns; however, the relative abundance of the first species was greater than that of the second. *Bryum caespiticum* is of particular interest because of its rather high relative abundance in the abandoned field north of Lake F in comparison to other habitats where it occurred.

The 5 species listed in Group IV were collected in 3 of the designated areas on the site, and were generally uncommon except for *Bryum* spp. on reclaimed minesoil. *Drepanocladus aduncus* is noteworthy because its occurrence in the area designated as reclaimed mine soil 1972-1973 was localized to the southeast corner of the site.

Table 2. Number of bryophyte specimens identified in collections for the land reclamation demonstration site and adjacent areas

Species 1/	On the Site	North of Site 2/	West of Site 3/
**Entodon cladorrhizans* (Hedw.) C. Muell.	-	-	1
Polytrichum commune Hedw.	-	3	-
**Amblystegium serpens* (Hedw.) B.S.G.	4	1	1
**Campylium hispidulum* (Brid.) Mitt.	2	1	1
Ceratodon purpureus (Hedw.) Brid.	58	3	7
Funaria hygrometrica Hedw.	40	2	2
Leptodictyum trichopodium (Schultz) Warnst.	3	2	2
Mnium cuspidatum Hedw.	4	1	1
Rhynchostegium serrulatum (Hedw.) Jaeg. & Sauerb.	15	3	2
Phycomitrium pyriforme (Hedw.) Hampe	6	1	1
Aulacomnium palustre (Hedw.) Schwaegr.	2	8	-
**Barbula unguiculata* Hedw.	61	2	-
**Brachythecium acuminatum* (Hedw.) Aust.	3	2	-
Bryum spp.	6	2	-
Ditrichum pallidum (Hedw.) Hampe	46	9	-
Pohlia spp.	1	1	-
Amblystegium varium (Hedw.) Lindb.	9	-	1
Bryum caespiticium Hedw.	33	-	2
**Entodon seductrix* (Hedw.) C. Muell.	3	-	1
Leskea gracilescens Hedw.	1	-	3
Weissia controversa Hedw.	16	-	1
Atrichum angustatum (Brid.) B.S.G.	1	-	-
**Atrichum undulatum* (Hedw.) P.-Beauv.	1	-	-
**Brachythecium acutum* (Mitt.) Sull.	1	-	-
**Brachythecium salebrosum* (Web. & Mohr) B.S.G.	11	-	-
**Bryum argenteum* Hedw.	1	-	-
Drepanocladus aduncus (Hedw.) Warnst.	6	-	-
**Eurpynchium pulchellum* (Hedw.) Jenn.	3	-	-
**Fissidens bryoides* Hedw.	2	-	-
**Fissidens cristatus* Wils. *ex* Mitt.	1	-	-
**Haplocladium virginianum* (Brid.) Broth.	1	-	-
Leptobryum pyriforme (Hedw.) Wils.	7	-	-
Lophocolea heterophylla (Schrad.) Dum.	4	-	-

1/ Species (*) are new reports for Grundy Co. (McCleary and Redfearn 1979, Zales 1971).
2/ Prairie area north of the site.
3/ Park sections west of the site consisting of abandoned fields and pasture and areas under cultivation.

Species in each of the final 3 groups were found only in 1 designated area. *Lophocolea heterophylla* (Group V) was the only liverwort found on the site. *Fissidens cristatus* should also be noted because it was uncovered only in the southeast corner of the site as mentioned for *Drepanocladus aduncus*. The occurrence of *Haplocladium virginianum* was apparently quite localized also having been found in only one location along the southern border of the site.

The number of bryophyte species for the designated areas in Table 3 ranged from 2 for the abandoned field south of Lake A to 22 for the oldest reclaimed mine soil (1972-1973). Seven moss taxa were found in each of the 2 following areas, the old (spoil) mine soil field south of Lake F and the reclaimed mine soil (1975-1976) of test plots I-40. The 2 remaining areas, the old (spoil) mine soil slope and the abandoned field north of Lake F, supported 14 bryophyte species each.

Closely associated species. Collected bryophyte species that were intermixed with one another are included in Table 4. Based on this tabulation, *Barbula unguiculata* occurred frequently by *Bryum caespiticium, Ceratodon purpureus,* and *Funaria hygrometrica.* On the other hand *Bryum caespiticium* associated considerably less with *Ceratodon purpureus* and *Funaria hygrometrica,* whereas the latter two species often occurred together. Another common taxon, *Ditrichum pallidum,* apparently had a low fidelity for occurrence with other bryophytes, was found intimately associated with algal-like filamentous mats. *Bryum caespiticium* and a few other species were also collected with these mats, but less frequently.

Although not of common occurrence on the site, some bryophyte taxa still seemed to be closely associated with other species. *Lophocolea heterophylla* was found only in 1 area and in association with *Amblystegium serpens, Campylium hispidulum, Fissidens bryoides,* and *Rhynchostegium serrulatum.* Another example is *Fissidens cristatus,* which was collected only in the southeast corner of the site in companionship with *Drepanocladus aduncus* and *Weissia controversa* (Tables 3 and 4).

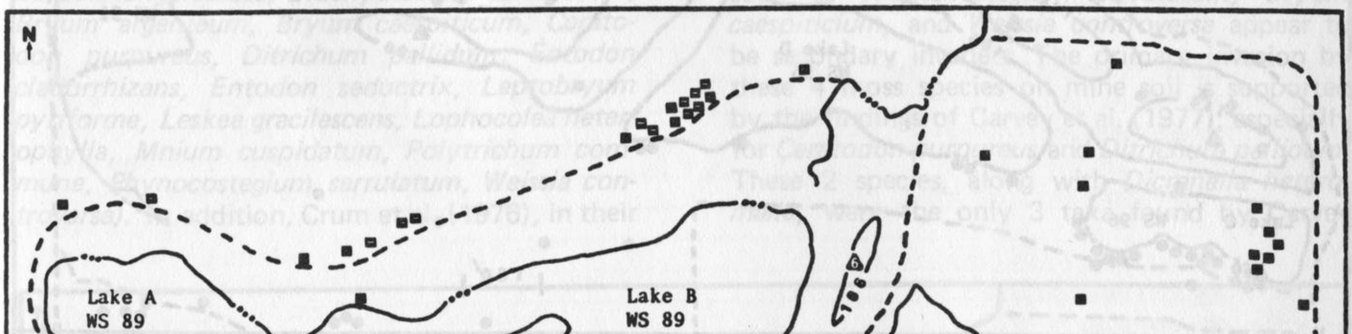


Fig. 5. Locations of bryophyte specimens collected in 1976 on (or near) the land reclamation demonstration site. Key: solid squares -- specimens from the site; solid squares with bar -- specimens collected along the northern boundary of the site. Scale: 160 ft. = 48.8 m.

Discussion and Conclusions

Taxonomic composition. Thirty species of mosses and liverworts were reported by Zales (1971) for Goose Lake Prairie State Park, whereas 33 bryophyte taxa are reported in the present study. Seventeen species are common to both reports, 13 taxa in Zales' list were not found in the present study, and 14 species are reported here as new for Grundy County. This brings the total known number of bryophytes for Grundy County to 44 species, which represents a single

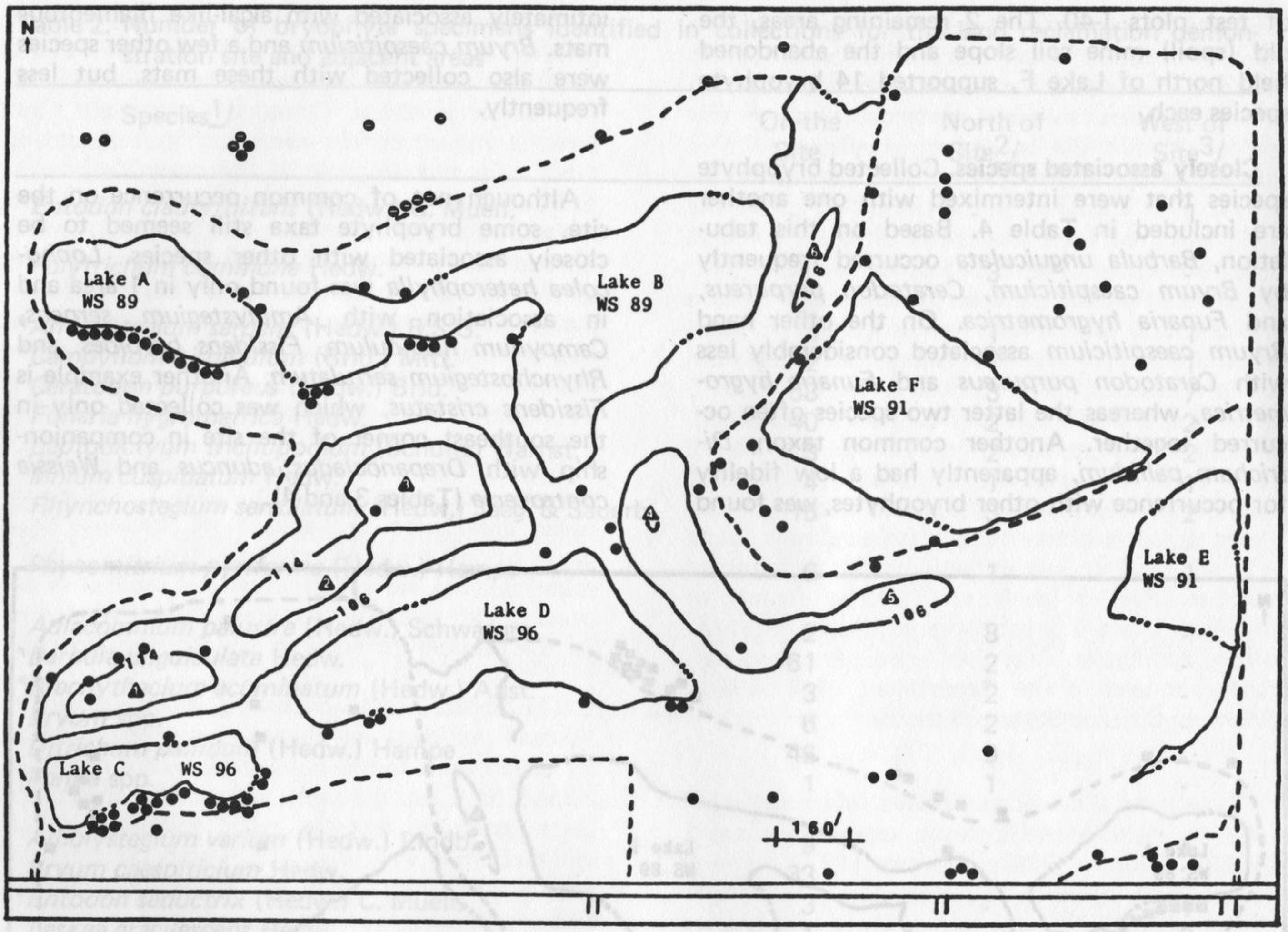


Fig. 6. Locations of bryophyte specimens collected in 1977 on (or near) the land reclamation demonstration site. Key: solid dots -- specimens collected on the site; dots with bar -- specimens collected along the northern boundary of the site. Scale: 160 ft. = 48.8 m.

locality within the county. Collections in other localities and habitats in Grundy County should add a considerable number of new species to its bryoflora.

Particular noteworthy in comparing the bryophyte taxa of Zales' list with those of this study is the larger number of liverworts and a hornwort reported by Zales. Important liverworts include species of *Cephalozia, Cephaloziella, Fossombronia, Riccia, Ricciocarpus,* and the hornwort *Phaeoceros laevis.* On the other hand, significant mosses in the present report (Table 2) include species of *Barbula, Brachythecium, Eurhynchium, Entodon,* and *Fissidens* which apparently were not found by Zales.

The moss *Bruchia sullivantii* collected by Zales (1971) and other taxa of the ephemeral moss group (e.g., *Ephemerum* ssp.) would be expected to occur on the reclamation site, but none were found. Abandoned (cultivated) fields are usually considered suitable habitats for ephemeral mosses. Nevertheless, the abandoned fields shown in Fig. 3 were probably too advanced successionally for *Ephemerum* and perhaps *Bruchia,* because 8 years had passed since the fields were cultivated and because they supported a dense cover of herbaceous plants at the time of the 1976-1979 study. Crum (1973) indicated that species of *Ephemerum* occur during the early stages of succession in abandoned fields following cultivation. In contrast, the recently reclaimed mine soil (1975-1976, Fig. 3) should have provided adequate exposed soil surface for the successful invasion of these mosses, but none were found. Perhaps the soil conditions were too harsh with respect to acidity, rapid desiccation, and high temperatures (Green and Zellmer 1976, Master and Taylor 1979).

Polytrichum commune and *Aulocomnium palustre* were well represented along the northern border of the site, but were not successful invaders of the reclamation site. No specimens of the *Polytrichum commune* were found on the site, whereas only 2 rather poor specimens of *Aulocomnium palustre* were located on the site. Certain disseminules were available, expecially from *Aulocomnium palustre*, which did produce gemmae on pseudopodia. Apparently some gemmae or plant gragments reached the site, but the microhabitats were unsuitable to foster proliferation of gametophytic plants. *Entodon cladorrhizans* is worthy of special mention because it was found only once, on a partially decayed cornstalk (*Zea mays*) west of the site.

There appear to be no research publications concerning the establishment of bryophytes on reclaimed coal stripmined land; however, Carvey et al. (1977) assessed the revegetation of mosses and liverworts on coal strip-mined spoil banks of different ages in southern Iowa. A total of 31 species were reported, of which 18 taxa are common to the present study *(Amblystegium varium, Atrichum angustatum, Aulacomnium palustre, Barbula unguiculata, Brachythecium salebrosum, Bryum argenteum, Bryum caespiticum, Ceratodon purpureus, Ditrichum pallidum, Entodon cladorrhizans, Entodon seductrix, Leptobryum pyriforme, Leskea gracilescens, Lophocolea heterophylla, Mnium cuspidatum, Polytrichum commune, Phynocostegium serrulatum, Weissia controversa).* In addition, Crum et al. (1976), in their generic treatment of *Sphagnum* in Iowa, cite *Sphagnum recurvum* from an abandoned stripmined area. In a study of trace metal accumulation by plants, Lawrey (1977) indicated that *Atrichum angustifolium, Atrichum undulatum, Ditrichum pussillum,* and *Polytrichum piliferum* occur frequently on coal stripmined land in southern Ohio. Apparently, *Polytrichum ohioense* also occurs on the same spoils in Ohio (Lawrey 1978).

Distribution patterns of selected taxa. Comparative distribution patterns and relative abundance assessments (Tables 2 and 3) indicate that *Barbula unguiculata, Ceratodon purpureus, Funaria hygrometrica,* and *Ditrichum pallidum* can be considered primary bryophyte invaders of reclaimed mine soil. On the other hand, species such as *Rhynchostegium serrulatum, Bryum caespiticium,* and *Weissia controversa* appear to be secondary invaders. The primary invasion by these 4 moss species on mine soil is supported by the findings of Carvey et al. (1977), especially for *Ceratodon purpureus* and *Ditrichum pallidum.* These 2 species, along with *Dicranella heteromalla,* were the only 3 taxa found by Carvey

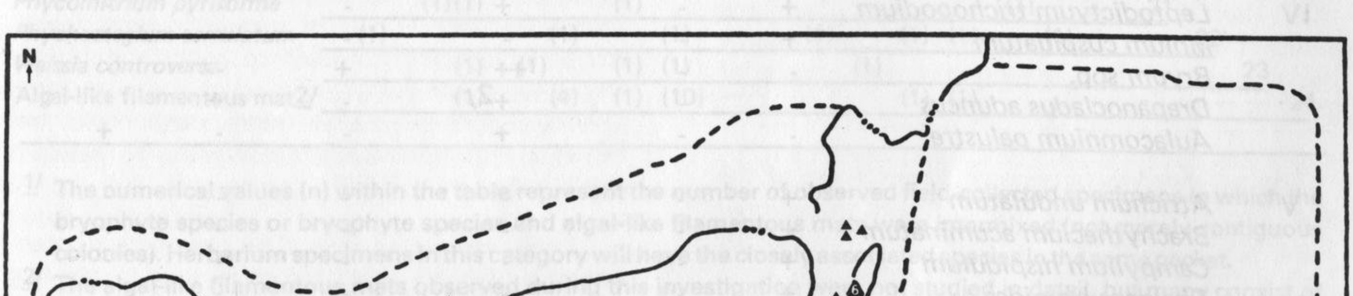


Fig.7. Locations of bryophyte specimens collected in 1978 on the land reclamation demonstration site. Scale: 160 ft. = 48.8 m.

Table 3. Bryophyte species occurrence and their relative abundance with respect to fine-textured mineral spoils in different areas on the land reclamation demonstration site

		Mine Soil				Abandoned	
		Old spoil		Reclaimed		Field Soil	
Group	Species	Slope 1/	Field	1972 - 1973	1975 - 1976	West	Northeast
I	*Ditrichum pallidum*	+	+	+++	++	-	+
	Weissia controversa	+	+	+	+	-	++
II	*Brachythecium salebrosum*	+	+	+	-	-	+
	Barbula unguicalata	-	+	+++	++	-	++
	Ceratodon purpureus	-	+	+++	++	-	++
	Funaria hygrometrica	-	+	+++	++	-	+
III	*Rhynchostegium serrulatum*	++	-	++	-	-	+
	Amblystegium varium	+	-	+	-	-	-
	Amblystegium serpens	+	-	+	-	+	-
	Bryum caespiticium	-	+	++	+	-	+++
	Physcomitrium pyriforme	-	-	+	+	-	+
IV	*Leptodictyum trichopodium*	+	-	+	-	-	-
	Mnium cuspidatum	+	-	-	-	-	-
	Bryum spp.	-	-	++	+	-	-
	Drepanocladus aduncus	-	-	+ 2/	-	+	-
	Aulacomnium palustre	-	-	+	-	-	+
V	*Atrichum undulatum*	+	-	-	-	-	-
	Brachythecium acuminatum	+	-	-	-	-	-
	Campylium hispidulum	+	-	-	-	-	-
	Fissidens bryoides	+	-	-	-	-	-
	Leskea gracilescens	+	-	-	-	-	-
	Lophocolea heterophylla	+	-	-	-	-	-
VI	*Atrichum angustatum*	-	-	+	-	-	-
	Bryum argenteum	-	-	+	-	-	-
	Fissidens cristatus	-	-	+ 2/	-	-	-
	Eurhynchium pulchellum	-	-	+	-	-	-
	Haplocladium virginianum	-	-	+ 3/	-	-	-
	Leptobryum pryriforme	-	-	++	-	-	-
	Pohlia spp.	-	-	+	-	-	-
VII	Brachythecium actum	-	-	-	-	-	+
	Entodon seductrix	-	-	-	-	-	+
Number of taxa		14	7	22	7	2	14

1/ Steep tree-covered slope on original mine spoil south of Lake A.

2/ Collected in extreme southeast corner of site, probably highly disturbed prairie soil rather than reclaimed mine soil (Area B, Fig 3).

3/ Recorded once in transition zone between reclaimed mine soil (1972 73) and tree-shaded fence row on southern boundary of site.

Table 4. Analysis of field-collected specimens for closely associated bryophyte species and bryophyte species associated with algal-like filamentous mats for the land reclamation demonstration site[1]

Species	No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Amblystegium serpens	1																							
Amblystegium varium	2																							
Atrichum angustatum	3																							
Barbula unguiculata	4																							
Bryum spp.	5																							
Bryum argenteum	6				(1)																			
Bryum caespiticium	7				(8)																			
Campylium hispidulum	8																							
Ceratodon purpureus	9			(1)	(8)			(2)																
Ditrichum pallidum	10					(1)		(2)		(1)														
Drepanocladus aduncus	11																							
Entodon seductrix	12				(1)																			
Eurhynchium pulcheilum	13				(1)																			
Fissidens bryoides	14								(1)															
Fissidens cristatus	15											(1)												
Funaria hygrometrica	16		(2)		(13)			(2)		(11)														
Leptobryum pyriforme	17		(1)							(1)							(4)							
Leptodictyum trichopodium	18				(1)				(1)															
Lophocolea heterophylla	19	(1)													(1)									
Mnium cuspidatum	20		(1)																					
Phycomitrium pyriforme	21				(1)	(1)					(1)								(1)					
Phychostegium serrulatum	22		(1)						(1)			(1)			(1)		(1)	(1)		(1)				
Weissia controversa	23					(1)		(1)			(1)	(1)				(1)								
Algal-like filamentous mat[2]	24					(1)			(4)		(1)	(10)					(1)	(1)						

1/ The numerical values (n) within the table represent the number of observed field-collected specimens in which the bryophyte species or bryophyte species and algal-like filamentous mats were intermixed (not merely contiguous colonies). Herbarium specimens in this category will have the closely associated species in the same packet.

2/ The algal-like filamentous mats observed during this investigation were not studied in detail, but many consist of moss protonemata, blue-green algae (Cyanophyta), green algae (Chlorophyta), or a combination of the three.

et al. in transect studies on the youngest coal stripmined spoil banks (5 years). *Barbula unguiculata* occurred on older spoil banks (22 and 27 years), whereas *Funaria hygrometrica* was apparently absent from spoil banks of all ages (5, 14, 17, 22, 17, and 38 years).

Repeated field observations on the most recently reclaimed mine soil at the demonstration site (1975-1976) revealed that the establishment of vascular plants was seemingly a prerequisite for the successful invasion of pioneer mosses (Fig. 5, 6, and 7). This was particularly apparent on the northwest-facing slope of "eskers" no. 4 and no. 6 in test plots 31, 30, and 29 (Fig. 4 and 7). These slopes supported mostly clumps of *Festuca arundinacea* and *Festuca rubra*. The relative abundance of these grasses increased from 1976 through 1978, providing intermediate to dense coverages. Subsequently in 1978, pioneer mosses became established on bare mine soil between grass clumps. Interestingly, species of *Trifolium (T. hybridum, T. pratense,* and *T. repens)* that were in a seed mixture used during the reclamation effort of 1975-1976 had not become successfully established, although a few scattered shoots were observed as were some other herbaceous plants (similar observations on vascular plants were made by William Master, personal communication).

The hypothesis that bryophytes require the prior establishment of higher plants before they can successfully invade fully exposed bare mine soil was advanced previously by Carvey et al. (1977). Their conclusion was based on vegetational observations and analyses of abandoned coal strip-mined spoil banks of different ages. The authors suggest that substrate (mine soil) stabilization by tracheophytes is effective in the growth of mosses and liverworts. This conclusion has considerable merit; however, the consequences of this stabilization must also be considered. With respect to bryophytes, amelioration of several abiotic factors by vascular plants at a narrow zone above and below the soil surface is likely to be critical. Such factors might include pH levels, available nutrients, and moisture and temperature regimes. Of these factors, moisture and temperature are most likely to be affected by higher plant shoots. Soil surface shading by stems and leaves (living and dead) should result in increased moisture and decreased temperatures at the soil surface in contrast to unshaded soil, thus preventing desiccation to protonemata and young gametophytic shoots of bryophytes. Indeed, mine-soil surface moisture levels at 0-3 inches (0-7.6 cm) and temperatures at 2 inches (5.1 cm) are known to become unfavorable for plant growth. Master and Taylor (1979) found that these abiotic factors were more favorable in mine soil, under straw mulch, than in exposed mine soil during late spring and early summer. Stations located on the northwest-facing slope of "eskers" no. 4 and no. 6 had mean (for 10 weeks) mine soil temperatures of 72.5°F (22.5°C) under straw mulch compared to 86°F (30°C) for a control (exposed) mine soil. Temperature ranges were 68 - 77°F (20 - 25°C) and 77 - 100.4°F (25 - 38°C), respectively. On the other hand, moisture levels for the same location averaged (for 10 weeks) 23% under straw mulch and 12% for the control with ranges of 20-25% and 10-18%, respectively.

Species diversity among different areas of the site. The number of bryophyte taxa in each designated area varied considerably (Table 3). This reflects differences in microhabitats both within and between areas (Figs. 3 and 4). The finding of only 2 species in the abandoned field south of Lake A was surprising. Perhaps a more exhaustive search would yield more taxa; however, this area is wetter than the abandoned field north of the Lake F, as indicated by the presence of *Drepanocladus aduncus.* On the other hand, the abandoned field north of Lake F supported 14 species, but this area is much larger than the abandoned field south of Lake A and is more diverse with respect to microtopography and vascular plant coverage.

The mine-soil areas consisting of old coal strip-mine spoil were quite different historically and in bryophyte composition. The small mine-soil field south of Lake F was apparently laid bare during the 1972-1973 reclamation effort, but was not treated with lime or seeded. A light-to-intermediate coverage of spermatophytes became established, consisting mostly of forbs. The few moss species that were found and their low relative abundance indicates that they were recent arrivals.

The second area in which the substratum consisted of old spoil was the slope above the south shore of Lake A. This area is quite small and represents a remnant coal strip-mine spoil bank that has probably been revegetated for over 30 years. The occurrence of 14 bryophyte species is not disappointing in view of the slope's limited area. In addition, this slope was undoubtedly subjected to some disturbance during reclamation operations. Interestingly, 7 of the 14 species were not reported by Carvey et al. (1977) in their vegetation analyses of abandoned coal strip-mine spoil banks in southern Iowa. Those found on the slope above the south shore of Lake A, but not found by Carvey et al. were *Amblysteguim serpens, Atrichum undulatum, Brachythecium acuminatum, Campylium hispidulum, Fissidens bryoides, Funaria hygrometrica,* and *Leptodictyum trichopodium.*

Soils of the remaining areas consist of reclaimed mine soils that differ with respect to reclamation efforts. These areas differ in bryophyte composition (22 species vs. 7 species). The larger number of moss taxa on the older reclaimed mine soil (1972-1973) indicates a greater number of microhabitats created by a slightly more diverse topography and an earlier establishment of flowering plants. The first successful moss invaders of the recently reclaimed mine soil (1975-1976) seem somewhat paradoxical because these species, especially *Ceratodon purpureus* and *Funaria hygrometrica, generally favor alkaline conditions (Crum 1973).*

Closely associated taxa. The observations mentioned previously in reference to species growing intermixed (Table 4) are not new to bryology (Rastorfer 1978). However, this study indicates that intimate associations among some mosses may not be indiscriminate. Particularly noteworthy was the observation that the pioneer moss species, *Barbula unguiculata, Ceratondon purpureus* and *Funaria hygrometrica* frequently frew intermixed. In contrast, the primary invader *Ditrichum pallidum* generally grew independent of other moss species, but was frequently associated with algal-like filamentous mats. These mats probably consisted primarily of moss protonemata; however, a cursory microscopic examination also revealed filaments of blue-green and green algae.

Role of bryophytes in plant community development. The function of mosses and liverworts during growth and differentiation of prairie plant communities on reclaimed mine soil is still unknown. However, past investigations provide evidence in support of the following 3 hypotheses.

Bryophytes, especially mosses, reduce soil erosion by binding soil particles with their rhizoidal systems and by the generally high water-holding capacity of their gametophytic shoots (Conard 1935, Leach 1931, Marsh and Loerner 1972, Odu 1978).

Mosses, and probably liverworts, reduce heavy-metal toxicity to certain vascular plants at soil surfaces because bryophytes have a capacity to concentrate heavy metal elements (Barclay-Estrup and Rinne 1979, Berg and Vogel 1973, Burton and Peterson 1979, Czarnowska and Rejment-Grochowska 1974, Lawrey 1977 and 1978, Shacklette 1965).

Bryophytes may enhance nitrogen fixation by means of their associations with blue-green algae and possibly with nitrogen-fixing bacteria (Granhall and Selander 1973, Snyder and Wullstein 1973, Spiess et al. 1977, Reddy and Giddens 1975, Rodgers and Henriksson 1976, Rodgers and Stewart 1977, Steward and Rodgers 1977, Vlassak et al. 1973).

Acknowledgements

I gratefully acknowledge support to this investigation by the Illinois Institute of Environmental Quality (now the Illinois Department of Energy and Natural Resources) and the U.S. Department of Energy through the auspices of Land Reclamation Program and the Center for Education Affairs at Argonne National Laboratory.

Literature Cited

Barclay-Estrup, P. and R. J. K. Rinne. 1979. Trace element accumulations in a feather moss and in soil near a Kraft paper mill in Ontario. The Bryologist 82:599-602.

Berg, W. A. and W. G. Vogel. 1973. Toxicity of acid coal-mine spoils to plants. In R. J. Hutnik and G. Davis, eds., pp. 57-68, Ecology and Reclamation of Devastated Land, Volume 1. Gordon and Breach, New York.

Burton, M. A. S. and P. J. Peterson, 1979. Studies on zinc localization in aquatic bryophytes. The Bryologist 82:594-598.

Carter, R. P., R. E. Zimmerman and A. S. Kennedy. 1973. Strip mine reclamation in Illinois. Illinois Institute for Environmental Quality (now Illinois Dept. of Energy and Natural Resources) Report, 102 pp. plus appendices.

Carvey, K., D. R. Farrar and D. C. Glenn-Lewin. 1977. Bryophytes and revegetation of coal spoils in southern Iowa. The Bryologist 80:630-637.

Conard, H. S. 1935. Mosses and soil erosion. Iowa State J. Sci. 9:347-351.

Conard, H. S. 1979. How to Know the Mosses and Liverworts, revised by P. L. Redfearn, Jr. Wm. C. Brown Company Publishers, Dubuque, Iowa.

Crum, H. 1973. Mosses of the Great Lakes Forest. University Herbarium, University of Michigan, Ann Arbor. 404 pp.

Crum, H. 1976. Mosses of the Great Lakes Forest. University Herbarium, University of Michigan, Ann Arbor. 404 pp.

Crum, H. A., N. R. Lersten and G. H. Crum. 1976. Sphagnum taxa and their distribution in Iowa. Proc. Iowa Acad. Sci. 83:98-101.

Crum, H. A., W. C. Steere and L. E. Anderson. 1973. A new list of moss of North America north of Mexico. The Bryologist 76:85-130.

Czarnowska, K. and I. Rejment-Grochowska. 1974. Concentration of heavy metals - iron, manganese, zinc and copper in mosses. Acta Polski Towargystwo Botaniczne 43:39-43.

Flowers, S. 1973. Mosses of Utah and the West, edited by A. Holmgren. Brigham Young University Press, Provo, Utah.

Green, B. B. and S. D. Zellmer. 1976. Grundy County demonstration site phase II progress report for 1975-1976. Argonne National Laboratory Report ANL/EES-TM-4.

Green, B. B. and S. D. Zellmer. 1977. Grundy County demonstration site phase II progress report for 1976-1977. Argonne National Laboratory Report ANL/EES-TM-5.

Grout, A. J. 1903-1910. Mosses with Handlens and Microscope. Published by the author, Brooklyn, New York.

Grout, A. J. (editor). 1928-1941. Moss Flora of North America North of Mexico, volumes 1-3. Published by the editor, Newfane, Vermont (Reissued, partly in facsimile, by Hafner Publishing Company, New York, 1972).

Lawrey, J. D. 1977. Trace metal accumulation by plant species from a coal strip-mining area in Ohio. Bull. Torrey Bot. Club 104:368-375.

Lawrey, J. D. 1978. Trace metal dynamics in decomposing leaf litter in habitats various influenced by coal strip mining. Can. J. Bot. 56:953-962.

Leach, W. 1931. On the importance of some mosses as pioneers on unstable soils. J. Ecology 19:98-102.

Marsh, W. M. and J. M. Koerner. 1972. Roll of moss in slope formation. Ecology 53: 489-493.

Master, W. A. 1979. Characterization of three acid strip mine lakes in Grundy County. Illinois. Argonne National Laboratory Report ANL/LRP-TM-15.

Master, W. A. and J. D. Taylor. 1979. Grundy County reclamation demonstration project phase II progress report for 1977-1978. Argonne National Laboratory Report, ANL/LRP-TM-16.

McCleary, J. A. and P. L. Redfearn, Jr. 1979. Checklist of the mosses of Illinois. Trans. Illinois State Acad. Sci. 72:28-51.

Odu, E. A. 1978. The adaptive importance of moss rhizoids for attachment to the substratum. J. Bryology 10:163-181.

Rastorfer, J. R. 1978. Composition and bryomoss of the moss layers of two wet-tundra-meadow communities near Barrow, Alaska. In L. Tieszen, ed., pp. 169-183, Vegetation and production ecology of an Alaskan arctic tundra. Ecological Studies 29, Springer-Verlag, New York.

Reddy, B. and J. Giddens. 1975. Nitrogen fixation by algae in fescuegrass soil crusts. Soil Sci. Soc. Am. Proc. 39:654-656.

Redfearn, Jr. P. L. 1972. Mosses of the interior highlands of North America. Ann. Missouri Bot. Garden 59:1-103.

Rodgers, G. A. and E. Henriksson. 1976. Associations between the blue-green *Anabaena variabilis* and *Nostoc muscorum* and the moss *Funaria hygrometrica* with reference to the colonization of Surtsey. Botanica Islandica 4:10-15.

Rodgers, G. A. and W. D. P. Stewart. 1977. The cyanophyte-hepatic symbiosis I. Morphology and physiology. New Phytologist 78:441-458.

Shacklette, Hansford T. 1965. Element control of bryophytes. Geol. Surv. Bull. 1198-D. 21 pp.

Snider, J. A. 1970. The genus *Sphagnum* in Illinois. Trans. Ill. State Acad. Sci. 63:329-338.

Snyder, J. M. and L. H. Wullstein. 1973. Nitrogen fixation on granite outcrop pioneer ecosystems. The Bryologist 76: 196-199.

Spiess, L. D., B. P. Lippincott and J. A. Lippincott. 1977. Comparative response of *Pylaisiella selwanii* to *Agrobacterium* and *Rhizobium* species. Bot. Gaz. 138:35-40.

Stewart, W. D. P. and G. A. Rodgers. 1977. The cyanophyte-hepatic symbiosis II. Nitrogen fixation and the interchange of nitrogen and carbon. New Phytologist 78:459-471.

Stotler, R. and B. Crandall-Stotler. 1977. A checklist of the liverworts and hornworts of North America. The Bryologist 80:405-428.

Vlassak, K., E. A. Paul and R. E. Harris. 1973. Assessment of biological nitrogen fixation in grassland and associated sites. Plant and Soil 38:637-649.

Welch, W. H. 1957. Mosses of Indiana. Dept. of Conservation, Indianapolis, Indiana.

Zales, W. W. 1971. Bryophytes of Goose Lake Prairie, Illinois. Trans. Ill. State Acad. Sci. 64:222-224.

USING PRAIRIE GRASSES FOR FORAGE PRODUCTION ON MINE SPOIL

William F. Kuenstler, Manager
Soil Conservation Service
Plant Materials Center
Quicksand, Kentucky 41363

Donald S. Henry, Plant Material Specialist
Soil Conservation Service
333 Waller Avenue
Lexington, Kentucky 40504

Samuel A. Sanders, Assistant Manager
Soil Conservation Service
Plant Material Center
Quicksand, Kentucky 41363

Abstract. To determine the usefulness of several prairie grasses for forage production on mine spoil, 8 species in 8 different seeding mixtures were established at 2 sites in Kentucky. Yield and forage quality of all species at both sites were determined. The data show that some prairie grasses, seeded alone or with a legume, can produce yields equal to or better than commonly used plants. Forage quality of prairie grasses grown on mine spoil is equal to the quality of grasses grown conventionally.

Introduction

Most of the 120,000 ha (Kentucky Department of Mine and Minerals 1980) stripmined in Kentucky since 1971 has been reclaimed in such a manner that is could be used for several purposes, such as residential or industrial development, or agriculture. However, much of this land is far from existing utilities, and is accessible only by unimproved roads, so it is not desirable to residential or industrial development. And although most of this reclaimed land is level enough for the operation of farm machinery, much of it is so rocky that tillage implements would be damaged in the normal tillage operations. A feasible agricultural use of this land is pasture or hayland. Forage species could be established during the reclamation process and no further tillage operations would be needed.

Henry et al. (1979) reported that some warm-season prairie grasses, both native and exotic, can establish as well as or better than the standard reclamation seeding mixtures. 'Blackwell' switchgrass (*Panicum virgatum* L.) and Caucasian bluestem (*Andropogon caucasicus* Trin.) whether seeded alone or in a mixture with a legume, produced stands equal to or better than a mixture of 'KY-31' tall fescue, *Festuca arundinacea* Schreb. and 'Interstate' sericea lespedeza, *Lespedeza cuneata* (Dumont) G. Don.

Although it is known that prairie grasses can be successfully established on mine spoil, information is lacking on the amount and quality of forage these grasses can produce.

Materials and Methods

Identical studies were established in the eastern and western Kentucky coal fields in April 1976. The differences in soils, climate, and type of mining between the 2 areas were the reasons for establishing separate evaluation sites.

The western Kentucky site is on the Vogue Mine of Peasbody Coal Company in Muhlenberg County near Central City, Kentucky. The soils in this area are formed in acid sandstone and shale, with a thin loess cap. The pH of the untreated spoil ranged from 4.5 to 5.5. The growing season averages 180-185 days, and rainfall distribution is split equally between the first 6 months and the last 6 months of the year. The summers tend to be hotter and drier, with a better chance of drought stress, than eastern Kentucky. Area stripmining is the most commonly used method of mining. The spoil is replaced so that the land is level enough for pasture or hayland production.

The eastern Kentucky site is in Breathitt County, near Jackson, Kentucky, on the Press Howard Fork Mine of Falcon Coal Company. The soils in this area are shallow residual soils formed in acid sandstone and calcareous shale. After mining, the spoil pH ranges from 6.4 to 6.8. Rainfall is split 45-55 between the first 6 months and last 6 months of the year. Summers are hot, but generally adequate moisture is available. The predominate mining method is mountaintop removal. As the name implies, this method removes the entire peak of the mountain, leaving the entire coal seam exposed. Once the coal is removed, the large, relatively flat areas left are suitable for hayland or pasture.

Eight species or cultivars were established at both sites. They are 'Kaw' big bluestem (*Andropogon gerardi* Vitman), "Cheyenne" Indian grass (*Sorghastrum nutans* (L.) Nash), 'Blackwell' switchgrass, 'Chemung' crownvetch, (*Coronilla varia* L.), Caucasian bluestem, 'KY-31' tall fescue, 'Interstate' sericea lespedeza, and 'Appalow' sericea lespedeza, a prostrate cultivar.

Eight different seeding preparations were used at each site. These are given in Table 1. Prior to seeding, 4-16-4 fertilizer was applied at 336 kg/ha. At the western Kentucky site, agricultural limestone was applied at 616 quintals/ha.[1/] No limestone was applied in eastern Kentucky. The fertilizer and limestone were incorporated with a disk. The seed was broadcast, by hand or with a cyclone seeder, on 2.1m x 3.8m plots. After seeding, straw mulch at 4484 kg/ha was applied.

Beginning in 1978, each plot was clipped twice a year according to the schedule in Table 2. At the western Kentucky site, additional plots were staked off on conventionally reclaimed spoil immediately adjacent to the study site. This area was seeded to 'KY-31' tall fescue and alfalfa, *Medicago sativa* L., by the coal company as a part of the required reclamation process. These plots were clipped on May 15 and August 25.

Before each plot was harvested, a sample of each seeded species was taken by hand. This sample was analyzed for forage quality. All scientific names are based on Hitchcock (1936, 1950) or Gleason and Cronquist (1963).

Results and Discussion

The 2 year average (1978 and 1979) for yield, and % DMD, sugar, and protein is given in Table 3.

In eastern Kentucky, there is no difference in yield among the seeding mixtures. These yields are very good for a site whose physical and chemical conditions for growth are somewhat less than optimum. Average yields from conventional pasture or hayland in eastern Kentucky is 3500 to 4500 kg/ha.

Table 1. Species and species mixtures with seeding rates (kg PLS/ha) used in experimental plots

Species	Seeding Rate
'Kaw' big bluestem	16.9
'Cheyenne' Indian grass	16.9
'Blackwell' switchgrass	11.1
'Chemung' crownvetch	22.5
Caucasian bluestem	22.5
'Blackwell' switchgrass & 'Interstate' sericea lespedeza	11.1 33.8
'KY-31' tall fescue & 'Interstate' tall fescue	33.8 33.8
Caucasian bluestem & 'Appalow' sericea lespedeza	22.5 33.8

Table 2. Clipping schedule

Species	5/15	6/15	7/15	8/25	After Frost
Big bluestem			x		x
Indian grass			x		x
Switchgrass			x		x
Crownvetch		x		x	
Caucasian bluestem		x		x	
Switchgrass & 'Interstate sericea			x	x	
Tall fescue & 'Interstate' sericea	x		x		
Caucasian bluestem & 'Appalow' sericea		x		x	

1/ A quintal is 100 kg.

Table 3. Average yield (kg/ha) and forage quality (percent sugar, protein and DMD) during 2 years (1978, 1979) for plots in (I) eastern and (II) western Kentucky

	I				II			
		Percent				Percent		
Species	Yield	Sugar	Protein	DMD	Yield	Sugar	Protein	DMD
Big bluestem	3646a[1]/	3.9a[1]/	5.4e[1]/	18.5f[1]/	1398bc[1]/	4.6a[1]/	5.6[1]/	19.7e[1]/
Indiangrass	4013a	5.1a	5.5e	21.1ef	1759b	4.3a	5.7d	19.8e
Switchgrass	5216a	4.7a	5.6e	22.7ef	3173ab	5.3a	5.2d	22.8d
Crownvetch	4796a	4.6a	24.1a	47.2a	3358a	3.5a	22.9a	51.0a
Caucasian bluestem	6087a	4.7a	7.8e	25.1de	4416a	5.1a	6.7a	24.6d
Switchgrass & 'Interstate' sericea	6797a	4.5a 3.1a	8.4cde 14.8abcd	25.4cde 26.6bcde	2379b	5.7a 5.2a	8.2cd 14.3bc	26.6d 30.4c
Tall fescue & 'Interstate' sericea	6468a	3.0a 3.0a	14.3bcde 17.3ab	30.8b 30.3bc	953c	3.6a 1.6a	13.5bc 17.6ab	29.1c 30.1c
Caucasian bluestem & 'Appalow'	6491a	4.7a 3.2a	7.0de 16.9abc	25.5cde 29.6bcd	3575a	5.3a 3.2a	14.3bc	29.2c
Tall fescue & alfalfa[2]/					1468b	3.3a 2.3a	13.3bc 18.5ab	30.0c 43.7b

[1]/ Within each column, means followed by the same letter are not significantly different at the 5% level of probability, using Duncan's multiple range test

[2]/ Harvested from conventionally reclaimed spoil adjacent to study area, western Kentucky only.

Forage quality varies considerably among the seeded species. Switchgrass, crownvetch, and Caucasian bluestem are higher in sugar than the other species. Crownvetch and 'Interstate' and 'Appalow' sericea lespedeza are higher in protein than the other species. Crownvetch is also highest in percent DMD, significantly higher than tall fescue, 'Interstate' sericea, Caucasian bluestem, and 'Applow' sericea, all of which are approximately equal in percent DMD. There is no significant difference in percent sugar among species.

In western Kentucky, Caucasian bluestem seeded alone, the Caucasian bluestem-'Appalow' sericea mixture, crownvetch, and switchgrass had the highest yields. Surprisingly the tall fescue-'Interstate' sericea mixture had the lowest yield.

The variation in forage quality follows almost the same pattern as in eastern Kentucky. Crownvetch, 'Interstate' sericea, and alfalfa are highest in protein. Crownvetch has the highest percent DMD, followed by alfalfa. So, in eastern Kentucky, there is no difference among the species in percent sugar.

The yields vary considerably between the 2 sites. Yields of all species or mixtures are higher at the eastern Kentucky site. The tall fescue-'Interstate' sericea mixture, one of the highest yieldling mixtures in the east, had the lowest yield in western Kentucky. With this exception, the species or mixtures producing the highest yields are the same at both locations. The consistently lower yields in western Kentucky cannot be attributed to any cause. The major contributing factor is probably moisture stress, since the western part of the state had prolonged periods of dry weather in the summer of both 1978 and 1979. Forage quality did not vary significantly between the 2 study sites for any species.

Conclusions and Summary

With an increasing number of acres being mined, there will be a demand for more plants that can be used to successfully revegetate mine spoil and also have an economic value. Some warm-season grasses can meet these needs. Switchgrass and Caucasian bluestem, whether seeded alone or with a legume, can be established on mine spoil, and will produce forage yields equal to or better than commonly used species. The forage quality of these grasses is somewhat lower than tall fescue, particularly in percent protein. But warm-season grasses in general are lower in protein than cool-season grasses.

The prairie grasses cannot replace tall fescue or other cool-season grasses for reclamation in the eastern coal field, but in a well-planned reclamation program where pasture or hayland is the ultimate use, prairie grasses can provide a valuable supplement to the cool-season grasses in forage production programs.

Literature Cited

Gleason, Henry A. and Arthur Cronquist. 1963. Manual of Vascular Plants of the Northeastern United States and Adjacent Canada. G. Van Nostrand Co., Inc., Princeton, New Jersey.

Henry, Donald S., William F. Juenstler and Samuel A. Sanders. An evaluation of establishment methods using various forage plants on surface mined land in Kentucky. Proc. Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation. University of Kentucky, Lexington, Dec. 4-7, 1979.

Hitchcock, A. S. 1950. Manual of the Grasses of the United States. Misc. Publ. 200 (rev. by Agnes Chase). U.S. Dept. Agri., Supt. Doc., Wash., D.C.

Hitchcock, A. S. 1936. Manual of the Grasses of the West Indies. Misc. Publ. 243. U.S. Dept. Agri., Supt. Doc., Wash., D.C.

Kentucky Department of Mines and Minerals, Personal communication, 1980.

STUDIES OF SOIL MICROFUNGAL POPULATIONS OF A PRAIRIE RESTORATION PROJECT

J. R. Holler
Department of Biology
University of Wisconsin in-Platteville
Platteville, Wisconsin 53818

Abstract. Microfungal populations were isolated from soil using the dilution plate technique. Soil samples were taken from the top 3 inches of the A_1 horizon in a prairie restoration area over a 3-year period. Average population numbers for each sampling period as well as indices of similarity were calculated. During the second and third year of sampling, samples were taken before and after burning the area. Populations from a natural prairie remnant were determined in the third year of sampling. In the first year of sampling, microfungal populations demonstrated a seasonal rise and decline. Indices of similarity showed the composition of the communities to be similar during the spring and summer sampling periods of the first year, becoming dissimilar in the fall. In the second year, comparisons showed only populations prior to burning to be similar to those of the same period of the previous year. During the remainder of the second and third years, all microfungal populations were dissimilar in the restoration area. Populations from all sampling periods differed from those of the prairie remnant.

Introduction

Assays of microfungal populations have been performed on a multitude of diverse terrestrial ecosystems. Orpurt and Curtis (1957) studied microfungal populations in the soils of 25 Wisconsin prairies. However, seldom is an opportunity provided to study the succession of microfungi in a long term restoration project. The following study was initiated in an attempt to ascertain what changes take place in soil populations as the vegetation of an area changes.

Materials and Methods

The restoration area consisted of an area of approximately 2 ha (5 - 6 acres) on the campus of the University of Wisconsin-Platteville. Eight sampling sites, 20 m apart, were distributed along a transect on a moderately sloping hillside. During the summer of 1977, a sampling of the vetetation was conducted. Some of the common plants were thistle, morning glory, ragweed, chickory, Queen Anne's lace, timothy, panicum, milkweed, lamb's quarter, red clover, sweet clover, mustard, dandelion, wild parsnip, sedges, and brome grass. A prairie remnant located along a railroad right-of-way was used for reference, and is designated as Ipswich.

In the restoration area, soil samples were taken from the top 3 inches of the A_1 horizon over a 3-year peiod. During the third year, samples were taken from the prairie remnant. Soil temperatures were recorded at the time of sampling. Soil samples were frozen until they could be processed. The pH of the soil was determined electrolytically at the time of plating.

The microfungi were isolated by the dilution plate method. A ml of the final $1/10^4$ dilution for each soil sample was pipetted on to each of 5 petri plates of Martin's medium. The plates were allowed to incubate 5 days at room temperature. The number of colonies on each plate was counted and an average taken. This number is reported as the population for each sampling period. Thirty isolates were taken at random from each plated sample. These were transferred to Malt Extract Agar slants allowed to incubate at room temperature for a period of 2 - 3 weeks. The cultures were then compared and a representative of each entity retained for identification.

The frequency percent of each entity isolated was calculated (Tresner, Backus, and Curtis 1954) by dividing the number of samples in which the species occurred by the total number of samples collected. The Index of Similarity (Curtis 1959) between populations of different sampling periods was also calculated. This was determined by the formula $(2W/(A+B))\times100$ where A is the total of the frequencies in one population, B is the total of the frequencies in the other population and W is the total of the frequencies shared by the 2 populations. Thus an index of similarity of zero would indicate no similarity in composition whereas an index of 100 would mean that the populations were identical in both species.

Results and Discussion

The average number of populations per gram of soil for each sampling period, average temperature and pH range for sampling sites are reported in Table 1. In the first year of sampling (1977), average populations demonstrated a seasonal rise and decline. Soil temperatures also reflected a seasonal change. There was some decline in number of populations after burning in the second and third year. The prairie remnant (Ipswich) demonstrated the lowest number for all sites. It was also noted that there was a considerable rise in soil temperatures after burning. This apparently was due to the removal of an insulating layer of dead vegetation. Why this should have a negative effect on total fungal populations is not clear.

Table 1. Average propagule populations per gram of soil, average temperature, and pH range of soil for different sampling periods

Sampling Period	Population Density ($X10^4$)	T^oC	pH
March 22, 1977	15.1	3.8	6.5-7.5
June 16, 1977	29.2	19.1	6.3-7.2
November 11, 1977	12.5	6.0	6.4-7.1
April 11, 1978-BB1/	15.1	7.9	6.4-7.2
April 27, 1978-AB2/	13.2	16.4	6.3-7.1
April 18, 1979-BB	9.2	7.2	6.1-7.2
April 26, 1979-AB	8.6	11.9	6.0-6.8
Ipswich3/ - April 14, 1979	8.2	4.5	6.5-7.2

1/ BB - before burning
2/ AB after burning
3/ Ipswich = natural prairie remnant

There seemed to be no significant change in the pH of the soil, although a slight trend toward increased acidity was noted. This could possibly lead to a favorable effect on microfungal populations; however, the decline in numbers of microfungal propagules seems to be in opposition to this concept.

Indices of similarity are reported in Table 2. Populations in the area under restoration were similar in March and June of the first year (1977). The populations of these 2 sampling periods were found to be dissimilar when compared to those of the fall of that year. In the second year of sampling only those populations determined before burning when compared to those of March 1977 were found to be similar; however, for the post-fire sampling periods in 1978 microfungal populations differed. All populations in the restoration area were dissimilar in similarity values to those determined for the prairie remnant.

The following fungal entities occurring in at least 6 samples over the 3-year period have been identified: *Verticillium glaucum* Bonorden, *Trichoderma lignorum* (Tode) Harz, *Spicaria violacea* Abbot, *Penicillium variable* Sopp, *P. pulvillorum Turfitt*, P. ochro-cholorn *Biourge*, *P. humuli* Van Beyma, *Metarrhizium brunneum* Petch, *Cephalosporium* sp. Corda, and *Fusarium* sp. Link.

Since there seems to be no substantial change in vegatation in the experimental area, it would appear that the changes in composition are due either directly or indirectly to burning. There was

Table 2. Matrix showing indices of similarity for each sampling period

Date	Mar -77	June -77	Nov -77	Apr 78-BB	Apr 78-AB	Apr 79-BB	Apr 79-AB
June 77	59.2	-	-	-	-	-	-
Nov. 77	36.7	36.1	-	-	-	-	-
Apr. 78-BB	52.1	45.3	48.3	-	-	-	-
Apr. 78-AB	37.3	40.8	36.9	45.5		-	-
Apr. 79-BB	28.7	30.0	24.3	27.2	27.1	-	-
Apr. 79-AB	30.2	31.5	12.0	26.6	27.6	47.7	-
Ipswich	7.9	10.3	10.6	17.3	10.6	27.7	20.4

at least 1 rainfall event between the burn and sampling. The leaching of minerals into the soil would be expected to have an effect on the composition of microfungal populations. Why this would cause a reduction in total numbers is not clear. This could be due to an increase in the concentration of certain minerals which at higher levels are toxic to some fungi. Perhaps more precise conclusions can be drawn when a complete identification of fungal entities is made.

Literature Cited

Curtis, J. T. 1959. The Vegetation of Wisconsin. The University of Wisconsin Press, Madison.

Orpurt, P. A. and J. T. Curtis. 1957. Soil microfungi in relation to the prairie continuum in Wisconsin. Ecology 38:628-637.

Tresner, H. D., M. P. Backus and J. T. Curtis. 1954. Soil microflora in relation to the hardwood forest continuum in southern Wisconsin. Mycologia 46:314-333.

in the other population and W is the total of the frequencies shared by the 2 populations. Thus an index of similarity of zero would indicate no similarity in composition whereas an index of 100 would mean that the populations were identical in both species.

Results and Discussion

The average number of populations per gram of soil for each sampling period, average temperature and pH range for sampling sites are reported in Table 1. In the first year of sampling (1977), average populations demonstrated a seasonal rise and decline. Soil temperatures also reflected a seasonal change. There was some decline in number of populations after burning in the second and third year. The prairie remnant (Ipswich) demonstrated the lowest number for all sites. It was also noted that there was a considerable rise in soil temperatures after burning. This apparently was due to the removal of an insulating layer of dead vegetation. Why this should have a negative effect on total fungal populations is not clear.

Table 1. Average propagule populations per gram of soil, average temperature, and pH range of soil for different sampling periods.

Sampling Period	Population Density ($X10^4$)	T°C	pH
March 22, 1977	15.1	[illegible]	6.6-7.6
June 16, 1977	28.2	[illegible]	[illegible]
November 11, 1977	12.8	[illegible]	[illegible]
April 11, 1978-BB[1]	15.1	[illegible]	6.4-7.2
April 27, 1978-AB[2]	13.2	[illegible]	[illegible]
April 18, 1979-BB	9.2	7.2	6.1-7.2
April 26, 1979-AB	8.6	11.9	6.0-6.8
Ipswich[3] - April 14, 1979	8.2	4.5	6.5-7.2

[1] BB - before burning
[2] AB - after burning
[3] Ipswich = natural prairie remnant

There seemed to be no significant change in the pH of the soil, although a slight trend toward increased acidity was noted. This could possibly lead to a favorable effect on microfungal populations; however, the decline in numbers of microfungal propagules seems to be in opposition to this concept.

Indices of similarity are reported in Table 2. Populations in the area under restoration were similar in March and June of the first year (1977). The populations of these 2 sampling periods were found to be dissimilar when compared to those of the fall of that year. In the second year of sampling only those populations determined before burning when compared to those of March 1977 were found to be similar; however, for the post-fire sampling periods in 1978 microfungal populations differed. All populations in the restoration area were dissimilar in similarity values to those determined for the prairie remnant.

The following fungal entities occurring in at least 6 samples over the 3-year period have been identified: *Verticillium glaucum* Bonorden, *Trichoderma lignorum* (Tode) Harz, *Spicaria violacea* Abbot, *Penicillium variable* Sopp, *P. pulvillorum* *Turfitt*, P. ochro-cholorn *Biourge*, *P. humuli* Van Beyma, *Metarrhizium brunneum* Petch, *Cephalosporium* sp. Corda, and *Fusarium* sp. Link.

Since there seems to be no substantial change in vegetation in the experimental area, it would appear that the changes in composition are due either directly or indirectly to burning. There was

ANNUAL VEGETATION CHANGES IN A RECONSTRUCTED PRAIRIE

Eugene E. Woehler
and
Mark A. Martin
Wisconsin Department of Natural Resources
3911 Fish Hatchery Road
Madison, Wisconsin 53711

Abstract. A 2-acre parcel of cropland was seeded to 23 species of native forbs and 7 species of native grasses in 1974. Seeds of all species originated from southern Wisconsin ecotypes. The objective of this study was to determine the degree of successful establishment of a simulated tallgrass prairie from a single seeding. Starting with a known seeding rate for all species, the vegetation was sampled annually using stratified random measurements. These data demonstrate the increasing importance and competitiveness of the native grasses and forbs. Prairie species became dominant after 4 growing seasons concurrent with the decline of exotic annual weeds. Weedy perennials have persisted although relative dominance of individual species is changing. The first complete clean burn made after 5 growing seasons stimulated growth of the native species but did not change the trends in plant composition. Twenty-one species of forbs are successfully established and 7 species of grasses are present.

Introduction

Interest in reconstruction or restoration of a tallgrass prairie plant community on denuded or intensively cultivated farm land is evident from the various accounts reported in past prairie conferences (Ode 1968, Riskind and Davis 1974, Schramm 1968, 1976, Zimmerman and Schwarzmeier 1976 and others). Primary objectives have varied from use on reclamation projects on disturbed areas, establishment for permanent summer pasture, provision of undisturbed diverse wildlife cover and/or soil conserving measures to sites where the accent is for educational purposes or landscape emphasis. Concern for the native prairie species and the prairie plant community encompasses various University Departments, their staff and students, local, state and federal agencies, private industry, national conservation organizations, and the dedicated individual who monitors the annual phenology of native plants or collects mature seeds and grows them from frail seedlings to maturity in a selected back yard location. Involvement with native plants crosses many individuals and organizations, all of whom have contributed to a better utilization and understanding of our long neglected flora.

Our interest and research efforts evolved from a project entitled, "Experimental Habitat Management on Farmlands". In this study the objective was to establish and evaluate permanent cover types on formerly intensively cultivated lands for optimum diverse habitat for resident and migratory wildlife on state wildlife areas. Following acquisition these tracts were sharecropped for corn, seeded to a mixture of agricultural grasses or legumes, or idle and allowed to revert through natural succession to Eurasion and/or native species. Prior to use of warm-season grasses reseeding was limited to agricultural grasses and legumes. Brome grass *(Bromus inermis)* and alfalfa *(Medicago sativa)* comprised the most common mixture. Idled cropland was dominated initially by annual weeds which were replaced by quackgrass *(Agropyron repens)*, bluegrass *(Poa pratensis)* and weedy composites.

Our first attempt to reintroduce the native species consisted of a small plot of Indiangrass *(Sorghastrum nutans)* seeded in 1966 followed by small acreages of Blackwell switchgrass *(Panicum virgatum)* seeded in 1967 through 1969. In 1970, we planted a mixture of native warm-and cool-season grasses and in 1974 we made our first attempt at prairie reconstruction. Typical of agricultural land acquired for wildlife areas in southern Wisconsin, the selected site had been previously cropped under a corn-oats-hay rotational system for many years. The field was last cropped for silage corn in 1971, idled in 1972 and 1973, treated with an herbicide application in 1974 and seeded in late May or June, 1974.

Methods

Pre-plant herbicide treatments, seed bed preparation and seeding rates for the 30 native species of grasses and forbs used in this experiment are described in the Proceedings of the Fifth Midwest Prairie Conference (Woehler and Martin 1978). Seed of the 7 grass species and 23 forb species was either hand colected from local relic stands in the summer and fall of 1973, produced at our state nursery at Boscobel from southern Wisconsin ecotypes or secured from the University of Wisconsin Arboretum seed bank. Pure live seed was calculated for the 5 primary grass species based on germination and purity tests. For other species pure live seed was estimated on the basis of data on seeds per ounce and assumed 50% germination provided by Schwartzmeier (1970). Seed of each species was divided into 4 equal parts and the separate lots of each species thoroughly mixed together prior to seeding dates of May 24, June 4, June 14 and June 26. Legumes were innoculated at planting time. The mixed seed was hand broadcast on freshly prepared seed bed and each plot was harrowed promptly after seeding. All plots were mowed twice during the establishment years for weed control. An excellent clean burn was achieved in April 1979.

From 1975 through 1980 the vegetation in each plot was sampled in late August or early September on 25 ± 5 ramdomly stratified points (Ohmann 1973), using a 1 x 2—foot frame. All species located within the sampling frame were recorded and the percent area occupied by each species was estimated. From presence and cover data the frequency, relative-frequency, relative-dominance, and importance values were calculated for each species on he 4 original planting date. Because establishment success was similar for each planting date, the annual data for all 4 seedings were pooled to quantify the annual changes occurring from 1975 through 1980 with emhasis on big bluestem *(Androgopon gerardi)*, little bluestem *(Andropogon scoparius)*, switchgrass *(Panicum virgatum)* and Indiangrass *(Sorghastrum nutans)*. The point for pacing off distance within plots was arbitrarily selected between years and sampling points within the stand were probably different each year. First flowering was recorded for all species while taking the vegetation measurements. Presence of species not included in sample plots was also noted.

Results and Discussion

Weedy species. The abundance and rapid growth of the agricultural weeds after seeding appeared overwhelming and seemed to preclude the possibility of any native species becoming established. In spite of the near-smothering competition, some native seeds germinated and survived that first growing season. Forty-three species of weeds were identified within the sampling plots over the 6 years. Grassy annuals *(Setaria* and *Panicum* spp.) dominated the first year and were gradually replaced by winter annuals, biennials and perennials Not all weedy species were exotics; lamb's quarter *(Chenopodium alba)* common ragweed *(Ambrosia artemsifolia)*, and fall panicum *(Panicum dichotomiflorum)* were natives. Prevalence of annual grasses is attributed to several decades of herbicide (atrazine) use for weed control in corn. *Panicum* and *Setaria* spp. can tolerate average application rates and will generate through midsummer and produce viable seeds before killing frosts.

Annual weedy grasses are believed to be the single most important factor limiting successful establishment of native grasses and forbs. In the establishment year, annual grasses germinate faster and grow rapidly on moderately fertile loam soils. For example, giant foxtail *(Setaria faberi)* can mature to heights of 4 - 5 feet in 6 - 8 weeks while the native grass seedling at best will range from 2 - 8 inches on the same site in the same time period. Rotary mowing is often necessary. Most annual grasses will tiller from the crown while broad-leaved annuals resprout from lateral buds after mowing. By the second growing season, the annuals are less competitive because of the high seedling density derived from previous years' seed production and subsequen germination. In effect, the annual weeds tend to be self destructive from intense intraspecific competition. To provide a perspective of the weedy competition in prairie seeding, Table 1 shows the importance values of the dominant weed species by years.

Quackgrass *(Agropyron repens)* was the dominant weed prior to the herbicide application and seeding. Data from Table 1 indicate that it was not eliminated and remained a dominant competitor. Late April or May burning apears to weaken quackgrass based on the reduced incidence of fruiting culms. Mature warm-season grass clones also create considerable shading and appear to restrict or interfere with the normal fall growth of quackgrass. Between 1977 and 1980, importance values of quackgrass declined steadily. After 7 growing seasons biennials or perennials now persist. Seeds of dandelion *(Taraxacum officinale)* and aster *(Aster pilosus)* drift in from nearby plants and continually reseed. The weedy agricultural legumes were probably present in the soil and continue to germinate. Decline of quackgrass and increase in legumes in 1979 may have been in response to the burn on April 29 of the same year. Quackgrass normally exhibit a decline in vigor and

Table 1. Importance values of primary weed species in a prairie seeding

Species	Year					
	1974	1976	1977	1978	1978	1980
Quackgrass	25	27	29	20	14	6
Common ragweed	26	16	2	-	5	T
Annual grasses	8	3	2	-	-	T
White cockle	5	6	1	-	1	
Common plantain	5	3	2	1	1	T
Legumes (4 spp.)	4	10	5	3	5	4
Dandelion	3	5	4	3	2	1
Aster	-	2	6	10	5	5
Others	12	7	4	4	4	7
Total	88	79	56	41	37	22

reduced frequency of fruiting stems after 5-7 years on undisturbed site. Bluegrass and/or the composites (aster and goldenrods) have invaded and continue to persist. None of the weedy species appear to be strong competitors after establishment of the native prairie species which grow vigorously and flower annually.

The native grasses. Reconstructing a tallgrass prairie would naturally emphasize the tall native grasses. Big and little bluestem, Indiangrass and switchgrass comprise the primary species used in this study. Minor grass species also seeded were prairie dropseed *(Sporobolus heterolepsis)*, Canada wild rye *(Elymus canadensis)*, and needlegrass *(Stipa spartea)*. The seeding rates for each species were arbitrary although rates for big bluestem and switchgrass was intentionally low to limit the possibility of their dominance as the stand matured (Table 2). We regard a seeding rate for primary grasses of 5.71 lbs/acre or 28 PLS (pure live seed)/ft^2 at the lower range of the recommended rates of 30-60 PLS/ft^2. The primary grasses and Canada rye produced fruiting stems in 1975. The number of fruiting stems per clone and the number of fruiting clones apeared to increase each year. Fruiting was probably stimulated in 1979 by the excellent burn in late April. Important values for each species were calculated from relative dominance and relative frequency values. Data show that big bluestem importance increased at a relatively faster rate compared to companion species during the early development, weighing seeding rates and the 1975 vegetation analysis (Table 3). At this stage, individual clone growth and leaf spread of big bluestem may account for differences in rates of increase in importance values. For example, Indiangrass had the highest seeding rate and highest absolute frequency between 1976 and 1980 (Table 4). However, mature individual Indiangrass clones are smaller in diameter and leaves tend to remain more erect than big bluestem clones and thereby occupy less area.

Switchgrass clones increased steadily in size, but the native ecotype seeded at a relatively low rate and in competition with other native species of grasses was not exceptionally aggressive and did not tend to form a sod, a characteristic attributed to other ecotypes or named varieties. However, the importance value and frequency of switchgrass increased at a faster rate between 1979 and 1980 than other species. Little bluestem also increased in frequency and importance dur-

Table 2. Seeding rate for native grasses expressed as pure live seed (PLS)

	PLS		
Species	ft^2	M^2	lbs/acre equivalent
Big bluestem	4.1	44.0	1.08
Little bluestem	6.9	74.0	1.16
Indiangrass	11.3	122.0	2.81
Switchgrass	5.9	63.0	0.66
Prairie dropseed	3.1	34.0	0.58
Canada rye	0.1	1.0	-
Needlegrass	0.03	0.3	-

ing the 5 years but at a slower rate than other species. This is also a function of smaller mature clonal size. Prairie dropseed was not recorded or observed until 1979 when several fruiting clones were noted. In this seeding and several other documented plantings after 1974, prairie dropseed has not established very successfully in relation to known seeding rate. Needlegrass and Canada wild rye were seeded at very low rates and comparisons to other species are confounded by lack of good seed distribution at planting because of the long awns. Both species were present with needlegrass concentrating on the drier parts of the plots. Canada wild rye persisted in moderate frequency from 1975 through 1978, declined sharply in 1979 and was not recorded in any plots in 1980 (Table 4). Clonal longevity of wild rye is believed to be less than 5 years based on the vegetation measurements and self-seeding is limited by the competition from sod-forming species.

Frequency of the dominant grasses increased steadily between 1975 and 1980 (Table 4). This increase is attributed to the anual growth of individual clones rather than self-seeding. During vegetation evaluation each season, no evidence of self-established native grass seedlings was observed. Native ecotypes, epecially the bluestems and Indiangrass showed marked variations between clones in regard to height, fall color, leafiness and susceptibility to foliar diseases. These differences can be expected considering the seed

Table 3. Importance values of native grasses

	Year					
Species	1975	1976	1977	1978	1979	1980
Big bluestem	2	4	9	14	17	18
Little bluestem	4	5	9	8	11	14
Indian grass	2	4	12	19	13	14
Switchgrass	2	3	5	9	9	13
Prairie dropseed	-	-	-	-	T	-
Canada wild rye	1	1	1	1	T	-
Needlegrass	-	-	-	-	T	T
Total	11	17	36	51	50	59

Table 4. Percent frequency of occurrence of native grasses

Species	1975	1976	1977	1978	1979	1980
			Year			
Big bluestem	19	29	46	59	70	72
Little bluestem	37	45	51	39	58	65
Indian grass	17	35	56	78	76	76
Switchgrass	15	27	26	46	58	72
Prairie dropseed	-	-	-	-	1	-
Canada wild rye	6	11	8	8	1	1
Needle grass	-	-	-	-	2	2

source was derived from numerous local populations.

In summation, all the native grasses seeded are firmly established and fruiting. Through 1980, there has not been a detectable decline in fruiting culms for any species except Canada wild rye. In older established stands consisting of commercial varieties, the bluestems and Indian grass flower inconsistently. A similar response is noted on relic natural sties in southern Wisconsin. Switchgrass, to the contrary, has produced fruiting stems with regularity in stands up to 13 years of age.

The prairie forbs. Response of the forb seeding was both pleasing and puzzling. Seeding rates were much lower than for grasses (estimated 7 PLS ft^2). Species selection was based primarily on those identified as typical of mesic prairies (Curtis 1959). Because of the larger number of species (23), discussion will be directed towards the forbs as a group with comment about certain species. Nineteen species were established ranging from a single clone to an estimated several hundred for the most common species. The most abundant species were yellow coneflower *(Ratibida connata)*, Canada tick trefoil *(Desmodium canadense)*, prairie dock *(Silphium terebinthinaceum)*, compass plant *(Silphium laciniatum)*, rosinweed *(Silphium intergrifolium)* and wild indigo *(Baptisia leucantha)* (Appendix I). The balance of the species were rare to intermediate in abundance. In general, individual plant development was much slower than the grasses. Wild indigo and prairie dock flowered for the first time in 1979. Leadplant *(Amorpha canescens)* although not abundant grew very slowly compared to other species in the legume group. Compass plant and prairie dock flowered infrequently despite the large size of some individual plants. Rosinweed flowered each season. Yellow coneflower was the most common species, flowering annually and increasing through natural reproduction. We also noted a number of dead or declining clones of this species throughout the growing season in recent years, the cause being unknown. Wild indigo plants produced an abundance of seed pods in 1979. Several hundred were collected in the fall of 1979, for future reseeding projects. None contained the snout beetle that commonly infests the seed pods of *Baptisia* species. Relative isolation from the beetle sources could account for their absence, at least temporarily.

The remaining forb species flowered each year and have persisted through the period of establishment. Because of their low presence, some forbs species did not occur in the sampling plots. These species were recorded as present. Species frequency, 1975-1980, is summarized in Appendix I. New Jersey tea *(Ceanothus americana)* and shooting star *(Dodecatheon meadia)*, which were sown, presumably did not establish. Illinois tick trefoil *(Desmodium illinoense)* was not present in the study plot although a single plant occurred in an adjacent plot of a companion study in which identical seeding rates were used.

Aggregate importance values for the native forbs determined each year from 1975-1980 showed a steady increase, as for the native grasses, with concurrent decline in importance of the weedy species (Table 5). It is probable that some of the forb seed did not germinate in 1975 because none was wet-stratified at low temperature prior to seeding. For native prairie species appeared that were not seeded; these were black-eyed susan *(Rudbeckia hirta),* evening primrose *(Oenethera biennis)*, wild bergamot *(Monarda fistulosa)* and tall sunflower *(Helianthus grosseserratus)*. These species are locally common. To gain another perspective on the establishment and clonal development of a reconstructed prairie, Table 6 shows the percentage of all plots examined that contain 1 or more of the species planted for the year 1975, 1977, 1979, and 1980. In 1975, 70% of the plots examined contained 1 or no species. By 1980, the percentage of plots with 1 or no prairie species de-

Table 5. Importance values of native grasses, native forbs and weeds

	1975	1976	1977	1978	1979	1980
Native grasses (7 species)	10	18	36	50	50	59
Native forbs (23 species)	2	3	8	9	13	19
Agricultural weeds (43 species)	88	79	56	41	37	22

clined to 2%. Each year we recorded an increasing number of plots with 4 or more species. A maximum of 8 species was found in 1 plot. Except for black-eyed susan, and yellow coneflower the increase is attributed primarily to the increase in size of individual clones rather than natural repor-duction and spread. Evidence of natural spread beyond the original field borders can be seen on the north and south ends of the field where occassional clones of big bluestem and Indiangrass extend 6-8 feet from the original boundary. At these sites the soil had also been treated with an herbicide and tilled prior to the initial seeding. Expansion of the native species had not occurred, however, into adjacent fields with vegetation originally present on the seeded area consisting primarily of quackgrass plus a few legumes and weedy forbs.

In conclusion our research has demonstrated successful establishment growth of 7 native grass species and 17 forb species from a single seeding. Annual vegetation measurements have documented a slow but steady decline of the weed competition and consistent increase in the native grasses and forbs. After 7 growing seasons, these data suggest the native plants are approaching moderate stability and, once established, can compete with the numerous weed species always present in the intensively cultivated lands of the upper Midwest.

Table 6. Percentage of plots containing native species

	No. Prairie Species/1x2-foot Plot[1/]							
Year	0	1	2	3	4	5	6	7+
1975	39	31	14	11	5	-	-	
1977	7	15	31	30	9	6	1	-
1979	-	1	16	30	29	15	6	3
1980	-	2	5	22	30	21	13	7

1/ Includes volunteer native species, *Rudbeckia, Oenethera, Monarda* and *Helianthus* spp. but not *Aster pilosus* and *Solidago* spp. which are classed as weedy competitors.

Literature Cited

Curtis, John T. 1959. Vegetation of Wisconsin. University of Wisconsin Press, Madison.

Ode, Arthur H. 1974. Prelude to prairie. Proc. Fourth Midwest Prairie Conf., pp. 389-391, M. K. Wali, ed., University of North Dakota, Grand Forks.

Ode, Arthur H. 1978. Some aspects of establishing prairie species by direct seeding. Proc. Prairie and Prairie Restoration Conf., pp. 52-60, P. Schramm, ed., Knox College, Galesburg, Illinois.

Ohmann, Lewis F. 1973. Vegetation data collection temperate forest research natural areas. Forest Service Research Paper NC-92, U.S. Dept. Agri., Wash., D.C., 35 pp.

Riskind, David H. and Arnold G. Davis. 1974. Prairie management and restoration in the state parks of Texas. Proc. Fourth Midwest Prairie Conf., pp. 369-373, M. K. Wali, ed., University of North Dakota, Grand Forks.

Schramm, Peter. 1968. A practical restoration method for tallgrass prairie, Proc. Prairie and Prairie Restoration Conf., pp. 63-65. P. Schramm, ed., Knox College, Galesburg, Illinois.

Schramm, Peter. 1976. The "do's" and "dont's" of prairie restoration. Proc. Fifth Midwest Prairie Conf., pp. 139-150, D. C. Glenn-Lewin and Roger Q. Landers, Jr., eds., Iowa State University, Ames.

Schwartzmeier, J. A. 1970. Mesic prairie suggested seeding rates for restoration planting. Unpubl. 2 pp.

Woehler, Eugene E. and Mark A. Martin. 1978. Establishment of prairie grasses and forbs with theuse of herbicides. Proc. Fifth Midwest Prairie Conf., pp. 131-138, D. C. Glenn-Lewin and Roger Q. Landers Jr., eds., Iowa State University, Ames.

Zimmerman, Janes H. and J. A. Schwartzmeier. 1978. Experimental prairie restoration at Wingra overlook. Proc. of the Fifth Midwest Prairie Conf., pp. 125-130, D. C. Glenn-Lewin and Roger Q. Landers, Jr., eds., Iowa State University, Ames.

Appendix I. Percent frequency of prairie forbs

	Year					
Species	1975	1976	1977	1978	1979	1980
Amorpha canescens			1			2
Anemòne cylindrica		1	2		3	5
Aster laevis				1	2	2
Asclepias verticillata		1	9		1	3
Astragalus canadensis[1/]						
Baptisia leucantha	2	3	7	8	12	30
Baptisia leucophaea[1/]						
Ceanothus americanius						
Coreopsis palmata						3
Coreopsis palmata						3
Desmodium canadense	1	1	3	3	1	2
Desmodium illinoense[1/]						
Dodecatheon meadia						
Echinacea pallida					3	2
Eryngium yuccifolium				1	8	11
Liatris aspera[1/]						
Lespedeza capitata					1	1
Petalostemum candida[1/]						
Petalostemum purpureum	1	2	6	3	9	5
Potentilla arguta		3	1		3	4
Ratibida pinnata	5	7	17	26	26	37
Silphium integrifolium		6	5	5	8	9
Silphium laciniatum		1		2	3	5
Silphium terebinthinaceum		3	4	6	8	9
Solidago rigida		1	4	5	5	

[1/] Uncommon, few flowering plants present

Literature Cited

Curtis, John T. 1959. Vegetation of Wisconsin. University of Wisconsin Press, Madison.

Ode, Arthur H. 1974. Prelude to prairie. Proc. Fourth Midwest Prairie Conf., pp. 389-391, M. K. Wali, ed., University of North Dakota, Grand Forks.

Ode, Arthur H. 1978. Some aspects of establishing prairie species by direct seeding. Proc. Prairie and Prairie Restoration Conf., pp. 52-60, P. Schramm, ed., Knox College, Galesburg, Illinois.

Ohmann, Lewis F. 1973. Vegetation data collection in temperate forest research natural areas. Forest Service Research Paper NC-92, U.S. Dept. Agri., Wash., D.C., 35 pp.

Riskind, David H. and Arnold G. Davis. 1974. Prairie management and restoration in the state parks of Texas. Proc. Fourth Midwest Prairie Conf., pp. 369-373, M. K. Wali, ed., University of North Dakota, Grand Forks.

Schramm, Peter. 1968. A practical restoration method for tallgrass prairie. Proc. Prairie and Prairie Restoration Conf., pp. 63-65, P. Schramm, ed., Knox College, Galesburg, Illinois.

Schramm, Peter. 1976. The "do's and don'ts" of prairie restoration. Proc. Fifth Midwest Prairie Conf., pp. 139-150, D. C. Glenn-Lewin and Roger Q. Landers, Jr., eds., Iowa State University, Ames.

Schwartzmeier, J. A. 1970. Mesic prairie suggested seeding rates for restoration planting. Unpubl. 2 pp.

Woehler, Eugene E. and Mark A. Martin. 1978. Establishment of prairie grasses and forbs with the use of herbicides. Proc. Fifth Midwest Prairie Conf., pp. 131-133, D. C. Glenn-Lewin and Roger Q. Landers, Jr., eds., Iowa State University, Ames.

Zimmerman, James H. and J. A. Schwartzmeier. 1978. Experimental prairie restoration at Wingra overlook. Proc. of the Fifth Midwest Prairie Conf., pp. 125-130, D. C. Glenn-Lewin and Roger Q. Landers, Jr., eds., Iowa State University, Ames.

Appendix I. Percent frequency of prairie forbs.

Species	Year 1975	1976	1977	1978	1979	1980
Amorpha canescens			1			2
Anemone cylindrica					3	5
Aster laevis				1	2	
Asclepias verticillata			3			9
Astragalus canadensis						
Baptisia leucantha	2			7	24	30
Baptisia leucophaea						
Ceanothus americanus						
Coreopsis palmata						3
Coreopsis palmata						3
Desmodium canadense	1	1	3	3	1	2
Desmodium illinoense 1/						
Dodecatheon meadia						
Echinacea pallida					3	2
Eryngium yuccifolium				1	8	11
Liatris aspera 1/						
Lespedeza capitata					1	1
Petalostemum candida 1/						
Petalostemum purpureum	1	2	8	9	9	6
Potentilla arguta		3	1		3	4
Ratibida pinnata	5	7	17	26	26	37
Silphium integrifolium		6	5	5	8	9
Silphium laciniatum		1		2	3	6
Silphium terebinthinaceum		3	4	6	8	9
Solidago rigida		1	4	5	5	

1/ Uncommon, few flowering plants present.

PROGRESS IN ESTABLISHING AND MAINTAINING PRAIRIE IN THE BAKER WETLANDS

Ivan L. Boyd
Baker University
Baldwin, Kansas 66006

Abstract. A 573-acre tract of land along the Waukarusa River was acquired by Baker University in the fall of 1968. Immediate steps were taken to preserve this native wetland meadow and to begin the establishing of prairie plantings in selected areas of the tract. Pure stands of Indiangrass, big bluestem, switch grass, bush lespedeza and Illinois bundle flower have been developed so that adequate quantities of seed could be harvested by combine. Seeds of other species of prairie plants have been collected by hand. Additional new plantings are made each year with the use of the available harvested seed. The ultimate goal of this project is to bring back the area to its natural state including the improvement of the wooded area along the banks of the river.

Introduction

A tract of land 1 mile wide bordering the south city limits of Lawrence and the north bank of the Waukarusa River (Fig. 1) had been abandoned by the Haskell Indian School, Lawrence, Kansas in 1958. It was considered by the faculty of this school to be of no further use in the educational curriculum. Vocational training in agriculture was not accepted by the students. This area of 573 acres was known as the Haskell Bottoms. During an interval of time the cultivated areas were being invaded by a secondary growth of cottonwood, willow and boxelder trees. At the same time the pasture land was becoming heavily populated by shrubby growth of dogwood, buckbrush and sumac. There remained 50 acres of virgin prairie containing flora and fauna typical of a lowland meadow.

Through application to the Department of Health, Education and Welfare, Baker University was granted custodial care and eventual ownership of this land. As an additional recognition the Department of the Interior and the National Park Service selected the virgin prairie in this tract as a Natural Landmark and to be placed on the National Registry. The selection was made because of the potential for the preservation of the flora and fauna typical of this area.

Program and Development

Soon after the University took over this area a class was organized and listed as Wetland Prairie Research and I was selected as instructor of the research course. At the same time I was designated as director of the newly recognized Baker Wetlands. Our first task was to collect seed of grasses and forbs from local remnant prairies. In the spring of 1969 we planted these seeds in 75-foot rows. The purpose of these experimental plantings was to determine the most suitable time to plant prairie seeds, whether the seeds needed to be scarified, stratified, or kept in cold storage. During the time we were observing these row plantings we marked off 6 x 10-foot plots and began transplanting mature prairie plants into these plots. These sod clumps were obtained from roadside remnants or from local prairies. About 20 species of prairie plants were obtained this way. More were added at later dates.

After several seasons of observation we determined from the row plntings that legume seeds of prairie clover, bush lespedeza and Illinois bundle flower germinated best when they had been scarified. Switch grass seed germinated best after being stored in cold storage. One of the factors we could not control was the weather. Prolonged dry conditions prevented the germination of many prairie seeds. Frequent precipitation encouraged the growth of the prairie seedlings but it also increased the growth of weeds. Plantings made in April and May appeared to be the most suitable months. The only advantage there seemed to be in planting prairie seeds in November and December in preference to spring planting was in getting the seeding done while there was less pressure from other activities and to avoid planting during excessive wet springs. Seed planted in late fall remained dormant until spring.

It became apparent that if we were to harvest adequate quantities of locally grown seed it would be

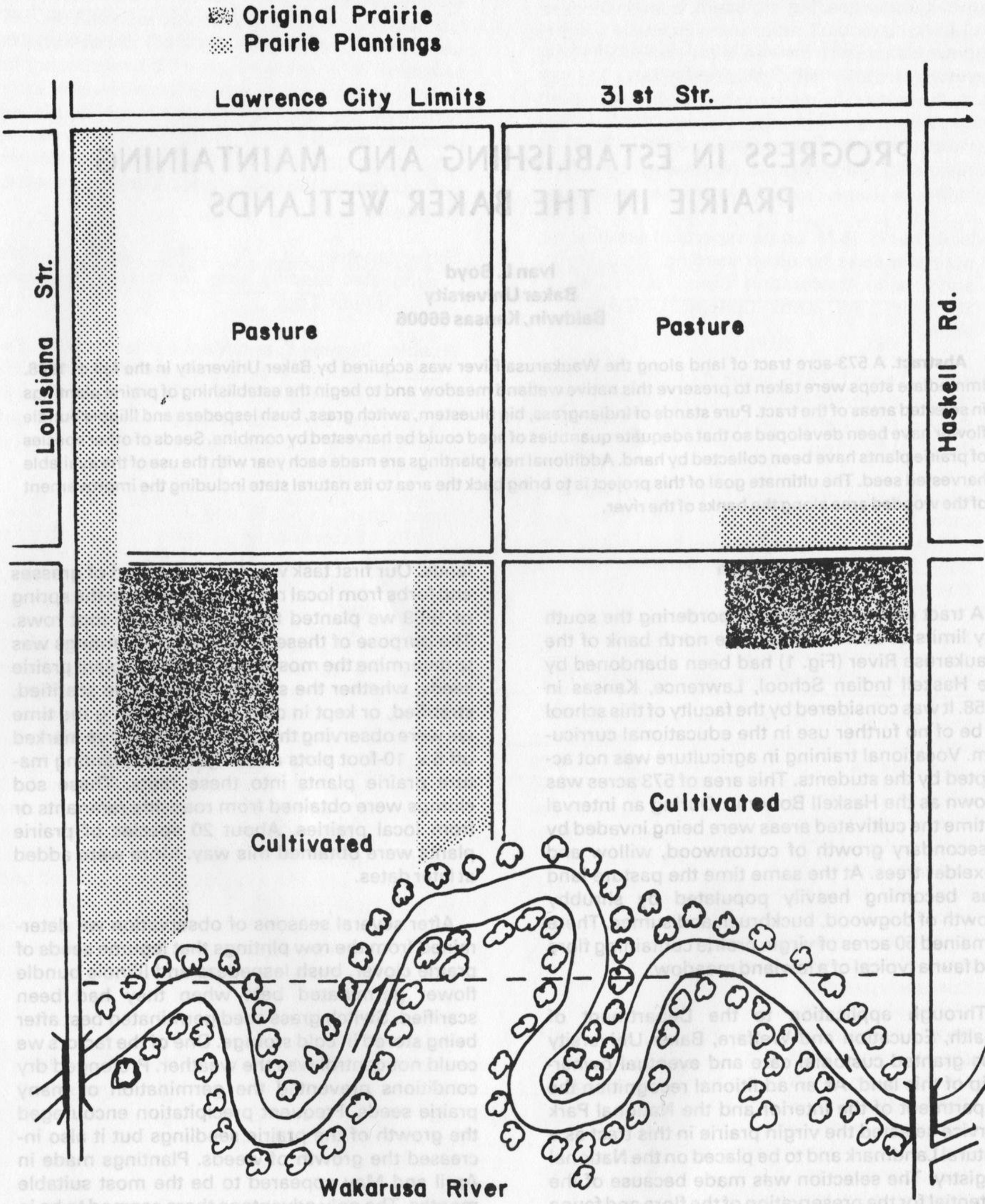


Fig. 1. The Baker University Wetlands

necessary to establish pure plantings of prairie grasses and legumes on our own ground. The areas selected to be planted were thoroughly disked and harrowed to remove weeds and to level the surface. We did not have access to a prairie drill so we used a fertilizer spreader to scatter the seed on the ground and followed this with a harrow to cover the seed lightly. During the summer if weeds became a problem in these plantings a rotary mower was used to clip the tops of the weeds but not low enough to damage the prairie seedlings.

We have established 1 to 2-acre fields of pure stands of each of the following species: switch grass, Indiangrass, big bluestem, bush lespedeza, and Illinois bundle flower. A combine is used to harvest and seed from these 5 pure stands. It is necessary to turn off the fan on the combine to prevent the seeds from being blown out with the straw. So far, all other prairie seeds must be harvestd by hand. Additional cleaning is needed on seeds collected to remove straw and weed seeds. This process is performed during inclement weather when students can not be outside. A hammer mill and fanning mill are used to remove the husks or outer coverings of bush lespedeza and prairie clover.

Most remnant prairies in this area are mowed for hay in July or August. Very few prairie plants mature their seed before late August or September. Prairies treated this way undoubtedly are eventually hurt because some plants can not replace themselves when they die. Because of early mowing we are unable to collect seed of many of these plants.

During the winter months some time is set aside for students enrolled in the research class to test the germination of various prairie seeds. This is an opportunity to learn the treatment necessary to get seeds to germinate and to study the identifying characteristics of the seedling plants. So far we have never discovered a way to get prairie hyacinth *(Camassia scilloides)* to germinate in the greenhouse or in row plantings. Seed of this species will eventually grow when scattered over waste areas.

Several prairie plantings of 2-3 acres have been established in the Wetlands in which every available prairie plant has been included. These plantings of mixed prairie serve as a source of study and adds to the aesthetics of the Wetlands. Many winter dwelling birds find these areas to serve as a source of food as well as protection from predators.

Burning of our prairie patches continues to be a concern. The heavy accumulation of biomass each year necessitates either mowing or burning yearly. Recently established plantings appear to be improved when controlled burning is brought about. Burning of our prairie patches apear to be most successful when completed in March. When weather conditions delay burning until April the eggs of early nesting birds are destroyed. Reptiles such as species of lizards and snakes are destroyed by fire. When burning is contemplated it is necessary to have at least 10 students and a large tank of water available to keep the fire under control. Because of the flatness of the terrain very little erosion seems to occur even through the bare surface may be exposed to heavy precipitation after burning.

In 1970 a flood canal was constructed along the west edge of the wetlands. The purpose of this canal was to drain the flood waters that occasionally came from the hilly slopes at the south edge of Lawrence directly into the Waukarusa River. Previous to the construction of this canal these flood waters spread over the Wetlands uninhibited. More recently the Clinton Lake was built on the Waukarusa River 5 miles up stream from the Wetlands. This huge impoundment of water has greatly reduced the flooding of the river onto the Wetlands.

Previous to 1968 the timber area along the banks of the Waukarusa River had been cleared of any lumber producing trees such as black walnut and burr oak. Transplanting of seedling trees of these 2 species to make up for the loss has been stressed each spring and fall. Also acorns and the nuts of walnuts have been collected from other wooded areas and then scattered along the river bank in hopes that fox squirrels wil bury or plant these nuts in the ground. In order to develop the best lumber producing walnut trees the seedling trees are pruned to produce straight trunks. It is recommended by foresters that weeds should be mowed around the areas where seedling trees are being grown. The banks of the river are too rough for mowing equipment to operate; consequently, weedy growth still is a problem. Recently we resorted to mulching around the trunks of a limited number of 6-8 foot walnut trees to determine if this method will control weedy growth and still do no damage to the trees.

The ultimate goals or problems to be solved at the Baker Wetlands are:

1) to continue the study of the germination, planting and harvesting of prairie seeds
2) to determine the amount of mowing, grazing and burning necessary to maintain a proper balance of the prairie
3) to determine the proper use of herbicides that will control the weedy growth in new prairie plantings
4) to improve the esthetic appearance of this wetland meadow
5) to remove the lumber producing walnuts as they mature and to maintain new growth
6) to develop an ongoing useful program for research studies in the biology department for future years.

grass, Indiangrass, big bluestem, bush lespedeza, and Illinois bundle flower. A combine is used to harvest and seed from these 5 pure stands. It is necessary to turn off the fan on the combine to prevent the seeds from being blown out with the straw. So far, all other prairie seeds must be harvested by hand. Additional cleaning is needed on seeds collected to remove straw and weed seeds. This process is performed during inclement weather when students can not be outside. A hammer mill and fanning mill are used to remove the husks or outer coverings of bush lespedeza and prairie clover.

Most remnant prairies in this area are mowed for hay in July or August. Very few prairie plants mature their seed before late August or September. Prairies treated this way undoubtedly are eventually hurt because some plants can not replace themselves when they die. Because of early mowing we are unable to collect seed of many of these plants.

During the winter months some time is set aside for students enrolled in the research class to test the germination of various prairie seeds. This is an opportunity to learn the treatment necessary to get seeds to germinate and to study the identifying characteristics of the seedling plants. So far we have never discovered a way to get prairie hyacinth (*Camassia scilloides*) to germinate in the greenhouse or in row plantings. Seed of this species will eventually grow when scattered over waste areas.

Several prairie plantings of 2-3 acres have been established in the Wetlands in which every available prairie plant has been included. These plantings of mixed prairie serve as a source of study and adds to the aesthetics of the Wetlands. Many winter dwelling birds find these areas to serve as a source of food as well as protection from predators.

Burning of our prairie patches continues to be a concern. The heavy accumulation of biomass each year necessitates either mowing or burning yearly. Recently established plantings appear to be improved when controlled burning is brought about. Burning of our prairie patches apear to be most successful when completed in March. When weather conditions delay burning until April the eggs of early nesting birds are destroyed. Reptiles such as species of lizards and snakes are destroyed by fire. When burning is contemplated it is necessary to have at least 10 students and a large tank of water available to keep the fire under control. Because of the flatness of the terrain very little erosion tends to be prevented through the bare surface may be exposed to heavy precipitation after burning.

In 1970 a flood canal was constructed along the west edge of the wetlands. The purpose of this canal was to drain the flood waters that occasionally came from the hilly slopes at the south edge of Lawrence directly into the Waukarusa River. Previous to the construction of this canal these flood waters spread over the Wetlands uninhibited. More recently the Clinton Lake was built on the Waukarusa River 5 miles up stream from the Wetlands. This huge impoundment of water has greatly reduced the flooding of the river onto the Wetlands.

Previous to 1968 the timber area along the banks of the Waukarusa River had been cleared of any lumber producing trees such as black walnut and burr oak. Transplanting of seedling trees of these 2 species to make up for the loss has been stressed each spring and fall. Also acorns and the nuts of walnuts have been collected from other wooded areas and then scattered along the river bank in hopes that fox squirrels will duly re-plant these nuts in the ground. In order to develop the best lumber producing walnut trees the seedling trees are pruned to produce straight trunks. It is recommended by foresters that weeds should be mowed around the areas where seedling trees are being grown. The banks of the river are too rough for mowing equipment to operate; consequently, weedy growth still is a problem. Recently we resorted to mulching around the trunks of a limited number of 6-8 foot walnut trees to determine if this method will control weedy growth and still do no damage to the trees.

The ultimate goals or problems to be solved at the Baker Wetlands are:

1) to continue the study of the germination, planting and harvesting of prairie seeds
2) to determine the amount of mowing, grazing and burning necessary to maintain a proper balance of the prairie
3) to determine the proper use of herbicides that will control the weedy growth in new prairie plantings
4) to improve the esthetic appearance of this wetland meadow
5) to remove the lumber producing walnuts as they mature and to maintain new growth
6) to develop an ongoing useful program for research studies in the biology department for future years.

REHABILITATION OF ERODED TALLGRASS PRAIRIE IN NORTH-CENTRAL TEXAS: THE LBJ NATIONAL GRASSLAND

Kent E. Evans
U. S. Forest Service
Caddo-LBJ National Grassland
P. O. Box 507
Decatur, Texas 76234

Abstract. The LBJ National Grassland is 20,000 acres of post oak/tallgrass savanna located 45 miles north of Ft. Worth, Texas. Administered by the U. S. Forest Service since 1954, it is managed under strong emphasis of multiple use. The original prairie soils were severely damaged during indiscriminate and highly intensive farming practices at the turn of the century. Rehabilitation of these gullied areas is a current program emphasized by the Forest Service on the LBJ. Restoration practices include reshaping gullied areas with bulldozers, vibratilling and mulching. Revegetation successes have been primarily with subclimax grasses.

CHANGES IN VEGETATION ON A RESTORED PRAIRIE AT PEA RIDGE NATIONAL MILITARY PARK, ARKANSAS

Edward E. Dale, Jr.
and
Thomas C. Smith
Department of Botany and Bacteriology
University of Arkansas
Fayetteville, Arkansas 72701

Abstract. Plant succession was investigated in a reestablished prairie at Pea Ridge National Military Park between 1975 and 1979. Seeds of *Andropogon gerardi, A. scoparius, Boutelous curtipendula, Panicum virgatum,* and *Sorghastrum nutans* were introduced on new plots each year at a PLS rate of 8.66/0.405 ha per year. Percent cover of prairie grasses and naturally occurring weedy grasses and forbs was measured in June and September of each year on all plots for 5 years. Mean percent cover of prairie grasses on 1-year-old plots increased from 21-89% in 5 years. Weedy grasses decreased from 31.9-4.0%, forbs from 24.9-2.0% and bare areas decreased from 22.2-5.0%. The density and diversity of weedy grasses and forbs decreased during this same period. Successional trends of weedy grasses and forbs were similar to those reported elsewhere on abandoned fields except that the introduction of prairie grasses in the restoration plots caused successional patterns to be altered sooner than would be expected otherwise.

Introduction

The reestablishment of prairie species by seeding or transplanting on areas where the original vetetation was completely removed has been accomplished in several areas of the United States. Examples of such restoration studies include those described by Christiansen (1967) in Iowa, Cottam and Wilson (1966) and Ode (1970) in Wisconsin, Schramm (1970) and Schulenberg (1970) in Illinois, and Bland (1970) in Michigan. Dale and Gibbons (1979) summarize the results of studies on prairie restoration made at Pea Ridge National Military Park during the first 2 years of establishment.

These investigations in Arkansas and elsewhere provide valuable information on techniques of prairie establishment, management practices, and changes in vegetation during early stages of succession. However, none of these studies presents quantitative data on successional changes each year for a 5-year period or compare vegetation on several reconstructed prairie plots of the same age but established in different years. The purpose of this paper is to report the successional changes in vegetation in the reconstructed prairie at Pea Ridge National Military Park over the 5-year period between 1975 and 1979.

The Study Site

Historical records of the Battle of Pea Ridge indicate that tracts of prairie once existed within the boundaries of the present military park during the Civil War (Bussey 1883); however, these tracts were later destroyed when the area was plowed and cultivated.

The prairie restoration site was a cultivated field until about 1960 when the battlefield area was acquired by the National Park Service. Essentially uninterrupted secondary succession occurred on the study site from about 1960 until 1975 when the restoration project was initiated. At that time the vegetation on the site and the surrounding area consisted mostly of broomsedge *(Andropogon virginicus),* blackberry *(Rubus* spp.) and a great variety of weedy grasses and forbs interspersed with scattered persimmon *(Diospyros virginiana)* and red cedar *(Juniperus virginiana)* trees.

Methods

Prairie restoration plots adjacent to areas established in 1975 and 1976 were added in 1977, 1978, and 1979. Methods of establishment were essentially the same as used previously (Dale and Gibbons 1979). The areas were plowed in early June of each year and a seed mixture consisting of big bluestem *(Andropogon gerardi)*, little bluestem *(A. scoparius)*, side oats grama *(Bouteloua curtipendula)*, switchgrass *(Panicum virgatum)* and Indiangrass *(Sorghastrum nutans)* was hand-broadcast on each plot at an equivalent rate of 8.6 kg (19.1 lbs) PLS (pure live seed) per 0.405 ha (1 acre).

Vegetation was first sampled in the early fall of the first year of establishment and late spring and early fall of each year thereafter using a modification of the point method as described by Winkworth and Goodall (1962). Generally an aggregate of 400 or more randomly distributed points were sampled in plots of the same age during each sampling period.

The field data were converted to percent cover by species for each year and arranged in groups consisting of prairie grasses, weedy grasses, forbs, and areas without living cover. Mean percent cover was then calculated for principal species present in each group and summed by years. Also, standard deviations were determined for the different groups within each age category.

Voucher specimens were collected periodically during the investigation. These are on file in the herbarium of the University of Arkansas at Fayetteville.

Results and Discussion

A comparison of vegetation present on all plots showed distinct successional trends between 1975 and 1979. The most notable change was the increase in prairie grasses from a mean cover of 21% during the fall of the first year of establishment to 89% after 5 years. This increase was continuously greater with each succeeding sampling period for the first 4 years (Table 1).

In contrast to prairie grasses the mean cover of the weedy grasses and forbs collectively was greatest (56.8%) on the 1-year-old plots decline to 6% after 5 years. Considered separately, the cover of weedy grasses was greatest during the fall on the 1-year-old plots (31.9%) but the highest value for forbs (30.6%) occurred during the spring of the second year.

Cover of weedy grasses declined consistently between fall sampling periods and of forbs between spring samplings on increasingly older plots. The relatively greater cover percentages of forbs as compared to grasses in the spring and the shift to greater cover of grasses in the fall is a reflection of usual seasonal growth patterns of mixed forb and grass populations in natural prairies of this region.

Areas without living cover (consisting of mulch and bare areas) showed a decline similar to those of the weedy grasses and forbs during the first 4 years, but increased from 1.8 to 12.8% between the fourth and fifth years. Most of this increase can be attributed to the heavy accumulations of mulch provided by the prairie grasses during the fourth and fifth years.

A large increase in cover of prairie grasses accompanied by declines in weedy grasses, forbs and areas without living cover occurred between the fall of the third year and spring of the fourth year (Table 1). Interference (competition, al-

Table 1. Mean percent cover of prairie grasses, weedy grasses, forbs and mulch and bare areas on plots 1-5 years old based on spring (S) and fall (F) sampling. Standard deviations in parentheses

	Age - yrs								
	1	2		3		4		5	
Species	F	S	F	S	F	S	F	S	F
Prairie grasses	21.0	31.0	45.0	48.9	53.3	74.0	82.2	77.7	89.0
	(2.7)	(6.5)	(12.8)	(8.0)	(8.5)	(3.5)	(0.2)	-	-
Weedy grasses plus forbs	56.8	51.6	44.4	32.9	36.8	24.3	16.0	9.5	6.0
	(13.9)	(15.3)	(13.7)	(2.2)	(4.7)	(5.6)	(2.0)	-	-
Weedy grasses	31.9	21.0	21.9	14.1	17.3	8.5	4.9	2.5	4.0
	(8.9)	(15.0)	(13.8)	(3.5)	(2.7)	(6.2)	(0.8)	-	-
Forbs	24.9	30.6	22.5	18.8	19.5	15.8	11.1	7.0	2.0
	(13.0)	(4.0)	(5.4)	(2.9)	(4.4)	(0.4)	(2.7)	-	-
Mulch and bare ground	22.2	17.4	10.6	18.2	9.9	1.7	1.8	12.8	5.0
	(12.1)	(12.8)	(5.1)	(4.8)	(3.6)	(2.3)	(3.1)	-	-
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

lelopathy or both) caused by the rapid increase in prairie grasses is probably the most important factor responsible for these changes.

Changes in the number and diversity of different species of weedy grasses and forbs during 5 years followed a trend similar to changes in cover. A high density and diversity of species were observed during the fall of the first year of establishment, but the greatest number and diversity of species occurred during the spring of the second year (Dale and Smith 1979). This was followed by a fairly consistent decline from the fall of the second year until the fifth year when only 7 species were present with 0.5% cover or more (Dale 1980).

There was considerable variation also in both percent cover of prairie grasses, weedy grasses, forbs, and amount of area without living cover on plots of the same age established in different years. This variation was greatest during the first 2 years, but declined rapidly after the second year as reflected by the standard deviations for each group (Table 1).

Species which were prominent only during the first year included tickseed *(Bidens aristosa)* and carpetweed *(Mollugo verticillata)* in 1975 and ragweed *(Ambrosia artemisiifolia)* in 1978. Prominent species in 2-year plots for 1 year only were poorjo *(Diodia teres)* and fall panic grass *(Panicum lanuginosum)* in 1976, and beaked panic grass *(Panicum anceps)* in 1977. Korean lespedeza *(Lespedeza stipulacea)* was prominently present in the 1975 plot when it was 3 years old (Dale and Smith 1979).

These changes in composition can be attributed to many factors such as varying weather conditions in different years, dispersal characteristics and nearness of potential invaders, soil conditions, and amount of bare areas suitable for establishment.

Prairie Grasses. Different species of prairie grasses introduced into the study area showed several successional patterns (Table 2). The mean cover percentage of big bluestem increased from 8.7% on the 1-year-old plots to 24% after 5 years. In contrast, little bluestem declined after 5 years, probably because of interference from the tall grasses.

Side-oats grama generally disappeared from all lots by the beginning of the third growing season. This is not surprising since it is a xerophytic short grass characteristic of open, dry areas (Weaver 1954). The more mesic habitat of the restoration area subjected it to competition from taller prairie grasses, weedy grasses, and forbs that became well established during the second year.

Switchgrass increased very slowly until the spring of the fourth year following establishment when it occupied a mean cover of 10.6%. Abundant rainfall during early spring promoted its increase in wet areas in 1978. It declined to 4.5% during the spring of the fifth year, but increased to 11% the following fall when timely rainfall made part of the restoration area wetter than usual. This could be expected since switchgrass has a tendency to occupy wetter areas than the other prairie grasses in the restoration area.

Indiangrass appears to be best adapted to growing conditions in the study area during the first 4 years. This can be attributed at least in part to its tendency to increase in disturbed areas of prairie (Weaver 1954). Mean cover increased from 5.5% in the 1-year-old plot to 59.3% in the 4-year-old plot, but it declined to 49% during the fall of the fifth year.

Weedy Grasses and Forbs. Weedy grasses and forbs can be grouped into several categories based on their frequency of occurrence and duration in the experimental plots (Table 2). The first category appears during the first year of establishment. These pioneers become established on the bare ground created by seedbed preparations, but generally do not persist after the first or second year. Their presence accounts for much of the variability in percent cover and diversity of species present during the first years of establishment. Examples include hogwort *(Croton capitatus)*, poorjo *(Diodia teres)*, carpetweed *(Mullugo verticillata)*, quack grass *(Paspalum setaceum)*, and blue foxtail *(Setaria glauca)*.

A second group becomes established during the second year, declines during the third year and generally disappears or is greatly diminished by the fourth growing season. These species invade after bunches of prairie grasses have become well established and occupy the area between the bunches. Examples include dogbane *(Apocynum cannabinum)*, purple gerardia *(Gerardia fasciculata)*, and Korean Lespedeza *(Lespedeza stipulacea)*.

A third category consists of species that become established in the fall of the first year, persist for 3 years, and then disappear. Examples include ragweed *(Ambrosia artemisiifolia)*, tickseed *(Bidens aristosa)*, and fall witchgrass *(Leptoloma cognatum)*. A fourth group persists for all 5 years. Constituent species include broomsedge *(Andropogon virginicus)*, beaked panic grass *(Panicum anceps)*, fall panic grass *(P. lanuginosum)*, and fall boneset *(Eupatorium serotinum)*. Many other species were noted in the restoration plots with cover values of less than 1% during any one year.

Table 2. Mean percent cover of species with cover values of 1% or more on plots from 1-5 years old based on spring (S) and fall (F) sampling. Dash (-) indicates species not present

	Age - yrs								
	1	2		3		4		5	
Species	F	S	F	S	F	S	F	S	F
Prairie Grasses									
Andropogon gerardi	8.7	8.8	9.5	12.5	7.5	19.1	9.9	18.5	24.0
Andropogon scoparius	8.9	9.6	13.3	11.1	9.6	14.5	8.5	13.5	5.0
Bouteloua curtipendula	1.7	1.1	1.7	-	-	-	-	-	-
Panicum virgatum	1.6	2.5	3.9	2.7	4.6	10.6	4.5	4.5	11.0
Sorghastrum nutans	5.5	9.0	16.6	22.6	31.8	29.8	59.3	40.5	49.0
Weedy Grasses									
Andropogon virginicus	3.3	-	8.8	2.4	3.5	-	1.3	-	1.5
Aristida longispica	0.5	-	2.1	1.8	0.9	-	-	-	-
Digitaria sanguinalis	4.0	0.9	0.6	-	1.0	-	-	-	-
Echinochloa crus-galli	3.2	-	-	-	0.7	-	-	-	-
Leptoloma cognatum	4.1	0.8	0.1	0.9	0.9	-	1.7	-	-
Panicum anceps	0.5	5.5	-	3.7	0.3	2.8	-	1.0	2.0
Panicum boscii	-	1.8	1.0	-	-	-	-	-	-
Panicum languinosum	0.5	4.8	5.0	2.1	1.6	0.5	-	1.0	-
Paspalum setaceum	2.2	0.2	0.8	-	-	-	-	-	-
Setaria glauca	6.6	1.2	2.8	0.9	1.2	-	0.3	-	0.5
Tridens flavus	4.5	1.2	2.8	0.9	1.2	-	0.3	-	0.5
All others	2.5	5.7	1.4	1.3	7.2	5.2	1.6	0.5	-
Forbs									
Ambrosia artemisiifolia	4.2	3.5	7.2	1.3	-	0.7	-	-	-
Apocynum cannabinum	-	1.2	0.2	0.3	-	0.1	-	-	-
Bidens aristosa	1.6	1.8	3.1	1.3	2.2	0.3	1.4	-	-
Cassia fasciculata	-	0.6	2.6	0.4	1.0	1.6	0.7	0.5	0.5
Croton capitatus	1.4	-	-	-	-	-	-	-	-
Diodia teres	1.8	1.6	-	-	-	-	-	-	-
Eupatorium serotinum	0.4	0.1	2.0	1.2	3.5	1.1	1.6	1.0	-
Euphorbia corollata	1.0	-	-	-	-	0.8	-	0.5	0.4
Gaura longiflora	2.9	7.7	1.7	-	-	-	-	-	-
Gerardia fasciculata	-	0.4	1.7	0.6	0.9	-	-	-	-
Lespedeza stipulacea	-	-	2.1	4.1	5.3	3.4	4.0	-	-
Mollugo verticillata	4.6		-						
Rubus spp.	-	0.6	-	1.4	1.2	0.6	0.3	1.0	0.5
Rudbeckia hirta	-	2.6	-	1.5	-	0.6	-	1.0	-
Solidago canadensis	-	1.7	1.9	1.0	1.8	2.2	0.8	2.0	0.4
All others	-	7.8	6.0	5.7	3.6	5.0	2.3	1.0	0.2

Successional trends in prairie grasses between 1975 and 1979 seem to be consistent with characteristics of the species present in regard to their usual responses to environmental conditions. Side-oats grama, little bluestem, and Indiangrass appears to be decreasing while the amount of big bluestem has started to increase. Changes in switchgrass populations seem to be closely related to rainfall since it increases during wet years.

The large amounts of mulch present in the 4 and 5 year old plots have eliminated most forb populations, but invasion by woody species such as blackberry and persimmon is increasing. If the restoration plot is to be maintained, management by mowing or burning must be initiated, which will likely alter present successional trends.

Successional trends of weedy grasses and forbs and changes in diversity of species during the first few days of succession in the restoration plots are strikingly similar to those described for the early years following abandonment in cultivated fields as reported by Thompson (1943) in Wisconsin, Quarterman (1975) in Tennessee, Bazzaz (1968) in Illinois, Tramer (1975) in Ohio, and many others elsewhere. However, the introduction of prairie grasses in the restoration plots has caused successional patterns to be altered by interference or competition sooner than would be expected otherwise.

Acknowledgements

The results of this study come in part from work under contract between the Southwest Region, National Park Service, Santa Fe, New Mexico and the University of Arkansas, Fayetteville, to re-establish a prairie at Pea Ridge National Military Park for use in their interpretative program. Grateful acknowledgement is made to the National Park Service without whose financial support this study could not have been made, and to Betty Gentry, Superintendent, Pea Ridge National Military Park, and her staff for their cooperation and assistance.

Literature Cited

Bazzaz, Faklri A. 1968. Succession on abandoned fields in the Shawnee Hills, Southern Illinois. Ecology 49:924-936.

Bland, Marilyn K. 1970. Prairie establishment at the Michigan Botanical Gardens. Proc. Prairie and Prairie Restoration Conf., pp 46-48, P. Schramm, ed. Knox College, Galesburg, Illinois.

Bussey, Cyrus. 1883. Report of Col. Cyrus Bussey, Third Iowa Cavalry, Pea Ridge or Elkhorn Tavern, Arkansas. In Robert M. Scott, Secretary of War, War of the rebellion Records of the Union and Confederate Armies. Official Record Series 8:232-235. Supt. Doc., Wash., D.C.

Christiansen, Paul A. 1967. Establishment of prairie species in Iowa by seeding and transplanting. Doctoral dissertation. Iowa State University, Ames.

Cottam, Grant and H. C. Wilson. 1966. Community dynamics on an artificial prairie. Ecology 47:88-96.

Dale, Edward E., Jr. 1980. Reestablishment of prairie at Pea Ridge National Military Park, Benton County, Arkansas. Final Report for 1979. Prepared for the Southwest Region, National Park Service, United States Department of the Interior. Dept. of Botany and Bacteriology, University of Arkansas, Fayetteville.

Dale, Edward E., Jr. and Thomas C. Smith. 1979. Reestablishment of prairie at Pea Ridge National Military Park. Benton County, Arkansas. Final Report for 1978. Prepared for the Southwet Region, National Park Service, United States Department of the Interior. Dept. of Botany and Bacteriology, University of Arkansas, Fayetteville.

Dale, Edward E., Jr. and James W. Gibbons. 1979. Reestablishment of prairie vegetation at Pea Ridge Nationa Military Park, Benton County, Arkansas. In Proc. First Conf. on Scientific Research in the National Parks, pp. 183-187, R. M. Lynn, ed. Trans. and Proc. Series, No. 5. Natl. Park Ser., Wash. D.C.

Ode, Arthur H. 1970. Some aspects of establishing prairie grasses by direct seeding. Proc. Prairie and Prairie Restoration Conf., pp. 52-61, P. Schramm, ed. Knox College, Galesburg, Illinois.

Quarterman, Elsie. 1957. Early plant succession on abandoned cropland in the central basin of Tennessee. Ecology 38:300-309.

Schramm, Peter. 1970. A practical restoration method for tall grass prairie. Proc. Prairie and Prairie Restoration Conf., pp. 63-65, P. Schramm, ed. Knox College, Galesburg, Illinois.

Schulenberg, Ray. 1970. Summary of Morton Arboretum prairie restoration work, 1963-1968. Proc. Prairie and Prairie Restoration Conf., pp. P. Schramm, ed. Knox College, Galesburg, Illinois.

Thompson, J. W. 1943. Plant succession on abandoned fields in central Wisconsin sand plain are. Bull. Torrey Bot. Club 70:34-41.

Tramer, Elliot J. 1975. The regulation of plant species diversity on an early successional old-field. Ecology 56:905-914.

Weaver, J. E. 1954. North American Prairie. Johnsen Publishing Company. Lincoln, Nebraska.

Winkworth, R. E. and D. W. Goodall. 1962. A cross-wire sighting tube for point quadrat analysis. Ecology 43:342-343.

VEGETATION RESTORATION: WILSON'S CREEK NATIONAL BATTLEFIELD

Bruce W. Reed
521 North Highway 60
Republic, Missouri 65738

Abstract. "The park vegetation should be returned to its 1861 condition...the condition to be based upon a professional determination." (General Management Plan). The purpose of this paper is to describe various management actions undertaken by the National Park Service toward the goal of restoration of 1861 ground cover conditions at Wilson's Creek National Battlefield. Dissertation will include: research determination, planting, seeding, and ongoing management practices.

Introduction

Wilson's Creek National Battlefield was established in 1960 to commemorate a major battle of the Civil War west of the Mississippi River.

The Battle of Wilson's Creek was fought on August 10, 1861. Named for the stream that crosses the area where the battle took place, the battle was a bitter struggle between Union troops and Confederate forces for control of Missouri during the first year of the Civil War.

The principal resource at Wilson's Creek is approximately 1,750 acres of natural terrain, relatively unspoiled by the passage of over a century since the battle. The dominant features are Wilsons Creek itself and "Bloody Hill" where climatic action occurred. Old farm fields, wooded hillsides, and one historic farmhouse are other significant resources. The Ray House was constructed about 1852 and still remains on the battlefield. The house was used as a post office and as a stage stop on the Overland Butterfield Stage Route. During the battle the house was used as a field hospital by Confederates. Also, the "Old Wire Road" traverses the battlefield and was the main connecting link between southwest Missouri and northwest Arkansas in the mid- to late 1800's.

Restoration and Management

It is the objective of the National Park Service to manage the resources at Wilson's Creek National Battlefield, to reestablish and perpetuate the natural processes that existed at the time of the 1861 battle, to preserve the historical and archeological features present, and to provide the American people an opportunity to understand and enjoy this portion of their heritage.

Since the National Park Service arrived on the battlefield in 1965, a number of actions have taken place toward reaching this objective.

A Master Plan (National Park Service 1977) for the park has been prepared and approved which provides direction for the dvelopment, management, and use of the battlefield. Subsequent to the Master Plan, an Environmental Statement (National Park Service 1977a) was also prepared and approved which analyzed the impact of the Master Plan upon the environments at Wilson's Creek.

Various research projects have been or are now underway in an effort to provide the National Park Service with a perception of what the battlefield area lookedlike in the 1860's.

With the assistance of the United States Soil Conservation Service (1975), a soil survey was conducted and a soil description was written for the battlefield. Subsequent to the soil survey, a soil and capability map, a conservation plan, and a conservation plan map have also been developed.

A report by Roger Landers (1975) provided a great deal of useful information relating to the various types of vegetation that may have existed in the area one hundred years ago. "The area is probably less forested today than it was in 1861... the forests are probably a different structure today even though they may be composed of the same species... It was also noted at the time of the battle the river bottom was an impenetrable jungle, a condition which is much the same today.

"The original vegetation was a mosaic of Oak-Hickory Forest, Bluestem-Prairie and brushy or scattered tree 'edge'..."

"The Bluestem Prairie of this region would be dominated by big bluestem *(Andropogon gerardi)*, little bluestem, switchgrass, and Indian grass *(Sorghastrum nutans)* with other components including Side-oats grama, black-eyed Susan *(Rudbeckia hirta)*, Butterfly milkweed *(Asclepias tuberosa)*, Purple coneflower *(Echinacea pallida)*, Prairie clover *(Petalostemum)*, Aster *(Aster* spp.*)*, Daisy fleabane *(Erigeron strigosus)*, Blazing star *(Liatris asper)*, Wild bergamot *(Monarda fistulosa)*, and many others..."

Through the Volunteers in the Parks program a floristic study is currently being done and herbarium samples of the vegetative species present at Wilson's Creek are being collected and mounted. Also, through the volunteer program, an ornithologic survey is underway which will help identify species, seasons of use, and numbers relating to the park's bird community.

In late 1979 Edwin Bearss (1979) completed his study of available historical data and submitted the "Historical Base and Ground Cover Map, Wilson's Creek National Battlefield" for review and use by the park. This document provides additional data as to what types of vegetation were on the battlefield during the 1860's and where they were located.

Over the past 10-15 years, in an effort to maintain the existing vegetation on the area and to begin restoring the 1860's vegetation, the following actions have taken place. Planting of some of the old fields to native grasses was accomplished in 1967, and additional prairie species were broadcast in 1971. Two other areas on the park are now under grazing/hay permit until September 30, 1980. The decision to terminate or continue these permits has not yet been made. Also, until planning is completed, the remaining grass fields in the battlefield are being mowed to reduce the invasion of woody plant growth and annual weeds.

We are continuing to gather data from all available sources which can be used in the development of a Natural Resources Management Plan for the battlefield. This plan will provide the specific actions we are going to be taking in the future toward reaching our objective of reestablishing and perpetuating the natural processes that existed at Wilson's Creek in 1861.

Literature Cited

U. S. Department of Interior. National Park Service. 1977. Final Master Plan, Wilson's Creek National Battlefield. Republic, Missouri.1/

U. S. Department of Interior. National Park Service. 1977a. Final Environmental Statement, Wilson's Creek Nationl Battlefield. Republic, Missouri. (FES-77-24).

U. S. Soil Conservation Service 1975. Soil Description for Battlefield National Park.

Landers, Roger Q., Jr. 1975. A Report on the Status and Management of Native Prairie Areas in National Parks and Monuments in the Midwest Region.

Bearss, Edwin C. 1979. Historical Base and Ground Cover Map, Wilson's Creek National Battlefield.

1/ All of the literature cited are documents of and for the National Park Service. Copies may be obtained through Wilson's Creek National Battlefield, Republic, Missouri.

SESSION V. Prairie Management and Preservation.
Bill T. Crawford, Presiding

In this final session of the conference, conservation and management are appropriately common themes, one supportive of the other in any successful land-use program. The effects of controlled fires as a tool in management are described from a number of locales. Burning interval is discussed by Hulbert and Wilson for Kansas prairie. Knoop's paper also deals with fire interval in Ohio. Changes in floristic composition are noted by Kohring, following a single fire in Michigan. Seasonal timing is also important, as shown by Nagel and Williams in Nebraska. In Wisconsin, Halvorsen describes the impact of burning, with other practices, on bird and mammal populations. Irving notes that cessation of annual haying favors prairie grasses at the expense of other grasses such as broomsedge, and that fire response is a source also for species manipulation. The paper by Hardell and Morrison describes the response of prairie grasses to various nitrogen applications including municipal waste, providing insights on future management of reclaimed land. Larson's paper describes a program of interpretive design as a major part of the management plan. The application of island biogeographical principles to conservation of bird species of the prairie is discussed by Samson. Lastly, a series of papers are presented by Bender and Jackson describing programs using prairie plants in grain crop research.

"The original vegetation was a mosaic of Oak-Hickory Forest, Bluestem-Prairie and brushy or scattered tree 'edge'..."

"The Bluestem Prairie of this region would be dominated by big bluestem *(Andropogon gerardi)*, little bluestem, switchgrass, and Indian grass *(Sorghastrum nutans)* with other components including Side-oats grama, black-eyed Susan *(Rudbeckia hirta)*, Butterfly milkweed *(Asclepias tuberosa)*, Purple coneflower *(Echinacea pallida)*, Prairie clover *(Petalostemum)*, Aster *(Aster* spp.*)*, Daisy fleabane *(Erigeron strigosus)*, Blazing star *(Liatris asper)*, Wild bergamot *(Monarda fistulosa)*, and many others..."

Through the Volunteers in the Parks program a floristic study is currently being done and herbarium samples of the vegetative species present at Wilson's Creek are being collected and mounted. Also, through the volunteer program, an ornithologic survey is underway which will help identify species, seasons of use, and [illegible] relating to the park's bird community.

[illegible] Edwin C. Bearss (1975) completed his [illegible] and submitted the [illegible] Cover Map [illegible] for review [illegible] provides [illegible] what types of vegetation were on the battlefield [illegible] and where they were located.

Over the past [illegible] to maintain the existing vegetation [illegible] and to begin restoring the 1861 [illegible] the following actions have taken place. Planting of some of the old fields to native grasses was accomplished in 1967, and additional prairie species were broadcast in 1971. Two other areas on the park are now under grazing/hay permit until September 30, 1980. The decision to terminate or continue these permits has not yet been made. Also, until planning is completed, the remaining grass fields in the battlefield are being mowed to reduce the invasion of woody plant growth and annual weeds.

We are continuing to gather data from all available sources which can be used in the development of a Natural Resources Management Plan for the battlefield. This plan will provide the specific actions we are going to be taking in the future toward reaching our objective of reestablishing and perpetuating the natural processes that existed at Wilson's Creek in 1861.

Literature Cited

U. S. Department of Interior, National Park Service. 1977. Final Master Plan, Wilson's Creek National Battlefield, Republic, Missouri.1/

U. S. Department of Interior, National Park Service. 1977a. Final Environmental Statement, Wilson's Creek National Battlefield, Republic, Missouri. [illegible]

U. S. Soil Conservation Service [illegible]

Landers, Roger Q., Jr. 1979. A Report on the Status and Management of Native Prairie Areas in National Parks and Monuments in the Midwest Region.

Bearss, Edwin C. 1975. Historical Base Map and Ground Cover Map, Wilson's Creek National Battlefield.

1/ All of the literature cited are documents [illegible] for the National Park Service. Copies may be obtained through Wilson's Creek National Battlefield, Republic, Missouri.

PRAIRIE STATE PARK, INTERPRETATION WITH PRESERVATION

Lorence W. Larson
Prairie State Park
Liberal, Missouri 64762

Abstract. Prairie State Park is a 1680-acre tract in Barton County, in southwestern Missouri. The tract lies in the prairie region and contains superb remnants of unglaciated tallgrass prairie. It was acquired with the assistance of the Nature Conservancy. As a state park, the area is managed by the Missouri Department of Natural Resources, Division of Parks and Historic Preservation. The park fills a gap in the state park system's representation of significant Missouri landforms and natural communities. Park management has 2 major objectives: preservation and restoration of the prairie community, and interpretation of the Missouri prairie for the public. Although other organizations and entities have been successful for years in the acquisition and management of prairies in Missouri, it is hoped that a Prairie State Park can provide the opportunity for a broader spectrum of the public to become aware of and concerned for the prairie resource. This objective can be met only through a thoughtfully conceived and sensitively executed interpretative plan. The plan must address such issues as facility location and design, trail design and aesthetics, prairie management and restoration strategies, and visitor information. If the park is successful in its attempt to provide a refreshing, enjoyable, and informative experience for park visitors, it will serve to add to the population of citizens who know something about the tallgrass prairie ecosystem and, so knowing, will be motivated to help protect the vanishing remnants of that ecosytem.

Introduction

Prairie State Park is a 680-ha tract located in Barton County in southwestern Missouri, Township 32 North, Range 33 West in Sections 16, 17, 20, and 21 (Liberal Mo-Ks Quadrangle).

Prairie State Park is owned by the Missouri Department of Natural Resources and was acquired with the assistance of the Nature Conservancy. It represents one of the large remnants of the unglaciated prairie region of southwestern Missouri. Barton County, in which it is located, was 86% prairie at the time of settlement (Schroeder 1980). Today the county is estimated to contain 4% native tallgrass prairie, of which Prairie State Park represents approximately 15%. The park has Dry Prairie, Dry mesic prairie, Mesic prairie, Wet-mesic prairie, Sandstone ledges, and Wet prairie seeps, all of which are formed on shale and sandstone substrates. It also has Mesic forest and Wet mesic forest, found on shale and sandstone which are located along several permanent streams. These forested areas were once prairie. The park also contains a prairie headwater stream of superb quality.

The park can be broken down into several areas according to past use. Ninety-seven ha are excellent natural area quality that have a past use of haying. Degraded prairie on unplowed soil that has been variably grazed and has in some areas had some cool season overseeding includes 486 ha. In general, this section is fair to good quality prairie. Thirty-seven ha on unplowed prairie soil have been invaded by woody species along permanent streams. The remaining 60 ha were plowed when the area was homesteaded, with cultivation continuing unti the 1930's. It has since been overseeded to cool season non-native grasses.

The park is dominated by mid to tall grasses which include *Andropogon gerardi* (big bluestem), *Andropogon ternarius* (beard grass), *Panicum virgatum* (switchgrass), *Schizachyrium scoparium* (little bluestem), *Sorgastrum nutans* (Indian grass), and *Spartina pectinata* (cordgrass). In addition to being a significant prairie remnant it also fills a gap in the State Park system's goal of representing major Missouri landforms and communities. Prairie State Park is the first Missouri park whose principal emphasis is the prairie.

Management Objectives

As with any state park, a Master Plan has been developed addressing management of Prairie State Park. The management of Prairie State Park has 2 major objectives: preservation and restoration or the prairie communities, and interpretation of the Missouri Prairie for the public.

The first objective of preserving and restoring the prairie community is what the park theme revolves around in that Prairie State Park is there because of prairie and anything done to harm that resource also harms the park.

This line of management has been carried on quite successfully by other organizations and entities in Missouri in the acquisition and control of prairies.

Our second objective is that of interpretation of the Missouri tallgrass prairie. Our first objective sets the basic ground rules for the second in that any facility for interpretation and the interpretation itself must not in any way interfere with the objective of preserving or restoring a presettlement prairie condition, only enhance it.

For to love the prairie is to experience it, and to experience it one has to consume part of it. A park visitor is a comsumptive user. So how do we allow the visitor to consume Prairie State Park and take part of the prairie? Doing away with wasted consumption of any resource, especially one as dwindling as Missouri's prairies, is the ultimate goal. To ensure that the 2 objectives, preservation and interpretation, are compatible, a sound interpretive plan has to be written.

The interpretive plan for Prairie State Park is just as important as the management plan in that through interpretation we intend to orient, alert, inform the public, enhance the general interest, provide enjoyment, and obtain public involvement in protecting and conserving prairie. By looking at geological and biological features to explain Dry mesic, Mesic, or Wet mesic, the complexity of the prairie will become apparent to the visitor. As one understands more and more about an environment the more appreciation one will have for it.

To do this we have to get the visitor out into the park. Therefore, our facilities will be directed toward that goal, and so designed to blend in and be compatible with the prairie environment. Presently, access is by gravel roads and it is planned that these will be retained. Small parking lots will be constructed at trail heads and at the Visitor Center to control vehicle parking and keep it off the county roads and within the park. These lots will be kept as small as possible to lessen their impact but large enough for expected needs. The main park facility will be the Visitor Center, the hub of the park and trail system. It is hoped a site can be found that will provide for the building design to be in part below ground level, and constructed from materials that will blend into the environment.

The upper one-half of the interpretive display in the exhibit room will consist of windows looking out on the prairie itself. In this way, part of the display is always changing with the season and with the time of day. Thus, the use of artificial displays in explaining prairie relationships will always be reinforced by the natural display. It makes much more sense to explain the geology and soil formation as factors in tallgrass prairie development if visitors can see the actual result before their eyes.

The purpose of the center will be to whet the interest of the visitor to take one of the trails that wind through the park. It is hoped that from the center's location, most of the trails will tend to disappear over the horizon. This combined with the pioneering spirit of the visitor makes the trail something that has to be realized. The park visitor may not initially understand past events or natural history of the prairie but few can escape the feeling of reverence when first walking on a prairie. Today's park visitor may truly empathize with the pioneer crossing "immense wilderness," and raise such questons as, "What did the early pioneer face while crossing the prairie?" To build appreciation by experience, naturalist-led walks will have titles such as: "In Search of a Tree", "A Hike Back in Time", "Sacramento–2000 Miles Away", "What is a Prairie?", "Why Can't You Plow This Prairie?", or "What's a Prairie to You?".

To convey this feeling of vastness and loneliness, the trails themselves are laid out just below the ridge lines so that the visitor is always looking over the horizon or at as broad a prairie vista as possible. The trails are curved to avoid straight lines so that the trail is not really obvious. At present we are constructing and maintaining trails with a tractor that mows paths 1–m wide to the height of approximately 10 cm. This has worked very well to date but we have had only dry springs and I question this working in wet years as rutting is a concern. To mow annually in exactly the same place would favor cool-season invaders so each year the trails will be moved slightly to avoid using the same path. The advantage of this is a trail that blends in very well and can be easily relocated. There is one possible problem as visitation increases. A trail may become excessively worn with irreversible damage before it could be relocated and would then have to be permanently located there and surfaced with natural material such as local creek gravel. Wood chips or asphalt would be out of the question in a prairie environment.

In addition to providing vistas of the prairie landscape the trail system needs to have the values of a wild area, those of solitude and loneliness, feelings frequently associated in American history with the prairie. If the visitor can come back with the feeling of having been lost in a sea of grass and have some understanding of how that sea works, appreciation is on the way. Interpretation is aided in a big part by visitor information as well. The park brochure, trail guides, and teacher aids can be invaluable in presenting the positive aspects of the park while explaining any special rules or considerations for its protection.

The park will also have a small picnic area and campground. These will be located in the band of timber along one of the streams so that they will not intrude upon the prairie itself. I feel that part of the interpretive message of the park can actually be met by making it an enjoyable place to eat or sleep. Again appreciation comes through enjoyment.

The Prairie State Park has two objectives: to maintain and restore the native tallgrass prairie and to interpret that tallgrass prairie for its visitors.

If the visitors have had an enjoyable experience based on sound objectives provided by the park staff and its facilities in providing information, orientation, enhancement, provocation, communication and enjoyment in a pleasant manner then the visitor will not look at Prairie State Park as a sun-filled weed patch. Instead it will be an area rich in diversity and history. If the second objective of interpretation is met in providing appreciation of the prairie then the first objective or preservation will be much easier throughout the state and elsewhere.

[illegible]

The first objective of preserving and restoring [illegible] sets the basic ground rules for the secondary [illegible] any facility for interpretation and the interpretation itself must not in any way interfere with the objective of preserving or restoring a presettlement prairie condition, only enhance it.

For to love the prairie is to experience it, and to experience it one has to consume part of it. A park visitor is a consumptive user. So how do we allow the visitor to consume Prairie State Park and take part of the prairie? Doing away with wasted consumption of any resource, especially one as dwindling as Missouri's prairies, is the ultimate goal. To ensure that the 2 objectives, preservation and interpretation, are compatible, a sound interpretive plan has to be written.

The interpretive plan for Prairie State Park is just as important as the management plan in that through interpretation we intend to orient, alert, inform the public, enhance the general interest, provide enjoyment, and obtain public involvement in protecting and conserving prairie. By looking at geological and biological features to explain Dry mesic, Mesic, or Wet mesic, the complexity of the prairie will become apparent to the visitor. As one understands more and more about an environment the more appreciation one will have for it.

To do this we have to get the visitor out into the park. Therefore, our facilities will be directed toward that goal, and so designed to blend in and be compatible with the prairie environment. Presently, access is by gravel roads and it is planned that these will be retained. Small parking lots will be constructed at trail heads and at the Visitor Center to control vehicle parking and keep it off the county roads and within the park. These lots will be kept as small as possible to lessen their impact but large enough for expected needs. The main park facility will be the Visitor Center, the hub of the park and trail system. It is hoped a site can be found that will provide for the building design to be in part below ground level, and constructed from materials that will blend into the environment.

[illegible] more sense [illegible] tion as factors in tallgrass prairie development if visitors can see the actual result before their eyes.

[illegible] of the center will be to [illegible] the visitor to take one of the trails that wind through the park. It is hoped that from the center's location, most of the trails will tend to disappear over the horizon. This combined with the pioneering spirit of the visitor makes the trail something that has to be realized. The park visitor may not initially understand past events or natural history of the prairie but few can escape the feeling of reverence when first walking on a prairie. Today's park visitor may truly empathize with the pioneer crossing "immense wilderness," and raise such questons as, "What did the early pioneer face while crossing the prairie?" To build appreciation by experience, naturalist-led walks will have titles such as: "In Search of a Tree", "A Hike Back in Time", "Sacramento–2000 Miles Away", "What is a Prairie?", "Why Can't You Plow This Prairie?", or "What's a Prairie to You?".

To convey this feeling of vastness and loneliness, the trails themselves are laid out just below the ridge lines so that the visitor is always looking over the horizon or at as broad a prairie vista as possible. The trails are curved to avoid straight lines so that the trail is not really obvious. At present we are constructing and maintaining trails with a tractor that mows paths 1-m wide to the height of approximately 10 cm. This has worked very well to date but we have had only dry springs and I question this working in wet years as rutting is a concern. To mow annually in exactly the same place would favor cool-season invaders so each year the trails will be moved slightly to avoid using the same path. The advantage of this is a trail that blends in very well and can be easily relocated. There is one possible problem as visitation increases. A trail may become excessively worn with irreversible damage before it could be relocated and would then have to be permanently located there and surfaced with natural material such as local creek gravel. Wood chips or asphalt would be out of the question in a prairie environment.

In addition to providing vistas of the prairie landscape the trail system needs to have the values of a wild area, those of solitude and loneliness, feelings frequently associated in American history with the prairie. If the visitor can come back

THE OJIBWAY PRAIRIE - A DISJUNCT PRAIRIE PRESERVE IN SOUTHWESTERN ONTARIO

P. D. Pratt
City of Windsor, Parks and Recreation Department
2450 McDougall Street
Windsor, Ontario N8X 3N6

Abstract. Tallgrass prairie originally occupied small areas of southern Ontario including an area within the present city limits of Windsor known as the Ojibway prairie. Two parks located within the original extent of this prairie contain the only protected and best remaining example of prairie vegetation in the province.

Introduction

The first settlers in extreme southwestern Ontario encountered not only extensive forest, but also many prairie-like clearings. Maps and accounts of this area between 1670 and 1847 described about 40,000 ha as "fine open plains" (Lajeuesse 1960), "extensive natural meadows. . .4 to 6 miles in depth" (McNiff 1791), or "prairie" (Rankin 1847).

Except for site at Windsor, in Essex County and Walpole Island, in Lambton County, these prairies were eventually replaced by farms. No botanist had the opportunity to describe the vegetation of these extensive prairie tracts and only place names such as Prairie Siding and Raleigh Plains remained as an indication of the prairies former existence. The Ojibway prairie lying on the edge of Windsor was briefly visited by John Macoun, botanist for the Geological Survey of Canada in 1892. He was familiar with the prairies of Western Canada and was impressed with what he termed "the eastern extension of the prairie flora" (Macoun 1893).

Protection Efforts

In a province where only forest was considered to be the true climax form of vegetation, the Ojibway prairie received little attention. Macoun's words were quickly forgotten and what prairie vegetation remained survived only by accident. Although many botanists continued to make collecting trips to the prairie there appeared to be no effort at affording it any protection. C. M. Rogers (1966), after collecting for many years at Ojibway published a brief account of the flora as he believed "the expanding city will surely obliterate it."

In 1968, Dr. P. F. Maycock visited Ojibway and expressed concern about the future of this prairie remnant. He had visited the area 10 years earlier and was struck by the number of recent encroachments on the prairie which include a city park, racetrack complex and industrial development. Together with the efforts of officials from the Windsor Parks and Recreation Department, Ontario's Ministry of Natural Resources, other botanists and local naturalists, a move to provide some form of protection for the prairie quickly accelerated. By 1972, several agencies were interested in the area's acquisition and a year later the Ontario Ministry of Natural Resources, together with the Nature Conservancy of Canada made an initial purchase of 86 ha for the creation of a provincial nature reserve. During the same period, development plans for the adjacent Ojibway Park, 44 ha, were altered to stress preservation of its plants and animal communities. Thus the best remaining example of prairie vegetation in Ontario was finally provided with effective protection from further development.

Flora

Only a brief account of the diverse flora associated with this area can be mentioned here. Rogers (1966) and Thompson (1975) have published lists of plants occurring on the Ojibway prairie. As part of the master planning for the park complex an extensive investigation of life science features was undertaken in 1976 and 1977 (Pratt 1979). Over 450 species of plants have been located within Ojibway Park and the adjacent Ojibway Prairie Provincial Nature Reserve.

In Ontario, prairie vegetation occurs in such few, widely separated sites that many of the species typically associated with prairie are considered very rare in the province. Argus and White (1977) have produced a list of all native plants considered to be rare in Ontario. Of those listed over 60 are present in the prairie stands at Ojibway, and over 40 of these are representative tallgrass prairie species such as *Panicum oligosanthes, Hypoxis hirsuta, Sisyrinchium albidum, Oxypolis rigiditor, Veronicastrum virginicum, Krigia biflora, Liatris aspera, L. spicata, Ratibida pinnata, Silphium terebinthinaceum,* and *Solidago rigida.* Many other species considered provincially rare but common and widespread in prairie stands at Ojibway include *Aristida purpurescens, Baptisia tinctoria, Coreopsis tripteris,* and *Vernonia altissima.* Botanists visiting Ojibway from other parts of Ontario are impressed by the abundance and diversity provided by these "rare" species.

The wetter moisture phase of prairie is best represented at Ojibway with *Spartina pectinata, Andropogon gerardi* and *Calamagrostis canadensis,* forming dense swards interspersed with tall forbs such as *Solidago canadensis, Desmodium canadense, Pycnanthemum virginianum, Veronicastrum virginicum, Monarda fistulosa,* and *Vernonia altissima.* By mid-August the highest flowering culms reach up 2-3 m in height.

However, large open treeless areas do not dominate the landscape. Ojibway Park contains an extensive swamp *Quercus palustris* forest which grades into savannah with prairie species dominating the understory. Within the Nature Reserve wet prairie grades into *Q. palustris* savannah with drier *Q. veluntina* savannah on higher ground. Also included in the Nature Reserve are areas once used for cropland, or otherwise disturbed which presently support a wide variety of vegetation ranging from weedy fields to areas dominated by the more aggressive and showy prairie forbs.

Planning and Management

The Ojibway Prairie Provincial Nature Reserve was one of the first major acquisitions in a system of nature reserve class provincial parks that are being created in order to assure protecton of representative and significant examples of Ontario's natural heritage. The planning for this reserve has taken a unique approach involving a cooperative planning programme between the City of Windsor's Parks and Recreation Department and Ontario's Ministry of Natural Resources. In 1975, representatives from the Ministry, City of Windsor and scientists from Ontario and Michigan Universities met to draw up a set of guidelines for the future development of the area. The goal statement prepared during this meeting was "to perpetuate and protect this unique prairie environment as part of our natural heritage in order to further our understanding and appreciation of its environmental, biological and aesthetic values."

When the acquisition programme is complete, approximately 175 ha of parkland will be afforded protection through the municipally operated Ojibway Park and the provincial nature reserve. The provision of visitor services and environmental interpretive programmes will be concentrated at Ojibway Park. A Nature Centre, completed in 1976, is currently offering year-round programming to visitors and city residents. Only minimal development is planned for the nature reserve to provide for and control access into the property.

Management will emphasize the maintenance and restoration of prairie and savannah communities. Controlled burns are seen as the most effective method of vegetation management in working towards the simulation of presettlement conditions.

Literature Cited

Argus, G. W. and D. J. White. 1977. The rare vascular plants of Ontario. Syllogeus Series No. 14. National Museum of Natural Sciences, Ottawa, Canada.

Macoun, J. 1983. Notes on the flora of the Niagara peninsula and the shores of Lake Erie. Hamilton Assoc. J. Proc. 9:78-86.

McNiff, P. 1791. Unpublished survey map of District of Hesse. In the files of the Survey Branch, Ontario Ministry of Natural Resources. Scale 40 chains: 1 inch.

Pratt, P. 1979. A preliminary life science inventory of the Ojibway prairie complex and surrounding area. Unpubl. ms. Corporation of the City of Windsor and Ontario Ministry of Natural Resources, Provincial Parks Branch. Ontario.

Rankin, C. 1847. Unpublished map of extreme southwestern Ontario. In the files of the Survey Branch, Ontario Ministry of Natural Resources. Scale 200 chains: 1 inch.

Rogers, C. M. 1966. A wet prairie community at Windsor, Ontario. Can. Field Nat. 80:195-199.

Thompson, P. W. 1975. The floristic composition of prairie stands in southern Michigan. Proc. Fourth Midwest Prairie Conf., pp.317-332, M. K. Wali, ed. The University of North Dakota, Grand Forks.

TALLGRASS PRAIRIE MANAGEMENT AT THE AULLWOOD AUDUBON CENTER AND FARM–DAYTON, OHIO

Paul E. Knoop, Jr.
Aullwood Audubon Center and Farm
1000 Aullwood Road
Dayton, Ohio 45414

Abstract. The Aullwood Audubon Center and Farm is a 190—acre environmental educational facility owned and operated by the National Audubon Society. A 70—acre portion consisting of "old farm" environments including meadow, old field, climax and second growth woodland, marsh and stream has been managed for maximum biological diversity since 1957. The decision was made in 1959 to establish a small tallgrass prairie to enhance the educational potential of the area and to preserve a bit of the rapidly disappearing prairie resource in Ohio. Advice on site selection was given by well known ecologists and a 10—acre field was chosen for prairie development. Seeds were collected in Ohio from relic prairie areas and planted in a 1—acre plot in the spring of 1960. Additional plantings in the intervening years has brought the prairie to its present size of 10 acres. Management at first consisted of yearly removal of litter in the fall followed by burning in the spring. Because of loss of species diversity this plan was modified to every other year burning. The present management plan for the 10—acre area consists of 6 different combinations of burning, mowing and control area. We feel this program will provide answers to maintaining species diversity in small restored prairies. The Aullwood prairie has become an important part of the education program at the Aullwood Audubon Center and Farm with large numbers of children and adults experiencing the area.

Introduction

The Aullwood Audubon Center and Farm is a 190—acre environmental education facility located 10 miles north of Dayton, Ohio. The original gift of 70 acres of land was given to the National Audubon Society in 1957 by Mrs. John W. Aull. In 1962 Mrs. Aull purchased an adjoining 120—acre farm and donated it bringing the total acreage to 190. The entire area is managed to maintain maximum biological diversity which in turn enhances the educational potential of the site. Typical "old farm" environments on the original 70—acre site included meadow, old field, climax and second growth woodland, marsh and stream. Our hope was to establish a small tallgrass prairie on this 70—acre parcel of land. Early land surveys indicated that prairie had been present in the county prior to settlement, however, not on the Aullwood site. Our decision to establish a tallgrass prairie was based on its educational potential and the fact that prairie vegetation was a disappearing resource in Ohio.

Management Procedures

Considerable effort went into selecting the planting site. The Aullwood staff sought guidance from Dr. Paul Sears of Yale University, Mr. Frank Preston of Butler, Pennsylvania, and Dr. J. T. Curtis of the University of Wisconsin. Valuable help was received from all these men on site selection and planting procedure.

The site selected was a gently sloping 2-1/2—acre portion of a 10—acre field containing well-drained Miami Silt Loam Soil at the upper end and poorly-drained Brookston Silty Clay Loam at the lower end. Vegetation on the site consisted of well established brome grass *(Bromus inermis)* which had been planted years earlier as a pasture crop. This species is highly competitive and very little other vegetation was evident at the time.

In the fall of 1959, prior to planting prairie seed, the 2-1/2—acre site was plowed and disked to eliminate the brome grass. During the same period prairie seeds were collected by hand from roadsides in Adams County, Ohio. Adams county is unique in its botanical makeup, and small relic prairies in the area have a good representation of prairie species including: *Sorghastrum nutans, Andropogon scoparius, A. gerardi, Echinacea purpurea, Liatris* spp., *Silphium terebinthinaceum, Ratibida pinnata, Solidago rigida,* and *Sabatia angularis.*

Collected seeds were buried in soil for the winter, dug up and planted in the spring of 1960. We had enough seeds to plant approximately 1 acre of the 2-1/2—acre plot. Thereafter annual expansion of the prairie in 1/4 acre increments was continued until the 2-1/2—acre area was completed in 1968. Subsequent plantings after 1968 have increased the present tract to 10 acres.

From the beginning, management of this small prairie consisted almost entirely of burning and hand cutting of hardwood trees. At the time small prairie management was what might be called a "pioneering effort" as we had few models to follow. We merely used our better judgement on the best techique to promote growth of prairie species. This judgement led us to a program of fall mowing and raking litter and spring buring to control annual weed growth. Burning at the time was accomplished by spreading dry straw over the site and igniting it. Fall mowing and removal of litter in conjunction with spring burning was continued through the spring of 1963.

In 1963 all plots seemed to be doing well. There were well established clumps of big bluestem, little bluestem and Indian grass with a nice sprinkling of forbs. Our major concern was the seemingly increased dominance of grasses in proportion to forbs. We began to notice how rapidly the grasses grew after each spring burn and how their increasing lushness competed with the forbs. It was at this time (spring 1963) that we went to a program of every-other-year burning as recommended by Kucera and Ehrenreich in an article in *Ecology* (1962) entitled, "Influence of Fire on Composition of Central Missouri Prairie". They found that "annual burning resulted in a uniform cover of prairie grass with a sharp decline in broadleaved species, whereas the effect of biennial burning was to maintain a mixture of both grass and broadleaved species".

The every-other-year burning continued until 1974. At that time the prairie was approaching 10 acres in extent and we felt a need to evaluate our management program. After much study the decision was made to divide the area into 6 fairly even sized study plots and a different management techinque was to be applied in each plot as follows:

Plot 1 - burn every year
Plot 2 - burn every other year
Plot 3 - mow every year in October
Plot 4 - mow every other year in March
Plot 5 - burn every third year
Plot 6 - control area - no burning or mowing - control woody growth by hand cutting only

At present we feel confortable with this management program as we feel in time it will give us some much needed answers to the problem of maintaining species diversity in small restored prairies. An inventory of prairie flora in the summer of 1979 resulted in a list of 75 prairie species presently growing in the Aullwood prairie. It is hoped that our diversified management program will allow all of these to persist into the future.

In conjunction with the above it should be added that the Aullwood prairie has become an important part of the total education program at the Aullwood Audubon Center and Farm. School classes visit and experience the prairie. The spring prairie burn has become an annual public event with as many as 300 people attending. In addition, individuals and groups from around the country have visited to learn about small prairie restoration.

During the past year a publication entitled "The Inland Sea - A Guide to Aullwood Prairie" was published and is now available for public use. This guide is another step in our continuing effort to develop public appreciation for the native American prairie.

Literature Cited

Kucera, C. L. and J. H. Ehrenreich. 1962. Some effects of annual burning on central Missouri prairie. Ecology 43:334-346.

FIRE INTERVAL EFFECTS ON FLOWERING OF GRASSES IN KANSAS BLUESTEM PRAIRIE[1]

Lloyd C. Hulbert
and
Jerry K. Wilson[2]
Division of Biology
Kansas State University
Manhattan, Kansas 66506

Abstract. The height, density, and weight of flower stems of big bluestem (*Andropogon gerardi*), Indian grass (*Sorghastrum nutans*), and little bluestem (*A. scoparius*) on ungrazed areas burned in spring of 1979 differed with respect to time elapsed since the areas had been last burned: 1, 2, or 6 years previously. These results were found on deep, fertile soils on lower slopes in areas experimentally burned on Konza Prairie Research Natural Area in Geary County, Kansas. Height, density, and weight of flower stems of big bluestem were highly significantly greater as the length of interval increased. Indian grass and little bluestem showed some of the same tendency, but primarily showed marked reductions in the 6-year interval area, resulting in an increased dominance by big bluestem.

Introduction

Burning stimulates production and flowering of the warm-season tall grasses in bluestem (tallgrass) prairie, at least when ungrazed, (Aikman 1955, Curtis and Partch 1950, Ehrenreich 1959, Ehrenreich and Aikman 1957, 1963 Hadley and Kieckhefer 1963, Kucera and Ehrenreich 1962, Old 1969). There is, however, little or no published information on whether or not number of years between burning will alter those responses. In 1979 we had opportunity to make such a comparison on Konza Prairie Research Natural Area, where experimental burnings at various intervals have been underway since 1972.

Study Site

Konza Prairie is a 3,487-hectare area that was purchased by The Nature Conservancy (part in 1971 and part in 1977) and then leased to Kansas State University for long-term ecological research. This study was made on the portion (371 ha) purchased in 1971, on which late-spring experimental burnings at various intervals were initiated in 1972. The area is in northern Geary County, about 13 km south of Kansas State University at Manhattan. The median annual precipitation, based on records kept for 105 years at Manhattan, is 779 mm. The vegetation is dominated by big bluestem (*Andropogon gerardi* Vitman). Other important species include Indiangrass (*Sorghastrum nutans* (L.) Nash) and little bluestem (*Andropogon scoparius* Michx). More than 300 species of vascular plants occur in this prairie.

Methods

Nine ungrazed experimental areas ranging from 9 to 42 hectres were burned from April 24 through April 28, 1979. Three of these that were adjacent to each other had been last burned 1, 2 and 6 years previously. Thus we could compare the effects of different intervals betwen burning. Differences were visually present in late summer after the tall grasses had flowered.

To reduce variance due to soil variability we compared the areas having 1 and 2 years between burning by sampling on the 2 sides of the fire boundary between them. The 1-year interval area has been annually burned from 1972 through 1979. The 2-year interval area has been burned in old years: 1973, 1975, 1977, and 1979. Similarly to reduce variance we compared the 2 and 6 years interval by sampling on the 2 sides of the boundary between them. The 6-year interval area was burned in 1973 and again in 1979. The fire boundaries, 5 meters wide, are mowed and hayed each summer. A 2 - 3 m wide strip is burned in them in the autumn or spring to provide a fire barrier. The soil in the sampled areas is deep and fertile, designated Tully silty clay loam, 4-8% slopes (Bidwell and Dunmire 1960).

Height, density, and oven-dry weight of flower

[1] Contribution No. 81-38-A, Division of Biology and Kansas Agricultural Experiment Station. This study was supported by the Agricultural Experiment Station.

[2] Present address: Bogue, Kansas 67215.

stalks of bluestem and Indian grass were obtained from systematically located samples in October, 1979. Weight was obtained by clipping 25 plots (0.25 m^2) in each treatment, and oven-drying at 70^0C. Vegetation. clipped at a height of 1 cm, was separated into 4 categories: flower stalks of big bluestem, flower stalks of Indian grass, flower stalks of little bluestem, and all remaining plant material (mostly vegetative growth of grasses).

Density of flower stalks was obtained in 25 1x1 m plots in each treatment. Density was recorded separately for each species.

In each treatment, the height to nearest cm was obtained for the flower stalk of each species nearest to 50 sampling points.

Results and Discussion

Increasing the interval between fires from 1 to 2 and from 2 to 6 years resulted in highly significant increases in height, density, and weight of flower stalks of big bluestem *Andropogon gerardi* (Table 1). For Indian grass, *Sorghastrum nutans,* the 2-year interval area had highly significantly greater height, density, and weight of flower stalks than did the 1-year interval area. The 6-year interval area, however, did not show the same results. Flower stalks of Indian grass were markedly less abundant in the 6-year than in the 2-year-interval area. The nearest flower stalk of Indian grass to a sampling point in the 6-year area was usually several meters from the point. At only 4 points was a flower stalk of Indian grass nearer than about 0.5 m, which indicated that big bluestem can tolerate greater accumulation of old plant material than can Indian grass. Such a reduction in Indian grass had been noticed previously in a double-fenced section line long undisturbed. It had nearly pure big bluestem, with Indian grass nearly absent (Hubert 1969). It surprised us to find such a reduction in Indian grass, in only 6 years.

Table 1. Effects of interval between burning times on average height, density and weight of flower stems of prairie grasses

	Years since previous burn					
	1	2	P	2	6	P
Height, flower stems - cm						
Big bluestem	101	120	.0001	109	143	.0001
Indian grass	89	100	.005	86	84	
Little bluestem	62	65	.01	69	73	.14
Density, flower stems - m^2						
Big bluestem	9.6	20.8	.0007	27.2	49.8	.0001
Indian grass	2.8	9.3	.0001	5.6	1.4	.0001
Little bluestem	35.8	34.1	.081	31.6	7.5	.0001
Flower stem biomass-g/m^2						
Big bluestem	31	99	.0005	84	192	.0001
Indian grass	4	14	.0009	9	0.7	.0003
Little bluestem	33	26	.28	31	3	.0001
Total flower stem biomass	68	139	.0002	124	196	.07
Vegetative biomass (all grasses)	376	376	.98	404	363	.02
Total biomass (flowering and vegetative)	444	516	.002	528	559	.28

Little bluestem, *Andropogon scoparius,* results were inconsistent. Although height of flower stalks was significantly greater for the 2-year than for the 1-year-interval area, density and biomass were not. Density and biomass were significantly lower at 6- than at 2-year-intervals, but not significantly different at 2- and 1-year-intervals.

Weight of vegetative growth of all species excluding flower stalks, was the same on the 1- and 2-year-interval areas, but was somewhat less on the 6- than the 2-year-interval areas, or opposite that for the flower stalk biomass.

Why flower-stalk production increases with increasing interval between fires we do not know. One possibility is differences in nutrient supply. Because all 3 sites were burned in the spring and because there was more old growth as the interval increased, the amount of nutrients left in the ash should have increased as the length of time between fires increased. If increased nutrient supply was a cause of increased flowering, it is not clear why there was no increase in vegetative growth. Also, earlier studies, in which burned plots (with ash present) were compared with clipped plots from which the clipped material had been removed, showed no significant difference in yield or flowering (Old 1969, Hulbert 1969).

Soil moisture may be a factor. Accumulation of old growth has commonly been found to reduce production, resulting in reduced evapotranspiration (for example, see Old 1969 or Hulbert 1969). This could mean that the greater the time since the previous fire, the greater would be the water stored in the soil at the beginning of the growing season, possibly increasing vegetative growth as well as flower stalk production.

There are other possible explanations. Soil temperature might differ as a result of the differing amount of carbon left to blacken the surface, the amount being proportional to the amount of old growth burned. However, this effect does not last long after rains. It is possible that the heat of the fire has a stimulating effect of the grasses. Other factors include changes in the microflora of the soil or accumulation of substances in the soil between fires. Ascertaining the correct explanation, and learning if the results are consistent from year to year, will help us understand the role of fire in bluestem prairie.

Literature Cited

Aikman, J. M. 1955. Burning in the management of prairie in Iowa. Proc. Iowa Acad. Sci. 62:53-62.

Bidwell, O. W. and R. G. Dunmire. 1960. Soil survey of Gearty County, Kansas. Series 1955, No. 6. Soil Conservation Serv., U.S. Dept. Agri., Wash., D.C.

Curtis, John T., and Max L. Partch. 1950. Some factors affecting flower production in *Andropogon gerardi.* Ecology 31:488-489.

Ehrenreich, John H. 1959. Effect of burning and clipping on growth of native prairie in Iowa. J. Range Manage. 12:133-137.

Ehrenreich, John H. and J. M. Aikman. 1957. Effect of burning on seedstalk production of native prairie grasses. Proc. Iowa Acad. Sci. 64:205-212.

Ehrenreich, John H. and J. M. Aikman. 1963. An ecological study of the effect of certain management practices on native prairie in Iowa. Ecol. Monogr. 33:113-130.

Hadley, Elmer B., and Barbara J. Kieckhefer. 1963. Productivity of two prairie grasses in relation to fire frequency. Ecology 44:389-395.

Hulbert, Lloyd C. 1969. Fire and litter effects in undisturbed bluestem prairie in Kansas. Ecology 50:874-877.

Kucera, C. L., and John H. Ehrenreich. 1962. Some effects of annual burning on central Missouri prairie. Ecology 43:334-336.

Old, Sylvia M. 1969. Microclimate, fire, and plant production in an Illinois prairie. Ecol. Monogr. 39:355-384.

(0.25 m^2) in each treatment, and oven-dried at 70^{0}C. Vegetation, clipped at a height of 1 cm, was separated into 4 categories: flower stalks of big bluestem, flower stalks of Indian grass, flower stalks of little bluestem, and all remaining plant material (mostly vegetative growth of grasses).

Density of flower stalks was obtained in 25 1x1 m plots in each treatment. Density was recorded separately for each species.

In each treatment, the height to nearest cm was obtained for the flower stalk of each species nearest to 50 sampling points.

Results and Discussion

Increasing the interval between fires from 1 to 2 [illegible]

[illegible] did the 1-year interval [illegible] area, however, did not show the same results. [illegible] eral meters from the p[illegible] flower stalk of Indian grass nearer than about 0.5 [illegible]

Table 1. Effects of interval between burning times on [illegible] and height of flower stems of prairie grasses.

	1	2	P	2	6	P
Height, flower stems, cm						
Big bluestem	101	120	[illegible]	[illegible]	[illegible]	[illegible]
Indian grass	98	100	[illegible]	[illegible]	[illegible]	[illegible]
Little bluestem	62	65	[illegible]	[illegible]	[illegible]	[illegible]
Density, flower stems [illegible]						
Big bluestem	9.6	20.8	[illegible]	[illegible]	[illegible]	[illegible]
Indian grass	7.5	9.3	[illegible]	[illegible]	[illegible]	[illegible]
Little bluestem	30.8	34.1	[illegible]	[illegible]	[illegible]	[illegible]
Biomass, flower stems [illegible]						
Big bluestem	[illegible]	99	[illegible]	[illegible]	[illegible]	[illegible]
Indian grass	4	14	.0009	3	0.7	.0003
Little bluestem	33	26	.28	31	3	.0001
Total flower stem biomass	68	139	.0002	124	196	.07
Vegetative biomass (all grasses)	376	376	.98	404	363	.02
Total biomass (flowering and vegetative)	444	516	.002	528	559	.28

EFFECT OF SPRING BURNING DATE ON MIXED—PRAIRIE SOIL MOISTURE, PRODUCTIVITY AND PLANT SPECIES COMPOSITION

Harold G. Nagel
Department of Biology
Kearney State College
Kearney, NE 68847

Abstract. Objectives of the study were to: determine burning effect on primary productivity, soil moisture, plant basal cover, and plant species composition, especially Kentucky bluegrass (*Poa pratensis*), a serious invader. The research was conducted on a prairie tract in south-central Nebraska. About 4 ha were burned 17 April 1979 and three 1/10-ha plots were burned 15 May. The prairie has not been burned recently, and only lightly grazed since 1974. Moisture blocks were placed at 13, 25, and 38-cm depths in 11 locations. Readings were taken through the growing season until 20 October. Inclined basal step points and 400 cm^2 clip quadrats were taken to determine species composition and standing crop biomass. Unburned sites had significantly higher amounts of soil moisture than April-burned sites. No significant differences were found between treatments for total end-of-season standing crop biomass. Bluegrass had significantly lower biomass on burned plots than on unburned, with the May burn reducing it the most. Basal plant cover was significantly higher on both burn-date sites. No significant correlation existed between standing crop biomass and soil moisture at the 13 and 35 cm depths; however, there was a significant correlation at 38 cm (r = + 0.86).

Introduction

Prescribed burning of prairies is not commonly used west of the 98th meridian in southern Nebraska and northern Kansas. Previous research has shown variable results of spring burning in mixed grass prairies. Hopkins et al. (1948) found that both spring and fall burning in western Kansas reduced basal cover and yields of dominant grasses. Launchbaugh (1964) found that a March burn on clay soils reduced yields of all species for two years. He attributed the reduced yields following the burn to crown damage and apparently less favorable moisture conditions on burned sites.

Hulbert (1969) stated "unless the overriding purpose is to control woody plants, to suppress wildfire hazard, or to reduce excessive mulch accumulation. . .periodic burning may result in such yield sacrifices that it cannot be considered as a practice *per se* of increasing livestock performance on many Mixed and Shortgrass Prairie range sites."

Launchbaugh (1973) however, concluded "where mulch accumulations of herbaceous vegetation are extremely great, burning will be beneficial, resulting in increased yields. Where mulch accumulations are tolerable, burning probably will reduce yields."

Most researchers have agreed with Anderson (1965) that burning reduced soil moisture but late spring burning reduced it the least.

Kentucky bluegrass (*Poa pratensis*) has been a problem invader in prairies of Nebraska for at least 30 years (Voigt and Weaver 1951). Spring burning has been shown to decrease the importance of bluegrass in most burning studies including Smith and Owensby (1973).

This study was done to determine which date of burning (mid-April or mid-May) was best to control Kentucky Bluegrass and to minimize the adverse effects of burning on soil moisture, productivity and species composition in a mixed prairie in south-central Nebraska.

Methods

The study was conducted on Willa Cather Memorial Prairie, a Nature Conservancy prairie located 8 km south of Red Cloud, Nebraska. The 247 ha (610 acre) mixed-grass prairie, purchased in 1974, had a history of overgrazing and excessive invader species, primarily Kentucky Bluegrass (Nicholson and Marcotte 1979).

On June 8, 1979, gypsum moisture blocks were set at 13, 25, and 38 cm (5, 10, 15 inches) deep at eleven sites, on both burn-date plots and the unburned control (total = 84 blocks). The moisture blocks were set in similar soil and topography conditions where possible. In most cases the block sites were 6 m apart.

Moisture readings were taken with an ohmmeter at 2-week intervals until October 19, 1979. Due to moist soil conditions, no useful data were obtained until August 10. About 12 cm of precipitation fell in June, 10 cm in July, 11 cm in August and 3 cm in September through October 10, 1979. Soil moisture was also determined gravimetrically. Cores 2 cm in diameter to a depth of 40 cm were separated into 10-cm increments, weighed, dried at 100°C for 24 hours, reweighed, and percent moisture determined. Data were analyzed for significance of difference.

Thirty step-points (Owensby 1973) were taken at each site on July 6, 1979, in each of 3 locations to determine effect of burning date on composition (N=450). Basal hits were recorded at each point for plant, litter, or bare soil. If no plant was hit, the plant nearest the pin in the 180 degree area in from of the pin was recorded. On October 19, 1979 seventy-six 400 cm^2 quadrats were clipped. These plant samples were air-dried and weighed as an estimate of total productivity. Prior to clipping, species composition by volume was determined visually. Applying the visually determined percentage for each species to total dry biomass provided an estimate of yield by species. The following year, May 13, 1980, density of Kentucky bluegrass was determined in ninety 400 cm^2 quadrats at the April and May burning sites.

Mann-Whitney (Zar 1974) tests were conducted to determine significance of differences in standing crop biomass between treatments. Analysis of variance was used to test significance of differences in bluegrass density by treatment. The Newman-Kuels multiple range test (Zar 1974) was used to determine significance of difference between treatment means of bluegrass density. Spearman's rank correlation statistic (Schefler 1969) was run on standing crop biomass *vs* soil moisture at different depths as determined with moisture blocks.

Results and Discussion

As expected, the unburned sites generally had higher soil moisture from August through October of the burn year as well as in May of the year after the burn. Only the April-burn sites were significantly different from the unburned sites ($P < 0.01$). May-burn sites, although having less moisture than control sites, were not significantly different at the 5 percent level (Fig. 1). One exception was in spring the year after the burn when the burned plots had more moisture at the 30-40 cm depth than did the unburned controls. Differences were not significant, however (Fig. 2.). No significant correlation occurred between standing crop biomass and soil moisture at the 13- and 25-cm depths (13 cm, $r = +0.19$; 25 cm, $r = +0.09$). However, at 38 cm, a correlation coefficient of +0.86 ($P < .001$) was found, indicating the importance of subsurface soil moisture to plant production in mixed-prairie vegetation.

No significant differences were found for total end-of-season standing crop biomass between treatments (Fig. 3.). The unburned site had slightly more standing crop biomass than did either burned site, but May-burn sites out-yielded comparable April-burn sites. Kentucky bluegrass biomass in October was reduced by burning, although May burning suppressed bluegrass significantly more than did April burning (Fig. 3). Figure 4 shows that basal plant cover was significantly increased on both burn treatments compared to unburned sites. Burning, as expected, decreased percent litter cover and conversely increased bare soil when compared to unburned plots in mid-July, 1979. Kentucky bluegrass basal cover was reduced over 100% for both burning dates ($P < 0.05$), when equated to the unburned cover (Fig. 4).

In addition to less bluegrass, April-burn sites had more *Carex* spp. then unburned plots, and more western ragweed (*Ambrosia psilostachya*) than either the unburned controls or May-burn plots ($P < 0.05$). Hopkins et al. (1948) also found increased amounts of ragweed on burned sites when compared to unburned plots. No other species showed a significant difference ($P < 0.05$) as sampled basally with the step point or clip quadrats.

The effect of burning on Kentucky bluegrass lasted into the following year (Table 1). The bluegrass was greatly suppressed by both burn dates on the shallow limy sites, but not nearly as much on the silty range side.

For Kentucky bluegrass suppression, while minimizing the adverse effect of burning on productivity and soil moisture, burning in May appeared somewhat better than in April. Both dates of burning gave excellent bluegrass control, however, and did increase vigor (greener and more seeds) of the prairie species. At the same time soil moisture and total plant productivity were not reduced significantly under present conditions.

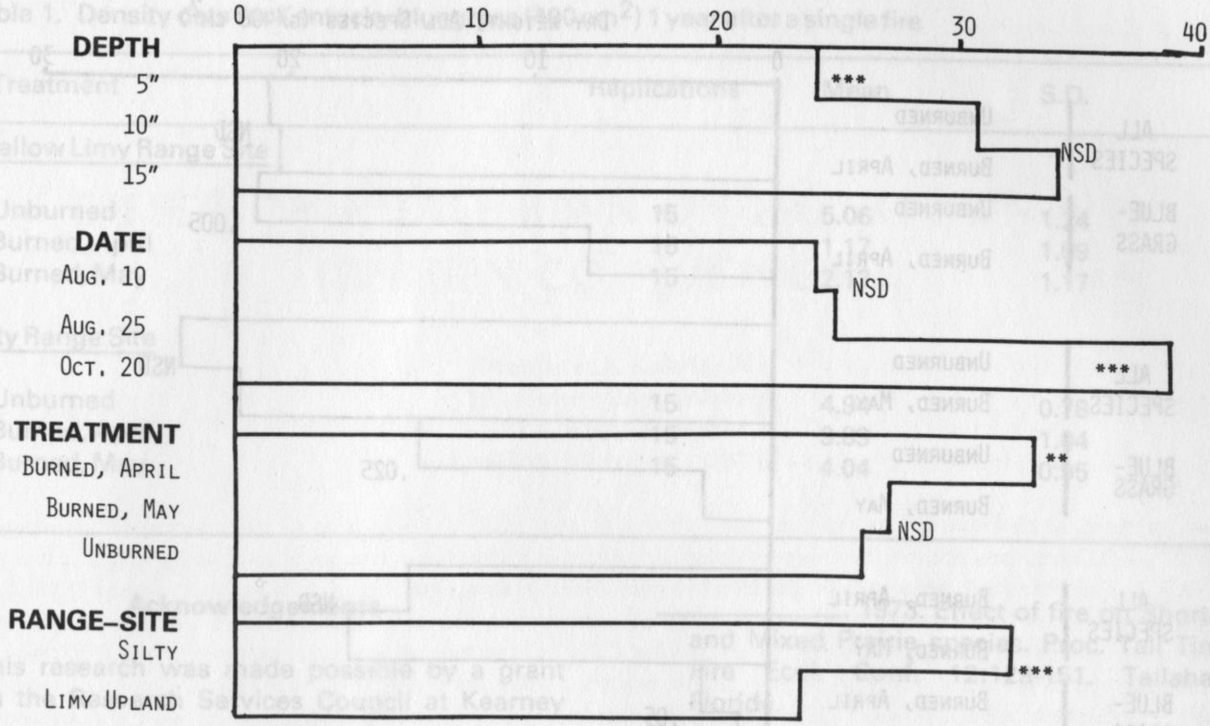


Fig. 1. Soil moisture as determined by gypsum blocks. Treatment and range site data are composite figures from 3 depths and 3 dates.

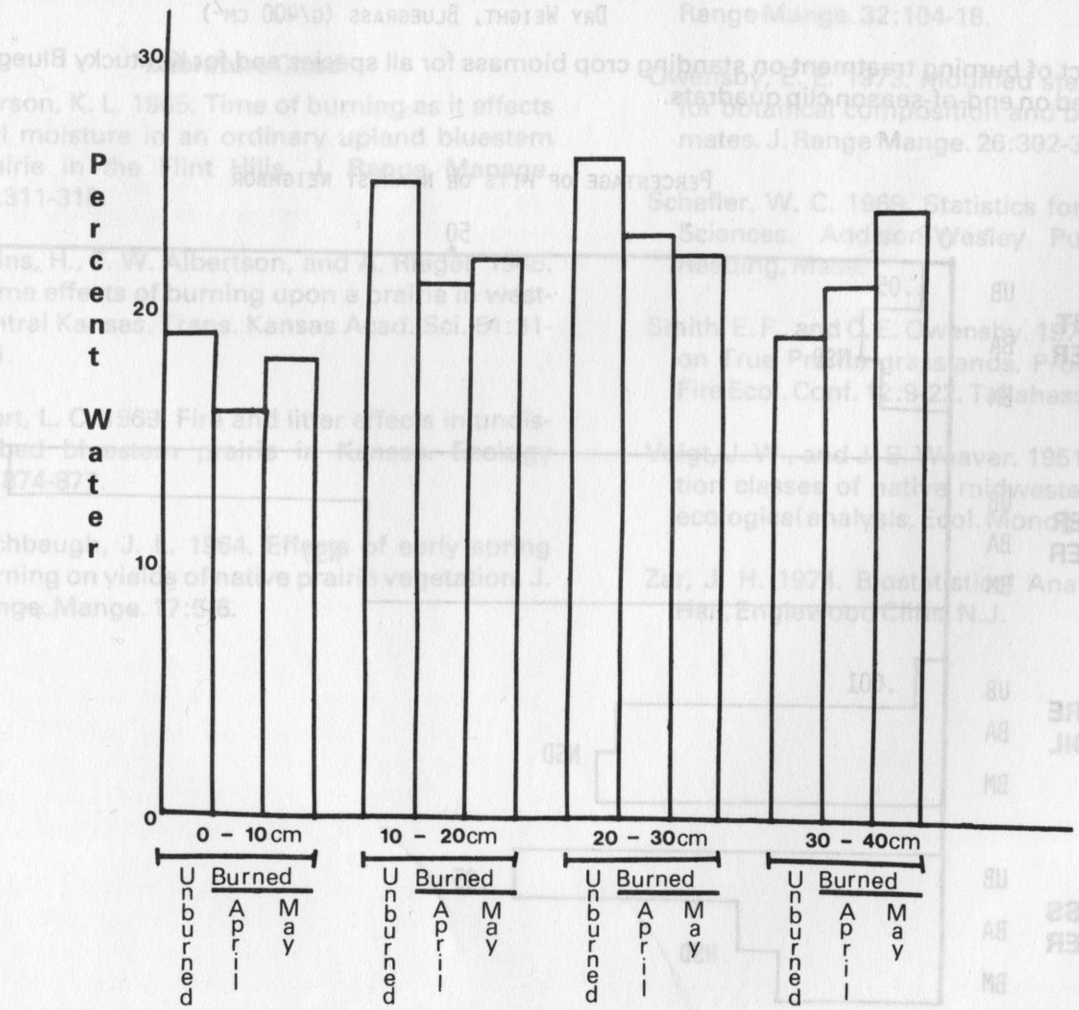


Fig. 2. Soil moisture determined gravimetrically in May, 1 year after the burn treatment, by treatment and depth on the silty range site. None of the differences were statistically significant.

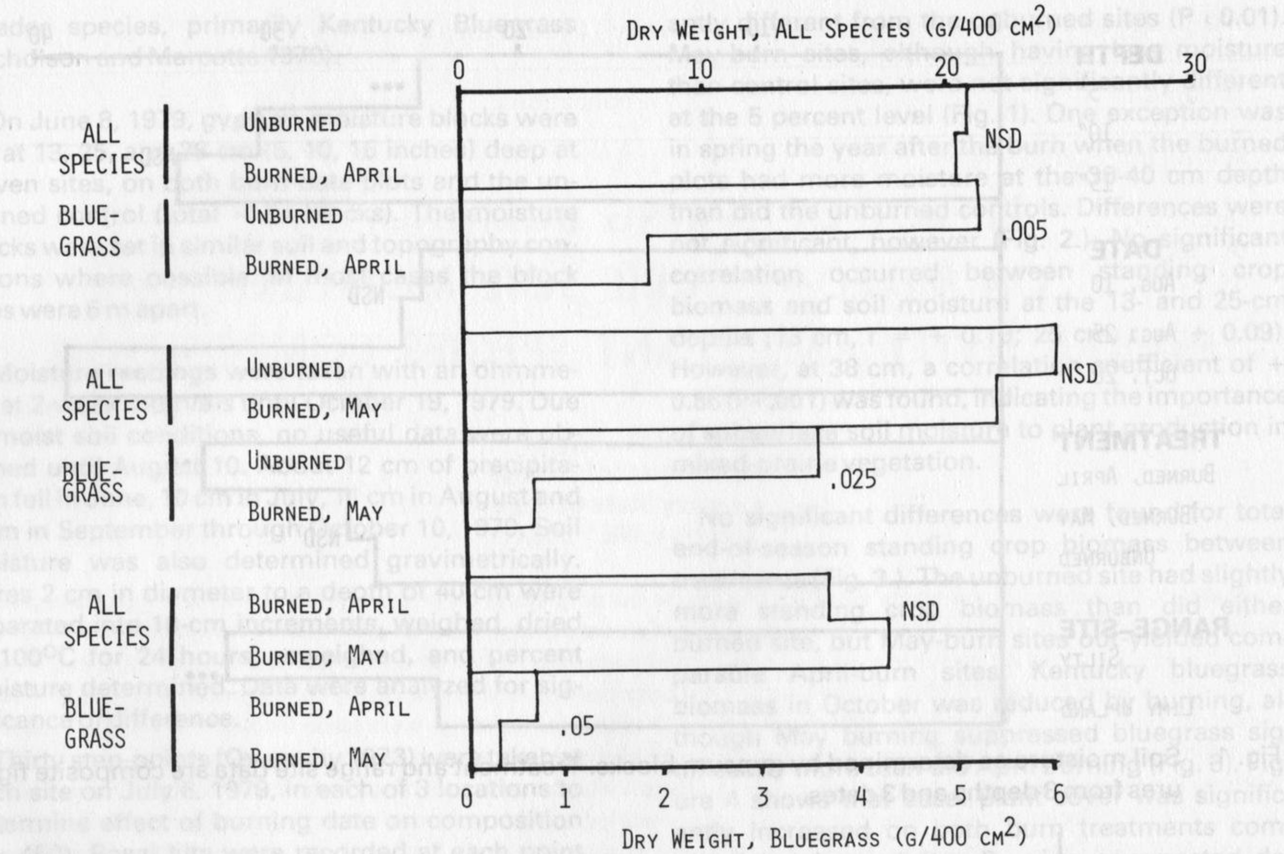


Fig. 3. Effect of burning treatment on standing crop biomass for all species and for Kentucky Bluegrass, based on end-of-season clip quadrats.

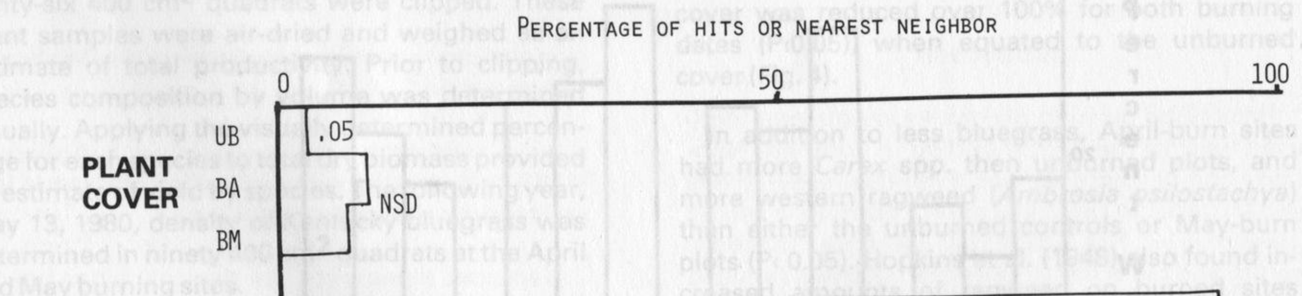


Fig. 4. Effect of burning on basal cover and Kentucky bluegrass composition. Step-points were taken in July. (UB = unburned, BA = April burn, BM = May burn).

Table 1. Density data for Kentucky bluegrass (400 cm^2) 1 year after a single fire

Treatment	Replications	Mean	S.D.
Shallow Limy Range Site			
Unburned	15	5.06	1.24
Burned, April	15	1.17	1.09
Burned, May	15	2.12	1.17
Silty Range Site			
Unburned	15	4.94	0.78
Burned, April	15	3.89	1.04
Burned, May	15	4.04	0.95

Acknowledgements

This research was made possible by a grant from the Research Services Council at Kearney State College. Dr. Marvin Williams helped with burning the plots.

Literature Cited

Anderson, K. L. 1965. Time of burning as it affects soil moisture in an ordinary upland bluestem prairie in the Flint Hills. J. Range Manage. 18:311-316.

Hopkins, H., F. W. Albertson, and A. Riegel. 1948. Some effects of burning upon a prairie in west-central Kansas. Trans. Kansas Acad. Sci. 51:31-141.

Hulbert, L. C. 1969. Fire and litter effects in undisturbed bluestem prairie in Kansas. Ecology 50:874-877.

Launchbaugh, J. L. 1964. Effects of early spring burning on yields of native prairie vegetation. J. Range. Mange. 17:5-6.

__________. 1973. Effect of fire on Shortgrass and Mixed Prairie species. Proc. Tall Timbers Fire Ecol. Conf. 12:129-151. Tallahassee, Florida.

Nicholson, R. A., and M. G. Marcotte. 1979. Vegetation of the Willa Cather Memorial Prairie. J. Range Mange. 32:104-18.

Owensby, E. E. 1973. Modified step-point system for botanical composition and basal cover estimates. J. Range Mange. 26:302-303.

Schefler, W. C. 1969. Statistics for the Biological Sciences. Addison-Wesley Publ. Company, Reading, Mass.

Smith, E. F., and C. E. Owensby. 1973. Effects of fire on True Prairie grasslands. Proc. Tall Timbers Fire Ecol. Conf. 12:9-22. Tallahassee, Florida.

Voigt, J. W., and J. E. Weaver. 1951. Range condition classes of native midwestern pasture: an ecological analysis. Ecol. Monogr. 12:39-60.

Zar, J. H. 1974. Biostatistical Analysis. Prentice-Hall, Englewood Cliffs, N.J.

Table 1. Density data for Kentucky bluegrass (400 cm²) 1 year after a single fire

Treatment	Replications	Mean	S.D.
Shallow Limy Range Site			
Unburned	15	5.06	1.24
Burned, April	15	1.17	1.09
Burned, May	15	2.12	1.17
Silty Range Site			
Unburned	15	4.94	0.78
Burned, April	15	3.89	1.04
Burned, May	15	4.04	0.95

Acknowledgements

This research was made possible by a grant from the Research Services Council at Kearney State College. Dr. Marvin Williams helped with burning the plots.

Literature Cited

Anderson, K. L. 1965. Time of burning as it affects soil moisture in an ordinary upland bluestem prairie in the Flint Hills. J. Range Manage. 18:311-316.

Hopkins, H., F. W. Albertson, and A. Riegel. 1948. Some effects of burning upon a prairie in west-central Kansas. Trans. Kansas Acad. Sci. 51:31-141.

Hulbert, L. C. 1969. Fire and litter effects in undisturbed bluestem prairie in Kansas. Ecology 50:874-877.

Launchbaugh, J. L. 1964. Effects of early spring burning on yields of native prairie vegetation. J. Range. Mange. 17:5-6.

______. 1973. Effect of fire on Shortgrass and Mixed Prairie species. Proc. Tall Timbers Fire Ecol. Conf. 12:129-151. Tallahassee, Florida.

Nicholson, R. A., and M. G. Marcotte. 1979. Vegetation of the Willa Cather Memorial Prairie. J. Range Mange. 32:104-18.

Owensby, E. E. 1973. Modified step-point system for botanical composition and basal cover estimates. J. Range Mange. 26:302-303.

Schefler, W. C. 1969. Statistics for the Biological Sciences. Addison-Wesley Publ. Company, Reading, Mass.

Smith, E. F., and C. E. Owensby. 1973. Effects of fire on True Prairie grasslands. Proc. Tall Timbers Fire Ecol. Conf. 12:9-22. Tallahassee, Florida.

Voigt, J. W., and J. E. Weaver. 1951. Range condition classes of native midwestern pasture: an ecological analysis. Ecol. Monogr. 21:39-60.

Zar, J. H. 1974. Biostatistical Analysis. Prentice-Hall, Englewood Cliffs, N.J.

EFFECT OF A FALL BURN ON BAKERTOWN FEN (BERRIEN CO., MICHIGAN)

Margaret A. Kohring[1]
The Nature Conservancy
531 N. Clippert Street
Lansing, Michigan 48912

Abstract. Bakertown Fen, in southwestern Michigan, is a calcareous seepage area dominated by grasses, sedges and forbs. Cover of each species was determined in randomly selected quadrats in both spring and fall of 1978. A total of 273 species was recorded; the dominants in decreasing order of importance were *Eleocharis* spp., *Carex* spp., *Thelypteris palustris, Solidago* spp., *Andropogon gerardi, Aster* spp., and *Cacalia tuberosa.* The fen was burned in October 1978 and the vegetation sample repeated in 1979. The burn did not significantly alter the spring cover values; however there was a significant difference between fall cover values, and a change in the order of dominance. This difference was due largely to an increase in cover contributed by *Carex* spp., *Eleocharis* spp., *Andropogon gerardi* and *Aster* spp. Species diversity in the spring sample increased following the burn, but species numbers were similar in the 2 fall samples. Ten species not recorded in the 1978 sample were recorded in the 1979 sample. Burning did not cause disappearance of any species from the area sampled.

1/ Present Address:
The Nature Conservancy
328 East Hennepin
Minneapolis, Minnesota 55414

EVALUATION OF GRASSLAND MANAGEMENT FOR WILDLIFE IN CENTRAL WISCONSIN

Harvey H. Halvorsen[1/]
and
Raymond K. Anderson
College of Natural Resources
University of Wisconsin
Stevens Point, Wisconsin 54481

Abstract. This study was initiated during the summer of 1977 to evaluate grassland management techniques on selected parts of a 4765 ha prairie chicken (*Tympanuchus cupido pinnatus*) management area within the Buena Vista Marsh in central Wisconsin. Plants were inventoried (percent cover, denisty, frequency, and height) on treatment and control plots the growing season before (1977) and after (1978) treatments. Small mammals and birds were censused on treatment and control plots before (1977) and after (1978) controlled burning, and insects on burned and control plots in 1978. Burning maintained cool season grasses without reducing density, frequency, percent cover, or standing crop. Burning significantly increased moisture content of grasses from May through July, yet had no effect of foliar nutrient composition throughout the growing season. Post-burn density of savannah sparrows (*Passerculus sandwichensis*) and clay-colored sparrows (*Spizella pallida*) declined 80 and 94% respectively. Fire-altered habitat had no effect on the relative abundance of meadow voles (*Microtus pennsylvanicus*) or short-tailed shrews (*Blarina brevicauda*), significantly increased relative abundance of deer mice (*Peromyscus maniculatus*) and meadow jumping mice (*Zapus hudsonius*), and significantly reduced the combined relative abundance of masked shrews (*Sorex cinereus*) and pigmy shrews (*Microsorex hoyi*). Burning had no statistically significant effect on total biomass or density or sweep-netted insects. Herbicide treatment (2.24 kg/ha dimethylamine salt of 2,4-D applied in a water carrier) significantly reduced the percent cover and density of goldenrod species (*Solidago*spp.) and significantly increased percent cover of quackgrass (*Agropyron repens*) the next growing season after spraying. Mowing had no statistically significant effects on stem density of quackgrass, Kentucky bluegrass (*Poa pratensis*), forbs or shrubs but significantly increased stem density and height of timothy (*Phleum pratense*). Percent cover of grasses and forbs on the mowed plot were not significantly altered between years by mowing. Plowing significantly reduced the percent cover and stem density of Kentucky bluegrass and meadow-sweet (*Spiraea alba*) the first growing season after disturbance but had no effect on percent cover of quackgrass or reed canary grass (*Phalaris arundinacea*). Revegetation of the plowed plot was chiefly by regeneration of root stock of perennial plants.

Introduction

This study was initiated during the summer of 1977 to evaluate the effects of grassland management practices on selected areas of a 4765 ha prairie chicken (*Tympanuchus cupido pinnatus*) management area located in the Buena Vista Marsh, Portage County, Wisconsin (Fig. 1). Controlled burning, rotary mowing, herbicides, grazing, and plowing are used to control plant succession on the management area by Wisconsin Department of Natural Resources (WDNR).

The objectives of this study were to determine the impact of controlled buring on old field vegetation and resident populations of insects, birds, and small mammals, and to determine the effectiveness of controlled burning, rotary mowing, herbicides, and root plowing as management tools.

Prairie chicken habitat needs and management have been researched by Hamerstrom et al. (1957) and Hamerstrom and Hamerstrom (1973) in Wisconsin, Drobney and Sparrowe (1977) in Missouri, Jones (1963) in Oklahoma, Kirsch (1974) in North Dakota, Westemeier (1971, 1973) in Wisconsin and Illinois, Robel et al. (1970) in Kansas, and Lehmann (1941) in Texas.

Management guidelines established by Hamerstrom et al. (1957) emphasized that grasslands need to be maintained in grass-forb stages of plant succession for nesting and brood rearing habitat. They state that "grassland is vitally important to prairie chickens, the keystone in prairie chicken ecology. . .the bird does not require true

[1/] Current address, NERCO, Inc., 111 S. W. Columbia, Portland, Oregon 97201

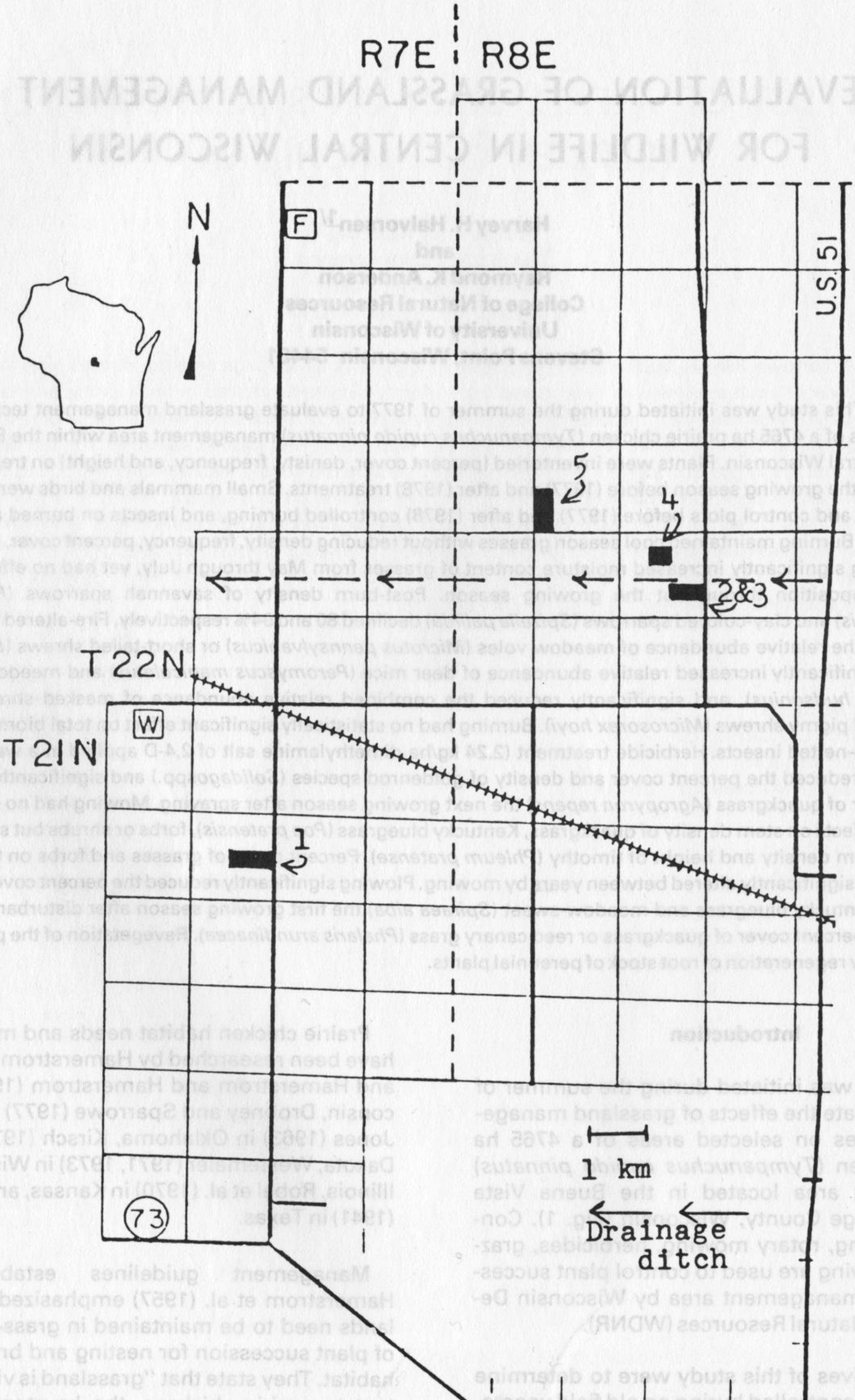


Fig. 1. Location of the study area in Buena Vista Marsh, and Study Sites 1 through 5.

prairie. . .and does get along reasonably well in the new and very different kind of grassland in which it now finds its home" in central Wisconsin. They report that medium dense nest-brood cover on Buena Vista consists of Kentucky bluegrass (*Poa pratensis*), and quackgrass (*Agropyron repens*) intermixed with broadleaved herbaceous plants and sedges (*Carex* spp.). They do not report on the degree of grass-forb interspersion nor the impacts of grassland management on these species. They do, however, report that lower quality nest-brood habitat was either "too weedy" or that the grass was "too thin". Kirsch (1974) concluded that brushy species and Kentucky bluegrass in North Dakota increase on most idled prairie areas and apparently make them unsuitable as chicken habitat.

Hamerstrom et al. (1957) pointed out the importance of wide, open horizons and grassland reserves for nesting and brood rearing. They found that components such as height and density of grass seem to be more important to prairie chickens than species composition. Drobney and Sparrowe (1977) found that nest site selection was heavily influenced by quality of cover rather than by proximity to a display ground. Robel et al. (1970) reports that vegetation density alone did not appear to be a significant factor in habitat selection by greater prairie chickens.

Managed lands on the Buena Vista Marsh are currently disturbed on a 4-6-year rotation to maintain them in early stages of succession and relatively free of brush invasion. Hamerstrom et al. (1957) believed that brush control could be achieved by burning or mowing parcels once every 3-5 years. They recognized that weed control may be more difficult since weeds are mostly governed by climatic and edaphic factors. They stressed that "the type of grassland that we want to maintain. .is the type that develops naturally on the drained peat of this area", i.e., weedy bluegrass.

Little quantitative data currently exist on the effects of herbicides, rotary mowing, grazing, controlled burning, or root plowing on old field vegetation on Buena Vista Marsh. These techniques have been used to retard and hamper the invasion of trembling aspen (*Populus tremuloides*), willow (*Salix* spp.), and meadow-sweet (*Spiraea alba*). These shrubs quickly dominate idle fields, resprout vigorously following distubance (Zedler 1966), and therefore are of major concern on prairie chicken management lands because they rapidly deteriorate nesting and brood rearing habitat. To further our understanding of the impacts of grassland management on Buena Vista Marsh, this study was undertaken to describe the interplay of management on muckland vegetation and determine the effects of fire-altered habitat on resident wildlife.

Study Area

The Buena Vista Marsh is a lowland of approximately 22,258 ha located on southwestern Portage County, Wisconsin. Prior to drainage in the early 1900's, the marsh supported a complex of tamarack (*Larix laricina*) and sedge (*Carex* spp.) meadow swamp communities. Alder (*Alnus rugosa*) swamps occurred in close association with the tamarack communities (Zedler 1966). Past and present land uses have been described in greater detail by Hamerstrom et al. (1957), Hamerstrom and Hamerstrom (1973), Zedler (1966, 1968), and Westemeier (1971).

The level topography of the marsh is a product of past glacial activity. The sands orignated from glacial outwash and fragmentation of the underlying Cambrian sandstone. The shallow depression that forms the marsh was once covered by Glacial Lake Wisconsin, a short-lived lake filled by glacial melt during the Pleistocene (Martin 1965). The marsh is approximately 7-9 m lower in elevation that the surrounding uplands. Cold air drainage into the marsh results in short growing seasons due to early and late frosts and creates the possibility of a killing frost during the growing season (Hamerstrom et al. 1957).

The soils that developed under the influence of the tamarack-sedge meadow swamp and frequent fires are characterized by high organic matter (muck) in shallow depressions and scattered sand ridges, each with very different chemical compositions (Wuenscher 1970) and vegetation (Zedler 1968). The water table lies very close to the surface, usually less than 1 m throughout most of the year. Large areas of sheet water form during spring snow melt and precipitation (Vandre 1975).

A U.S. weather bureau recording station is located at Coddington on the northeast side of the marsh. The average annual temperature is $6^{0}C$ with extremes of -42 and $41^{0}C$. The average growing season is 104 days. Annual precipitation averages 81.3 cm. Sixty-five percent of the total yearly precipation occurs during the growing season (Holt 1965).

Five sites which were idle for a minimum of 4 years were selected for study (Fig. 1). These plots had not been plowed for more than 10 years, nor burned, sprayed, grazed, or mowed for at least 4 years. Descriptions of each site are given in Table 1. Study sites (SS) were divided into homogeneous treatment and control plots of equal size. The size of the SS varied according to the ascribed

Table 1. Description of study sites on Buena Vista Marsh, Wisconsin

Study Sites	Size (ha)	Dominant plant Cover	Soil Series & Texture1/
1	16	Goldenrod species, butter and eggs *(Linaria vulgaris)*, quackgrass, Kentucky bluegrass, meadow-sweet, little bluestem *(Andropogon scoparius)*	Roscommon muck, Markey shallow much, Roscommon-Meehan sandy loam complex
2	8	Goldenrod species, butter and egges, quackgrass, Kentucky bluegrass	Roscommon muck
3	4	Goldenrod species, butter and eggs, meadow-sweet, quackgrass, Kentucky bluegrass	Roscommon muck
4	0.4	Goldenrod species, quackgrass, Kentucky bluegrass, meadow-sweet, beard-tongue *(Penstemon digitalis)*, timothy	Markey shallow muck
5	8	Meadow-sweet, quackgrass, butter and eggs Kentucky bluegrass, dewberry *(Rubus spp.)*	Roscommon muck, Meehan loamy sand

1/ Portage County Soil Survey, 1978.

treatment and wildlife censused. SS 1 was selected to determine the effects of fire on shrub, forb, and grass cover types, each containing representative flora of Buena Vista Marsh. SS 2 and 3 were selected to determine the effects of burning and herbicide application separately, on a forb dominated (*Solidago altissima, S. canadensis, Linaria vulgaris*) plant community. SS 4 was selected to determine the effects of mowing on common grasses and forbs. SS 5 was selected to determine the effects of plowing and disking on a dense stand of meadow-sweet (*Spiraea alba*).

Experimental Treatments

Burning on the Buena Vista Marsh is commonly conducted by WDNR from mid-March to late April, usually after snow melt and before the prairie chicken nesting season. Burning is limited to the spring when peat soils are frozen or water-logged in order to prevent possible ignition of the peat. Due to these burning restrictions, this study employed the same burning guidelines as used by WDNR.

A ring of fire was used to burn the treatment plots of SS 1 and 2 on April 5 and March 28, 1978 respectively. The ignition sequence was as follows: a backfire to widen the fire baseline, simultaneous flank fires, and the head fire (Davis 1959). Firelines were plowed around the perimeter of the 2 treatment plots during the fall, 1977, and again prior to burning, where natural breaks, i.e., roads and water-filled ditches, were not available. Firelines were 2.5 to 3 m wide; surface fuels were turned under and soil exposed. Drip torches were used to ignite the vegetation after evaporation of dew.

The treatment plot of SS 3 was sprayed with 2,4-D on August 18, 1977. The herbicide (0.5 kg/l acid equivalent weight, non-volatile dimethylamine salt of 2,4-D) was applied with a rotomist sprayer at the rate of 2.2 kg/ha. Equipment, formulation, and methods of application followed WDNR guidelines. The concentrated herbicide was diluted 1:100 in a water carrier. Spraying was conducted on a clear, calm morning after dew evaporated to prevent drift. Application was conducted when the goldenrod was approximately 50-60% in bloom.

A tractor mounted rotary mower (bush hog) was used to mow the treatment plot of SS 4 on August 22, 1977 when goldenrod was approximately 50-60% in bloom. Vegetation was mowed to a height of 20-25 cm. Clippings after mowing remained on the plot. Mowing by WDNR on prairie chicken management lands is restricted until after August 1 to prevent nest destruction. Grassland mowing is continued until either snow depth becomes too deep or all planned acreage is cut.

The treatment plot of SS 5 was mowed in October 1977 to facilitate spring plowing. The plot was disked once prior to plowing to break-up the tough mat of rhizomatous meadow-sweet roots. The plot was plowed on June 13 and 14, 1978 to a depth of 15 cm. The plot was disked twice, 1 week after plowing to eliminate vigorously growing meadow-sweet shoots.

Vegetation Anaylsis

The quadrat method (Brower and Zar 1977) was used to sample grasses, sedges, forbs, and small shrubs. Rectangular quadrats (1.0 x 0.5 m) were used. A total of 120 permanent quadrats were randomly established on SS 1 through 5. Vegetation within the quadrats was inventoried prior to treatment in 1977 and the growing season after (August-September) in 1978. Plant density, frequency, percent cover, and height were compared between years to detect differences in vegetation induced by treatments. Differences for mean values between years were tested for significance with paired t tests (Ryan et al. 1976). Plant frequency was determined by presence or absence within quadrats, plant density and percent cover by stem counts and ocular estimation respectively. Bare ground and exposed mulch were included in the estimation of cover. Only percent cover of dominant and common plant species is included in this paper. A list of all plant species encountered and additional details on experimental methods and results including plant density data are available in Halvorsen (1981).

Samples were collected monthly from quadrats (0.25 m^2) on burned and unburned plots on SS 1 and 2 from May through October 1978. Vegetation was clipped to a stubble height of approximately 0.5 cm, sorted into grass-sedge or forb categories, weighed (nearest 0.1 g), oven dried (65^{0}C for 48 hrs) and weighed again to determine moisture content.

Nitrogen (N), phosphorus (P), potassum (K), calcium (Ca), and magnesium (Mg) content of grasses and sedges combined, were compared in burned and control plots from May through October 1978. A pooled sample was prepared for SS 1 and 2 by combining herbage (leaves, stems, seeds) collected in the standing crop study. N was determined by the macro-Kjeldahl method; P, K, Ca, and Mg by flame photometry (Liegel and Schulte 1977) at the Wisconsin State Plant and Soil Analysis Lab in Marshfield, Wisconsin.

Census of Wildlife

Population density of savannah sparrows and clay-colored sparrows was monitored before and after burning to determine the effects of fire-altered habitat on breeding density. Infrequent and migrant bird species on SS 1 and 2 were recorded but densities not determined. Sparrows were censused by repeated (ave. 3x) transect counts between 29 June to 14 July 1977 (pretreatment) and again from 31 May to 13 June 1978 (post-treatment). Birds were counted within strips 92 m wide and 0.8 km long on SS 1 and 0.4 km long on SS 2. All sparrows heard or seen within the strip were counted. One census route bisects each strip lengthwise. Treatment and control plots were censused the same day. Counts were repeated along the same route within a 2 week period as close to the peak of the breeding season as possible. Transects were tranversed once in the morning between sunrise and 3 hrs thereafter on days with little wind and sky less than 50% overcast.

Small mammal abundance was determined by the removal method (Smith 1975) in August 1977 and 1978. Trap grid were established on adjacent treatment and control plots of SS1 and 2. A grid consisted of 5 rows of trap stations, 10 stations per row at 15 m intervals. An 8.5 m buffer zone was established from the perimeter of the trap grid to the edges of the study site. A trap station consisted of 1 pitfall trap (Burt 1977) and 2 Victor snap traps with wooden treadles. Pitfalls were made with a No. 10 food can, top removed and buried flush to ground level. Snap traps were baited with a mixture of peanut butter and rolled oats and strategically placed within 1 m of the pitfall. Grids were run for 5 trap nights, traps checked once each morning. Treatment and control plots were trapped concurrently.

Insect density and biomass were determined by sweep netting (Romney 1945) burned and control plots on SS 1 and 2. A total of 100 sweeps were collected monthly from each study plot, 25 sweeps from each quarter of each plot. Samples were collected from the same transect at 4-week intervals from May through October 1978. Combined insect density on burned plots was compared to the controls on the basis of the average number of insect taxa captured per 25 sweeps, biomass on average dry weight (g) per 100 sweeps. The number of insects in each order were counted and oven dry weight (60^{0}C, 48 hrs) determined to the nearest 0.1 mg.

Results

The treatment plots of SS 1 and 2 were burned 5 April and 28 March 1978 respectively, approximately 1 week after snow melt. Approximately 96% of the residual dry surface fuels were eliminated. Scattered patches of snow and moist depressions precluded complete removal. Most surface fuels were water-saturated due to lodging. Burning did not expose organic soils in depressions but was more effective in biomass removal on sand ridges.

Average percent cover of grasses, sedges, forbs, and shrubs was not significantly different between years on either burned or unburned plots (Table 2). Differences in cover between sites was due to microtopographical changes, usually less than 1 m. Percent cover generally increased for all plants in 1978 because of favorable growing conditions, i.e., increased rainfall.

Table 2. Average percent cover of plants, mulch, and bare ground before (1977) and after burning (1978) (tr = <0.5%)

	Study Site 1				Study Site 2			
	Burn		Control		Burn		Control	
	1977 (Pre)	1978 (Post)	1977	1978	1977 (Pre)	1978 (Post)	1977	1978
Grasses and Sedges								
Agropyron repens	2.5	2.0	7.5	6.0	10.3	14.0	12.0	21.0
Poa pratensis	3.1	5.8	11.5	13.5	1.0	4.0	6.5	15.0
Andropogon scoparius	6.3	7.0	5.0	6.8				
A. gerardi	5.5	5.8						
Carex spp.	1.4	0.5	3.4	3.5				
Phleum pratense			1.5	1.5	tr	0.5	1.5	2.0
Forbs								
Solidago spp.	18.3	30.0	14.3	19.3	44.5	48.5	39.0	33.5
Linaria vulgaris	15.0	8.3	17.3	19.5	35.7	16.0	19.0	18.5
Urtica dioica	2.0	1.8	tr	tr	tr	2.5		
Verbascum thapsis	tr	0.0	tr	1.0	tr	3.5		
Achillea millefolium	0.0	tr	3.0	1.0				
Fragaria virginiana	1.8	tr	1.3	1.0				
Asclepias syriaca	tr	0.8	tr	1.0				
Shrubs								
Spiraea alba	19.8	17.5	5.3	5.8			2.5	1.5
Populus tremuloides	5.8	3.5	2.8	4.0			2.5	1.5
Mulch	13.8	8.0	15.8	8.0	8.5	10.5	11.5	11.0
Bare Ground	0.5	3.8	0.0	0.5	0.0	0.0	1.0	0.5

Mulch cover was affected more by increases in plant cover than by burning. Burning significantly increased the percent cover of bare ground on SS 1, where mulch on sand ridges was consumed by fire.

Burning did not significantly affect forb or shrub density. Stem densities of quack grass and Kentucky bluegrass appear to have been reduced by burning when compared to control densities in 1978. These species initiated growth prior to burning and were fire injured. Consequently increases in stem density on control plots in 1978 were greater than on burned plots.

Burning did not significantly alter grass or forb production throughout the 1978 growing season (Table 3). Standing crops of grasses and forbs peaked on burned and control plots in August. This peak reflected the period of maximum growth for a plant community dominated by perennial grasses and forbs. Monthly standing crop of grasses stablilzed after August. Forb standing crop rapidly decreased following the August peak due to the loss of deciduous lower leaves of the dominant forb, goldenrod.

Moisture content of grasses was significantly higher on burned grassland from May through July but was similar to unburned grassland from August through October (Table 3). Burning did not affect forb moisture content. Forbs remained approximately 10% higher in moisture content than grasses throughout the growing season. Moisture

Table 3. Average production (g/0.25m^2) and moisture content (% oven-dry weight) of vegetation clipped on burned (B) and control (C) plots, 1978

	Production				Percent Moisture			
	Grasses		Forbs		Grasses		Forbs	
Sample date	B	C	B	C	B	C	B	C
26 May	7.2	10.9	7.4	9.0	68.5	64.0*	78.5	77.5
27 June	21.0	29.1	42.5	40.0	64.0	58.0*	72.5	70.0
24 July	32.1	35.2	70.5	58.9	59.0	53.5*	67.5	67.5
26 August	39.6	41.0	79.1	76.2	49.5	47.0	60.5	59.5
23 Sept.	40.8	33.3	51.7	65.9	46.0	44.0	54.5	52.5
28 Oct.	41.6	35.6	38.2	31.7	34.5	34.0	29.5	31.0

*Difference significant, P‹0.05., between B and C values for grasses

content decreased approximately 48 and 61% in grasses and forbs respectively by the end of the growing season.

Nutrient content of combined vegetation from the 2 burned plots varied by season but was not affected by burning. Total percent N was highest (3.19%) in grasses clipped in May from both burned and control plots, it decreased approximately 60% by August. Total P, K, Ca, and Mg peaked in August on burned and control plots and remained higher than pre-August samples for the duration of the growing season.

Average density of savannah sparrows and clay-colored sparrows was significantly lower on burned plots compared to the controls in 1978 (Table 4). Post-burn density declined an average of 83 and 93% for savannah and clay-colored sparrows respectively when compared to pre-burn density.

Six small mammal species were sufficiently present on treatment and control plots during both years of the study to assess the influence of fire on their relative abundance (Table 5). Post burn fire-altered habitat had no significant effect on relative abundance of meadow voles or short-tailed shrews. Relative abundance of prairie deer mice and meadow jumping mice was significantly higher on burned plots. Combined relative abundance of masked and pygmy shrew was significantly reduced after burning (Table 5).

The average number of total insects captured per 25 sweeps on burned and control plots was not

Table 4. Average population density (individuals/ha) of claycolored and savannah sparrows before (1977) and after burning (1978)

	1977		1978	
Species	Pre-burn	Control	Post-burn	Control
Savannah sparrows	1.25	1.43	0.21	0.88**
Clay-colored sparrows	0.58	0.33	0.04	0.41*

**Difference significant, P‹0.01.
*Difference significant, P‹0.05.

significantly different throughout the sample period (Table 6). Numbers of heteropterans, coleopterans, dipterans, and homopterans (in decreasing order of abundance) represented 80.1% of all insects samples and 63.5% of total biomass. Numbers of orthopterans accounted for 2.2% of total captures, but 20.7% of total biomass. Insect captures were lowest on 27 October following a series of 17 frosts after the previous sample. Average dry weight of insects was greater, but not significantly so, on burned plots in June, July, August, and October. Responses of individual taxa (order) are available in greater detail in Halvorsen (1981).

Quackgrass cover increased significantly the growing season following herbicide application. Muhly (*Muhlenbergia mexicana*) slightly increased on sprayed plots, but no response was observed in timothy or Kentucky bluegrass cover. Spraying significantly decreased the percent cover of goldenrod, stinging nettle (*Urtica dioica*), and yarrow (*Achillea millefolium*), all common rhizamotous perennials. Percent cover of butter and eggs (*Linaria vulgaris*) was significantly reduced on both sprayed and control plots in 1978, suggesting that environmental factors may have contributed more to its reduction than the herbicide. Percent cover of smartweed (*Polygonum natans*) and meadow-sweet was reduced 54 and 69% respectively by herbicide treatment. Mulch cover increased after treatment; however, differences between years were not statistically significant. The increase in mulch cover was attributed to the significant reduction of goldenrod.

Herbicide treatment had no effect on stem densities of quackgrass, Kentucky bluegrass, timothy, muhly, or meadow-sweet. Goldenrod, stinging nettle, and yarrow density was significantly reduced by herbicide treatment. Smartweed and common mullein density was reduced by spraying; however, the differences were not significant.

Table 5. Relative abundance of small mammals before (1977) and after burning (1978) SS 1 and 2 based on captures per 100 trap nights1/

	1977		1978	
Species	Pre-burn	Control	Post-burn	Control
Microtus pennsylvanicus	5.36 (79)2/	5.83 (85)	2.46 (36)	3.28 (48)
Peromyscus maniculatus	1.72 (25)	1.44 (21)	1.50 (22)	0.35 (5)**
Sorex cinereus and *Microsorex hoyi*	0.69 (10)	1.17 (17)	0.35 (5)	1.64 (24)*
Blarina brevicauda	0.21 (3)	0.07 (1)	0.89 (12)	0.82 (13)
Zapus hudsonius	0.41 (6)	0.34 (5)	1.43 (21)	0.41 (6)*

1/ Calculated according to Nelson and Clark (1978) using 5 traps nights per trap period.
2/ Total number of individuals captured in ( ).
**Significantly different from the burn, P<0.01.
*Significantly different from the burn, P<0.05.

Mowing did not significantly alter the average percent cover of grasses, sedges, forbs, shrubs or mulch. Comparison of plant response between mowed and unmowed plots revealed that Kentucky bluegrass, timothy, and goldenrod increased in percent cover following mowing, however decreased on the unmowed plots. Although these differences are not significant, they indicate a general trend of increasing cover with mowing. Mowing reduced meadow-sweet cover and prevented an increase in willow (*Salix* spp.) cover.

Stem density of quackgrass and Kentucky bluegrass increased significantly on mowed and unmowed plots in 1978 and did not appear to be affected by mowing. Mowing significantly increased timothy density in 1978 and accounted for a 2.2-fold increase in sedge stem density. Forb density was not affected by mowing. Average density of penstemon (*Penstemon digitalis*) increased significantly on both mowed and control plots in 1978. Meadow-sweet and willow density was not significantly altered by mowing; however, meadow-sweet density was slightly reduced on the mowed plot.

Table 6. Average number and oven-dry weight of insects on burned (B) and control (C) plots, 1978

Sample	No. Captured		Oven-dry weight[2/]	
date	B	C	B	C
26 May	44.2	47.3	.180	.385
22 June	86.1	82.7	.484	.443
19 July	135.1	114.3	.717	.642
29 August	97.7	92.8	.752	.620
22 Sept.	149.9	226.3	1.182	2.050
27 Oct.	13.2	12.3	.173	.123

1/ Average number captured per 25 sweeps, each value representing the average of 8 samples.
2/ Dry weight per 100 sweeps, each value representing the average of 2 samples.

Spring plowing had no effect on the average percent cover of quackgrass, reed canary grass, or thistles (*Cirsium arvense*) but significantly reduced percent cover of Kentucky bluegrass, butter and eggs, meadow-sweet, and mulch. Although not statistically significant, plowing reduced the percent cover of dewberry (*Rubus* spp.) but increased goldenrod and smartweed cover. Plowing significantly increased the percent cover of bare ground, which subsequently allowed an invasion of cranesbill (*Geranium carolinianum*) and rough cinquefoil (*Potentilla norvegica*).

Plowing significantly reduced stem density of Kentucky bluegrass and meadow-sweet. Although not statistically significant, density of quackgrass and butter and eggs was reduced by plowing. Cranesbill, rough cinquefoil, and smartweed density increased significantly after plowing while density of reed canary grass, goldenrod, thistle, and dewberry appeared unaffected by treatment.

Discussion

The use of fire to hamper or reduce Kentucky bluegrass and other cool season grasses in midwestern grasslands has been well documented (Curtis and Partch 1948, Daubenmire 1968, Old 1969, Schramm 1978). Controlled burning is presently used on Buena Vista Marsh where the majority of the grass cover is predominantly Kentucky bluegrass or quackgrass. Results of this study have shown that early spring burning can be an effective management techinque to maintain these species without reduction of density, frequency, percent cover, and standing crop. Zedler and Loucks (1969) found that spring burning affected growth of Kentucky bluegrass yet effects varied according to microtopography. They concluded that Kentucky bluegrass was susceptible to fire damage on dry sandy ridges but was little affected in depressions. They found that burning increased stem density of bluegrass on both ridges and depressions, decreased the height of bluegrass on ridges, and noticed a general trend for fire to decrease fruiting of the blooming grasses but increase flowering of late blooming species. They observed however, a tremendous increase in fruiting of Kentucky bluegrass after burning in depressions. This response was thought to reflect the reaction of Kentucky bluegrass to mulch removal where favorable site conditions existed. Woehler and Martin (1978) in Wisconsin have observed that burning in late April or May retarded the development of quackgrass and prevented its fruiting. Kirsch and Kruse (1973) in North Dakota reported that cover of Kentucky bluegrass and quackgrass did not change after burning.

In this study, burning decreased fruiting of Kentucky bluegrass. Fruiting of quackgrass on burned plots was temporarily retarded in June, but exceeded that on the control plots in July and August. Little bluestem flowered one month earlier and produced more fruiting stems with more spikelets per stem on burned plots (Halvorsen 1981). Burning had little effect on percent cover of goldenrod (*Solidago canadensis, S. altissima*) and accounted for greater increases in stem density on burned plots in 1978 than on the controls. Schramm (1978) reported that goldenrod (*Solidago altissima-canadensis*) will persist even when regularly burned for up to 15 years. Dix and Butler (1954) found that burning had no effect on goldenrod (*Solidago nemoralis*) the first growing season following the burn whereas Swan (1970) found goldenrod to increase after burning in New York. The combination of mulch removal and increased rainfall in 1978 stimulated goldenrod growth. Goldenrod did not initiate growth until after the burn and therefore was not directly fire injured. Butter and eggs, however, had already begun growth prior to burning. The burn reduced its density but appeared to have no effect on its percent cover. Burning decreased the percent cover of meadow-sweet and aspen but had little effect on density or frequency of occurrence of these species because of their habit of vigorously resprouting after crown disturbance. Burning will provide little shrub control if it is conducted in early spring at 4 to 6 year intervals under the same burning conditions as in this study.

Significant reductions of savannah sparrows and clay-colored sparrows occurred on burned plots. This reduction was thought to be in response to the removal of residual cover. Bendell (1975) reported that reduction of residual cover by fire may decrease the abundance of grassland sparrows, bobolinks (*Dolichonyx oryzivorus*), and voles, whereas *Peromyscus* tends to increase in response to litter removal by burning. Similar increases in *Peromyscus maniculatus* on burned habitat were reported by Beck and Vogl (1972) in northwestern Wisconsin, and Tester and Marshall (1961) in Minnesota.

Although burning significantly reduced mulch depth and biomass, there was enough duff overlying the loose organic soils and adequate surface vegetation to accomodate small mammals. This is substantiated by the capture of meadow voles and short-tailed shrews equal in number to those captured on control plots during August after burning. Bendell (1974) reported that mulch reduction decreased the abundance of grassland voles (*Microtus*), whereas *Peromyscus* tends to increase in response to litter removal. Springer and Schramm (1972) reported that meadow jumping mice increased on burned grassland but that the population density of the short-tailed shrew was substantially reduced the summer following a spring burn. Schramm (1970) suggested that burning improves meadow jumping mouse habitat because it increases locomotory movement for the mice by reducing excessive surface litter.

Similar increases of deer mice on burned habitat as reported in this study were reported by Beck and Vogl (1972) on a burned brush prairie savanna in northwestern Wisconsin, and by Tester and Marshall (1961) on a prairie in Minnesota.

Hurst (1972) and Tester and Marshall (1961) reported increases in grasshoppers, beetles, and leafhoppers after burning. Queal (1973) believes that fire produces a greater variety of insects on burned than unburned grasslands. Cancelado and Yonke (1970) found that differences in insect populations between burned and unburned areas was greatest from the beginning to the middle of the growing season than later in the year. Burning had little impact on the density or biomass of insects on Buena Vista Marsh. Colepteran and hymenopteran populations were slightly more numerous on burned grasslands whereas heteropteran and homopteran populations were more numerous on unburned grassland. Ahlgren (1974) pointed out that in most grassland studies, burned areas were usually small and recolonization of burned plots from adjacent unburned land could be rapid. This situation is most likely present on Buena Vista Marsh, where controlled burns are usually limited to parcels 16 to 24 ha in size.

The use of 2,4-D has largely been reported in research dealing with brush control (Gratkowski 1977, Linde 1969). Linde (1969) reported that a 1:1 mixture of 2,4-D and 2,4,5-T ester produced a 90 to 100% kill of willow and meadow-sweet on Buena Vista Marsh. The use of 2,4,5-T was banned in Wisconsin in 1974 but Crafts and Robbins (1962) and Linde (1969) reported that a 2,4-D ester formulation will control willow when applied at the rate of 2.4-3.5 kg/ha to fully expanded leaves when soil moisture is available. On Buena Vista Marsh, percent cover and density of goldenrod were significantly reduced the growing season after application of an aminebased 2,4-D. Reduction of goldenrod allowed for a significant increase in quackgrass cover.

Rotary mowing is used to slow brush invasion but it does not eradicate aspen, willow, or meadow-sweet. Currently, mowing management by WDNR on Buena Vista Marsh involves a 6-year rotation where 1/6th of each management unit is disturbed each year. Repeated mowing (2-3 times/year) is not economically possible due to the extensive land area involved. Consequently, the impact of mowing is considerably less on the herbaceous vegetation of the marsh and results in little change of species composition, community structure, and frequency of grasses, forbs, and shrubs.

Linde (1969) describes the use and operation of a tractor-mounted brush mower on Buena Vista Marsh for mowing willow. Current costs are prohibitive (ca. $20-25/ha) and most mowing is limited to areas with dense brush. Some managed lands are contracted to local farmers for hay removal after July 15. Acceptance of these contracts is usually limited to the less weedy stands of bluegrass and quackgrass, rather than those with brush or large stands of goldenrod.

Root plowing followed by disking has recently been used on Buena Vista Marsh to convert dense monotypic stands of weeds and brush to earlier successinal stages. Future management of these problem areas would be to share-crop 16-24 ha parcels to local farmers for 4 years followed by a seeding program to develop dense nest cover for prairie chickens. Timothy and brome would be planted on muck sites and switch grass (*Panicum virgatum*) on dry sandy sites.

In this study, plowing was tested to determine its effects on a field with meadow-sweet as the dominant plant cover. Plowing and disking resulted in a significant reduction of percent cover and stem density of meadow-sweet. Revegetation of the plowed plot was chiefly through root-stock generation of perennial plants. Interspersion of dominant vegetation was similar before and after plowing. Quackgrass flowered profusely the second and third growing seasons after soil disturbance. Exposed soil was invaded by cranesbill and sundrops (*Oenothera biennis*) the first and second seasons respectively after plowing.

Zimmerman and Schwarzmeier (1978) in Wisconsin reported a rapid invasion of quackgrass rhizomes and sweet clover (*Melilotus* spp.) on an early plowed (May) plot the first year and a dense flowering weed growth the second year. Similarily, Robocker and Miller (1955) in Wisconsin found bluegrass to develop extensively the first growing season after plowing.

Plowing on Buena Vista Marsh will result in adequate shrub control for a minimum of 5-8 years and increase grass and forb density. Duffey et al. (1974) believes that long term plowing, every 10-20 years, would allow a herb-rich community to develop which would contain unusual combinations of plant species not usually found in older grassland. It would also encourage the build up of populations of phytophagous insects associated with arable weeds and so increase the diversity of invertebrate fauna.

Acknowledgement

Bruce Gruthoff, Area Wildlife Manager (WDNR), provided heavy equipment and manpower for all experimental treatments. Tom Zeisler, academic computing specialist at the University of Wisconsin-Stevens Point, provided advice and computer programs for the statistical treatment of data. Dan Waranius, Bruce Bacon, Don Chapman, and Helen Rabbitt provided much of their time and assistance with field work. Kim Bettinger provided very capable field assistance and spent many tedious hours key punching data and sorting insects.

Literature Cited

Ahlgren, I. F. 1974. The effect of fire on soil organisms. In T. T. Kozlowski and C. E. Ahlgren, eds., Fire and Ecosystems. Academic Press, New York.

Beck, A. M. and R. F. Vogl. 1972. The effects of spring burning on rodent populations in a brush prairie savanna. J. Mammal. 53:336-346.

Bendell, J. F. 1974. Effects of fire on birds and mammals. In. T. T Kozlowski and C. E. Ahlgren, eds., Fire and Ecosystems. Academic Press, New York.

Brower, J. E. and J. H. Zar. 1977. Field and Laboratory Methods for Genreal Ecology. W. C. Brown Co., Dubuque, Iowa.

Burt, W. G. 1977. Mammals of the Great Lakes Region. University of Michigan Press, Ann Arbor.

Cancelado, R. and T. R. Yonke. 1970. Effects of prairie burning on insect populations. J. Kans. Entomol. Soc. 43:274-281.

Crafts, A. S. and W. W. Robbins. 1962 Weed Control. McGraw-Hill Book Co., Inc., New York.

Curtis, J. T. and M. L. Partch. 1948. Effect of fire on the competition between bluegrass and certain prairie plants. Am. Mid. Nat. 39:437-443.

Daubenmire, R. 1968. Ecology of fire in grasslands. Adv. Ecol. Res. 5:209-266.

Davis, K. P. 1959. Forest Fire: Control and Use. McGraw-Hill Book Co., Inc., New York.

Dix, R. L. and J. E. Butler. 1954. Effects of fire on a dry, thin-soil prairie in Wisconsin. J. Range Manage. 7:265-268.

Drobney, R. D. and R. D. Sparrowe. 1977. Land use relationships and movements of greater prairie chickens in Missouri. Trans. Missouri Acad. Sci. 10 and 11:146-160.

Duffey, E., M. G. Morris, J. Sheail, L. K. Ward, D. A. Wells, and T. C. E. Wells. 1974. Grassland Ecology and Wildlife Management. Chapman and Hall, London.

Gratkowski, H. J. 1977. Seasonal effects of phenoxy herbicides on ponderosa pine and associated brush species. For. Sci. 23:2-12.

Halvorsen, H. H. 1981. An evaluation of grassland management practices in central Wisconsin.

M.S. Thesis. University of Wisconsin, Stevens Point.

Hamerstrom, F. and F. Hamerstrom. 1973. The prairie chicken in Wisconsin. Wisc. Dept. Nat. Res. Tech. Bull. 64. 52 pp.

Hamerstrom, Jr., F. N., E. E. Mattson, and F. Hamerstrom. 1957. A guide to prairie chicken management. Wisc. Conserv. Dept. Tech. Bull. 15. 129 pp.

Holt, Jr., C. L. R. 1965. Geology and water resources of Portage County, Wisconsin. Geological Survey Water Supply Paper 1796. Wash., D. C. 77 pp.

Hurst, G. A. 1972. Insects and bobwhite quail brood habitat management. In J. A. Morrison and J. C. Lewis, eds., Proc. First National Bobwhite Quail Symposium. Oklahoma State University, Stillwater.

Jones, R. E. 1963. Identification and analysis of less and greater prairie chicken habitat. J. Wildl. Manage. 27:757-778.

Kirsch, L. M. and A. D. Kruse. 1973. Prairie fires and wildlife. Proc. Tall Timbers Fire Ecol. Conf. 12:289-303. Tallahassee, Fla.

Kirsch, L. M. 1974. Habitat managaement considerations for prairie chickens. Wild. Soc. Bull. 2:124-129.

Lehmann, V. W. 1941. Attwater's prairie chicken--its life history and management. North Am. Fauna Rep. 57. Fish and Wildlife Service, Wash., D. C. 63 pp.

Liegel, E. A. and E. E. Schulte (eds.). 1977. Wisconsin Soil Testing, Plant Analysis and Feed and Forage Analysis Procedures. University of Wisconsin, Madison. 48 pp.

Linde, A. G. 1969. Techniques for wetland management. Wisc. Dept. Nat. Res. Res. Rep. 45. 156 pp.

Martin, L. 1965. The Physical Geography of Wisconsin. University of Wisconsin Press. Madison.

Old, S. M. 1969. Microclimate, fire and plant production in an Illinois prairie. Ecol. Monogr. 39:355-384.

Queal, L. 1973. Fire--tool or tyrant? Kansas Fish and Game 30:7-9.

Robel, R. J., J. N. Briggs, J. J. Cebula, N. J. Silvy, C. E. Viers, P. G. Watt. 1970. Greater prairie chicken ranges, movements, and habitat usage in Kansas. J. Wildl. Mange. 34:286-306.

Robocker, W. C. and B. J. Miller. 1955. Effects of clipping, burning and competition on establishment and survival of some native grasses in Wisconsin. J. Range Manage. 8:117-120.

Romney, V. E. 1945. The effect of physical factors upon catch of the beet leafhopper by a cylinder and two sweep-net methods. Ecology 26:135-148.

Ryan, Jr., T. A., B. L. Joiner, B. F. Ryan. 1976. Minitab Student Handbook. Duxbury, Press, North Scituate, Mass.

Schramm, P. 1978. The "Do's and Don'ts" of prairie restoration. Proc. Fifth Midwest Prairie Conf., pp. 139-150, D. C. Glenn-Lewin and R. Q. Landers, Jr., eds. Iowa State University, Ames.

Smith, R. L. Sampling plant and animal populations. In Ecology and Field Biology. Harper and Row Publ. Inc., New York.

Springer, J. T. and P. Schramm. 1972. The effects of fire on small mammal populations in a restored prairie with special reference to the short-tailed shrew, *Blarina brevicauda.* Proc. Second Midwest Prairie Conf., pp. 91-96, J. H. Zimmerman, University of Wisconsin, Madison.

Swan, Jr., F. R. 1970. Post-fire response of four plant communities in south-central New York state. Ecology 51:1074-1082.

Tester, J. R. and W. H. Marshall. 1961. A study of certain plant and animal interelations on a native prairie in northwest Minnesota. Minn. Mus. Nat. Hist. Occas. Pap. 8. 51 pp.

Vandre, W. G. 1975. Effects of channel redredging on wildlife and wildlife habitat of Buena Vista Marsh. M.S. Thesis. University of Wisconsin, Stevens Point.

Westemeier, R. L. 1971. The history and ecology of prairie chickens in Central Wisconsin. Univ. Wisc. Res. Div. Bull. 281. 66 pp.

Westemeier, R. L. 1973. Prescribed burning in grassland management for prairie chickens in Illinois. Proc. Tall Timbers Fire Ecol. Conf. 12:317-338. Tallahassee, Fla.

Woehler, E. E. and M. A. Martin. 1978. Establishment of prairie grasses and forbs with the use of herbicides. Proc. Fifth Midwest Prairie Conf., pp. 131-138, D. C. Glenn-Lewin and R. Q. Landers, Jr., eds. Iowa State University, Ames.

Wuenscher, M. L. 1970. Survival of little bluestem and blazing star in phosphorous deficient soils of Buena Vista Marsh. M.S. Thesis. University of Wisconsin, Madison.

Zedler, J. 1966. Buena Vista Marsh in historical perspective. M.S. Thesis. University of Wisconsin, Madison.

Zedler, J. 1968. Vegetational response to microtopography on a central Wisconsin drained marsh. Ph.D. Thesis. University of Wisconsin, Madison.

Zedler, J., and O. L. Loucks. 1969. Differential burning response of *Poa pratensis* fields and *Andropogon scoparious* prairies in central Wisconsin. Am. Mid. Nat. 81:341-352.

Zimmerman, J. H. and J. A. Schwarzmeier. 1978. Experimental prairie restoration at Wingra overlook. Proc. Fifth Midwest Prairie Conf., pp. 125-130, D. C. Glenn-Lewin and R. Q. Landers, Jr., eds. Iowa State University, Ames.

Point.

Hamerstrom, Jr., F. N., E. E. Mattson, and F. [illegible]

Holt, Jr., C. L. [illegible] sources of Portage County, Wisconsin. Geological Survey Water Supply Paper 1796. Wash., D. C. 77 pp.

Hurst, G. A. 1972. Insects and bobwhite quail brood habitat management. In J. A. Morrison and J. C. Lewis, eds., Proc. First National Bobwhite Quail Symposium. Oklahoma State University, Stillwater.

Jones, R. E. 1963. Identification and analysis of less and greater prairie chicken habitat. J. Wildl. Manage. 27:757-778.

Kirsch, L. M. and A. D. Kruse. 1973. Prairie fires and wildlife. Proc. Tall Timbers Fire Ecol. Conf. 12:289-303. Tallahassee, Fla.

Kirsch, L. M. 1974. Habitat management considerations for prairie chickens. Wild. Soc. Bull. 2:124-129.

Lehmann, V. W. 1941. Attwater's prairie chicken--its life history and management. North Am. Fauna Rep. 57. Fish and Wildlife Service, Wash., D. C. 63 pp.

Liegel, E. A. and E. E. Schulte (eds.). 1977. Wisconsin Soil Testing, Plant Analysis and Feed and Forage Analysis Procedures. University of Wisconsin, Madison. 48 pp.

Linde, A. G. 1969. Techniques for wetland management. Wisc. Dept. Nat. Res. Res. Rep. 45. 156 pp.

Martin, L. 1965. The Physical Geography of Wisconsin. University of Wisconsin Press, Madison.

Old, S. M. 1969. Microclimate, fire and plant production in an Illinois prairie. Ecol. Monogr. 39:355-384.

Queal, L. 1973. Fire--tool or tyrant? Kansas Fish and Game 30:7-9.

Robel, R. J., J. N. Briggs, J. J. Cebula, N. J. Silvy, C. E. Viers, P. G. Watt. 1970. Greater prairie

Robocker, W. C. and B. J. [illegible] of clipping, burning and competition on establishment and survival of some native grasses in Wisconsin. J. Range Manage. 8: 117-120.

Romney, V. E. 1945. The effect of physical factors upon catch of the beet leafhopper by a cylinder and two sweep-net methods. Ecology 26:135-[illegible]

Ryan, Jr., T. A., B. L. Joiner, B. F. Ryan. 1976. Minitab Student Handbook. Duxbury, Press, North Scituate, Mass.

Schramm, P. 1978. The "Do's and Don'ts" of prairie restoration. Proc. Fifth Midwest Prairie Conf., pp. 139-150, D. C. Glenn-Lewin and R. Q. Landers, Jr., eds. Iowa State University, Ames.

Smith, R. L. Sampling plant and animal populations. In Ecology and Field Biology. Harper and Row Publ. Inc., New York.

Springer, J. T. and P. Schramm. 1972. The effects of fire on small mammal populations in a restored prairie with special reference to the short-tailed shrew, *Blarina brevicauda*. Proc. Second Midwest Prairie Conf., pp. 91-96, J. H. Zimmerman, University of Wisconsin, Madison.

Swan, Jr., F. R. 1970. Post-fire response of four plant communities in south-central New York state. Ecology 51:1074-1082.

Tester, J. R. and W. H. Marshall. 1961. A study of certain plant and animal interrelations on a native prairie in northwest Minnesota. Minn. Mus. Nat. Hist. Occas. Pap. 8. 51 pp.

Vandre, W. G. 1975. Effects of channel redredging on wildlife and wildlife habitat of Buena Vista Marsh. M.S. Thesis. University of Wisconsin, Stevens Point.

Westemeier, R. L. 1971. The history and ecology of prairie chickens in Central Wisconsin. Univ. Wisc. Res. Div. Bull. 281. 66 pp.

Westemeier, R. L. 1973. Prescribed burning in grassland management for prairie chickens in Illinois. Proc. Tall Timbers Fire Ecol. Conf. 12:317-338. Tallahassee, Fla.

Woehler, E. E. and M. A. Martin. 1978. Establishment of prairie grasses and forbs with the use of herbicides. Proc. Fifth Midwest Prairie Conf., pp. 131-133, D. C. Glenn-Lewin and R. Q. Landers, Jr., eds. Iowa State University, Ames.

COMPOSITION, PRODUCTION AND MANAGEMENT OF EASTERN ARKANSAS PRAIRIES

Robert S. Irving
1422 Summit
Little Rock, Arkansas 72202

Abstract. Most of the few uncultivated remnants of eastern Arkansas' terrace prairies are dominated by broomsedge (*Andropogon virginicus*) and splitbeard (*A. ternarius*). In 1976, the composition and net aboveground primary production were determined for three prairie remnants of the Grand Prairie. Two of these had been burned and hayed annually for at least 65 years, the third had been protected. On the managed prairies, broomsedge and splitbeard contributed approximately 50% of the annual aboveground yield, and net primary, aboveground production was 623 and 628 g/m^2 per year. On the protected prairie, broomsedge and splitbeard were absent and annual productivity was 1,131 g/m^2 per year. Both the presence of broomsedge and the lower production of managed prairies were ascribed to long term burning and haying management. Since 1976, the 2 managed prairies have been subjected to a variety of management strategies including non-burning and non-haying. A prairie which has only been subject to burning management and a prairie plowed nearly 50 years ago were also examined. In the fall of 1979, the dominant grasses and terminal crop were assessed. On the prairies where burning and haying management had ceased, the relative density of broomsedge and splitbeard significantly decreased and the relative density of little bluestem, increased. Terminal crop was also increased over 1976 levels. On the prairie which received only burn management, broomsedge and splitbeard were nearly absent. It is concluded that the primary cause of broomsedge dominance or the prairie remnants of eastern Arkansas is annual haying. When this practice ceases the broomsedge rapidly declines in favor of more of the typical prairie dominants.

Introduction

In Louisiana and eastern Arkansas a series of discontinuous prairies developed on the poorly dissected Pleistocene terraces of the Mississippi River Valley. These tallgrass prairies can be viewed as some of the southeasternmost extensions of the Prairie Peninsula. Yet, they have considerably more rainfall, higher temperatures, and longer growing seasons than their counterparts to the north and west.

In 1976 a study was made of the species composition and net aboveground herbage production for 3 remnants of the Grand Prairie in eastern Arkansas (Irving et al. 1980). Two of the studied prairies had been burned and hayed annually for at least 65 years, the third had been protected for approximately 16 years. The managed prairies were dominated by broomsedge and splitbeard which together contributed 48-63% of the annual aboveground production. Other, more characteristic prairie grasses, such as little bluestem represented less than 6% of the annual yield. Annual aboveground production for the managed prairies, estimated by summing the peak production of each species, was 623 and 628 g/m^2 per year. On the protected prairie, broomsedge and splitbeard were absent and the dominant species were largely legumes and composites. Annual production was 1,131 g/m^2 per year.

Given the close relationship between the occurrence of broomsedge and reduced soil fertility, and considering the absence of broomsedge from the protected prairie, we concluded that the dominance of broomsedge and splitbeard on the managed prairies was due to their long history of burning and haying management.

To test this hypothesis and to develop a workable management plan for prairies recently acquired by the Arkansas Natural Heritage Commission a number of different management strategies were initiated in 1976. In the Fall of 1979, as reported here, these variously managed prairie tracts were evaluated as to composition and annual production as estimated by terminal harvest.

Procedures

Five prairies or former prairie sites, representing different management histories, were studied on the Grand Prairie of eastern Arkansas. These prairies are relic examples of poorly drained terrace prairies which formed an extensive but disjunctive prairie region along the Arkansas and White Rivers. The study sites and their recent management are as follows:

Konecny Prairie: hayed and burned annually for 60-65 years.

Roth Prairie (north): hayed in 1974, burned in 1974-1977.

Roth Prairie (south): hayed and burned in 1974.

Weber Prairie: burned annually for past 12-15 years.

Weber Field: plowed ca. 1930, burned sporadically since.

The Roth and Konecny prairies have been acquired recently by the Arkansas Department of Natural and Cultural Heritage; the Weber prairie and field are in private ownership.

The present study was conducted in October of 1979. The vegetation analyses were conducted using permanent quadrats; sample design and sampling methodology are presented elsewhere (Irving et al 1980). Only the fall grasses were sampled in this study and the corresponding data were taken from the earlier publication.

To make comparisons, above-ground production was estimated by terminal harvest. Ten to 20 0.25 m^2 subplots were clipped in October. Shoots and litter were manually sorted into the crop of the current season and the litter of the previous season. Samples were oven dried for 48 hours at 60°C and weighed.

Results

The Konecny Prairie, with its long history of annual burning and haying management, was dominated by Broomsedge (*Andropogon virginicus*) and Splitbeard (*Andropogon ternarius*). Together these 2 grasses accounted for nearly 85% of fall composition (Fig. 1). The composition of the Konecny Prairie is typical of many of eastern Arkansas' prairie remnants.

Both north and south Roth prairies had been burned and hayed annually for at least 60 years until 1975. In 1976, they were floristically similar to the Konecny prairie and dominated largely by

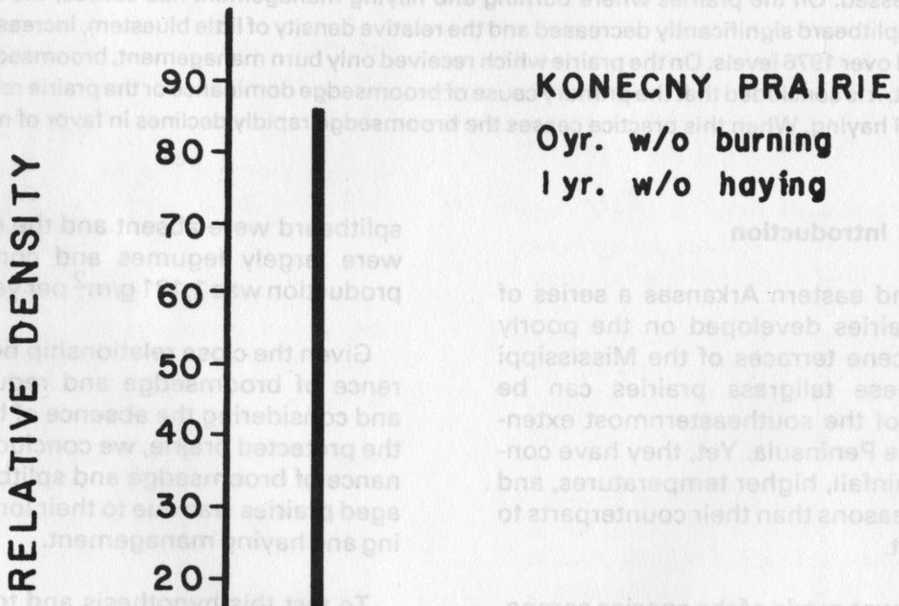


Fig. 1. Relative density of dominant fall grasses on the Konecny Prairie. B & S = broomsedge and splitbeard, LB = little bluestem, BB = big bluestem, SG = switchgrass; IG = Indiangrass.

broomsedge and splitbeard (Irving et al. 1980). In 1979, both prairie tracts displayed significant (.01 level) shifts in the relative densities of broomsedge - splitbeard and little bluestem. Broomsedge (including splitbeard) and little bluestem (*Schizachyrium scoparium*) made up 71.6% and 2.3% or the 1976 fall samples respectively on the north Roth (Fig. 2) and 62% and 23.3% of the south Roth (Fig. 3). In 1979 samples, broomsedge had decreased to 23.2% on the north Roth and 10% on the south Roth. Little bluestem, in contrast, had increased to 41.3% on the north Roth and to 74.9% on the south Roth. With the other fall grasses only the shift on the north Roth from less than 0.5% big bluestem (*Andropogon gerardi*) to 3.4% was highly significant (.01). The north Roth differs from the south in being slightly more mesic and in having been burned in 1977, 2 years prior to the final sample.

The Weber prairie has undergone only annual burning for the past 12-15 years and only sporadic haying prior to 1965. Its fall density is more evenly balanced than the other prairies and broomsedge-splitbeard was less than 5% of its fall flora (Fig. 4). The prairie was dominated by big bluestem and Indian grass (*Sorghastrum avenaceum* = *S. nutans*). The Weber field is a small tract adjacent to the Weber prairie. It was plowed in ca. 1930 and has remained fallow since. It has had no reintroduction of typical prarie grasses from the adjacent Weber Prairie and was dominated by broomsedge, splitbeard, three-awn (*Aristida longespica*) and crabgrass (*Digitaria filiformis*) (Fig. 5).

Annual production, as estimated by terminal harvest (corrected for the previous year's litter) was an approximate 625 g/m^2 on the Roth in 1976, and 800 g/m^2 in 1979 (Fig. 6). For the Weber Prairie it was 873 g/m^2 and 300 g/m^2 on the Weber Field.

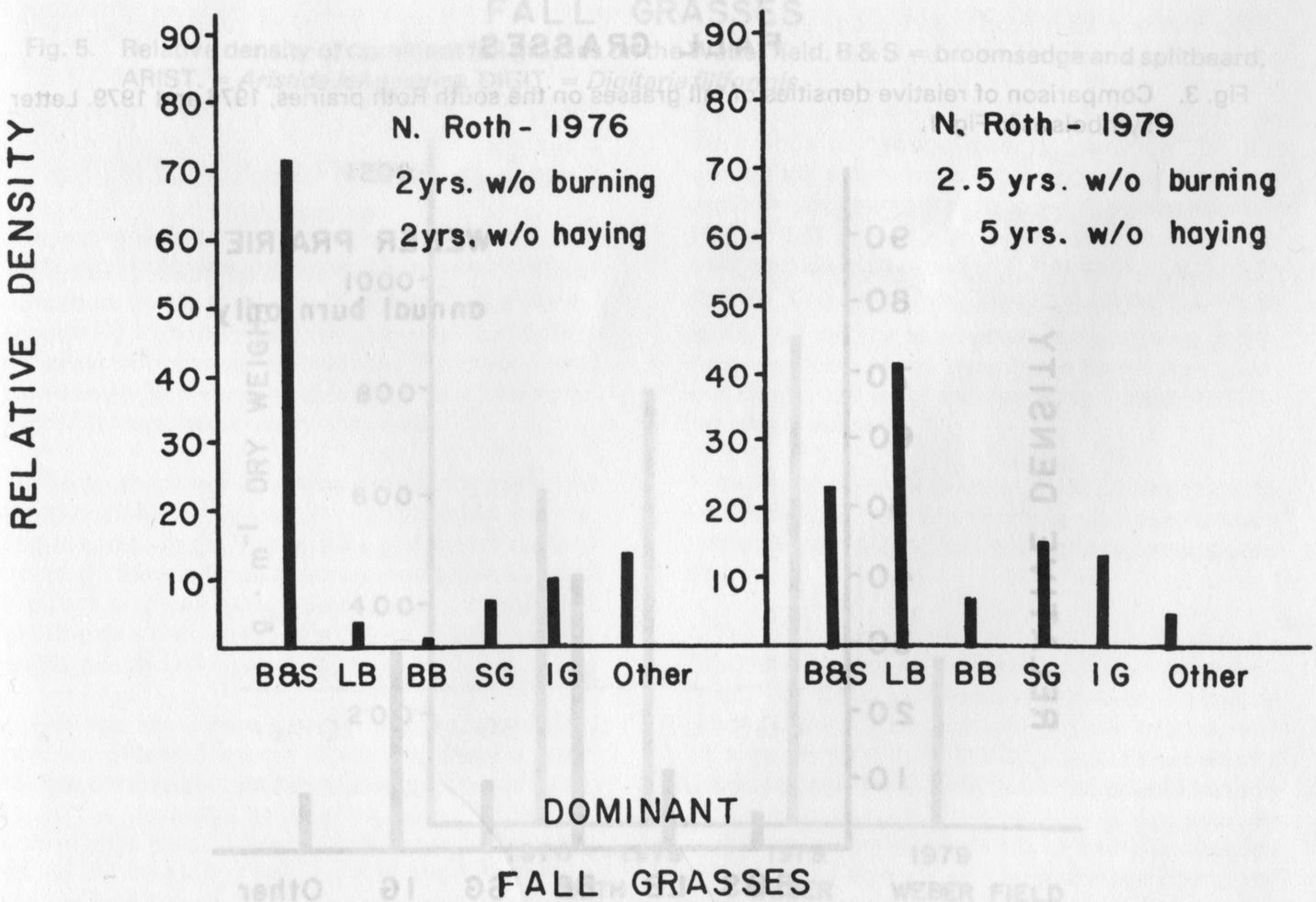


Fig. 2. Comparison of relative densities of fall grasses on the north Roth prairies, 1976 and 1979. Letter symbols as in Fig. 1.

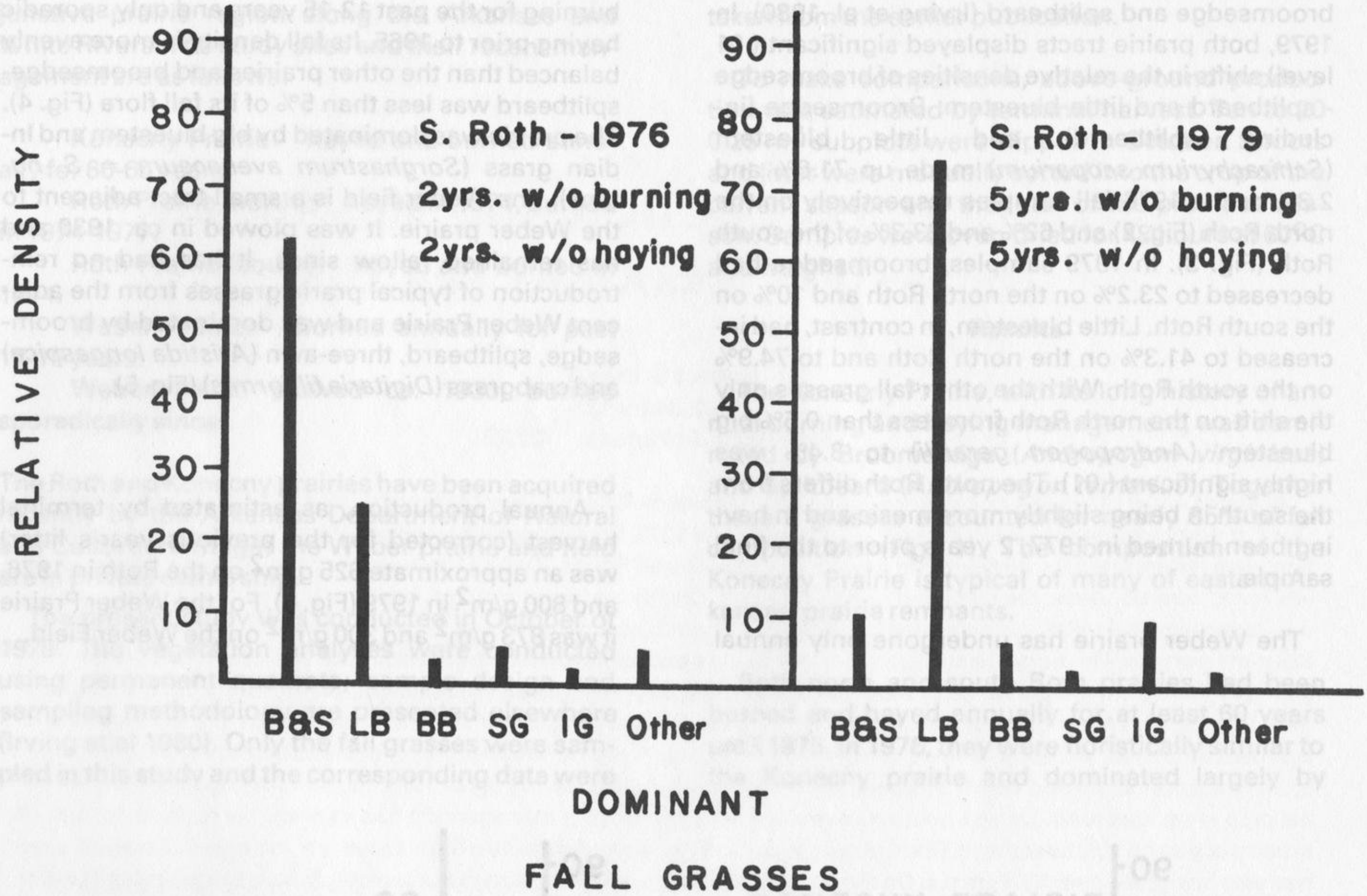


Fig. 3. Comparison of relative densities of fall grasses on the south Roth prairies, 1976 and 1979. Letter symbols as in Fig. 1.

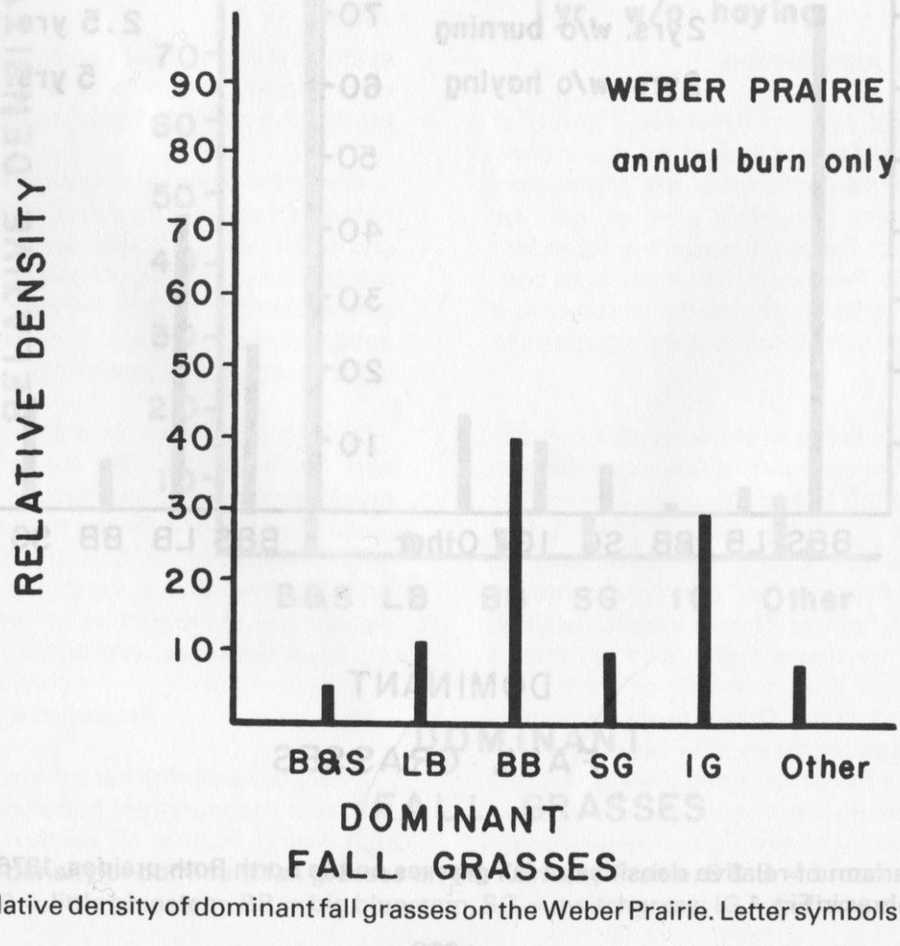


Fig. 4. Relative density of dominant fall grasses on the Weber Prairie. Letter symbols as in Fig. 1.

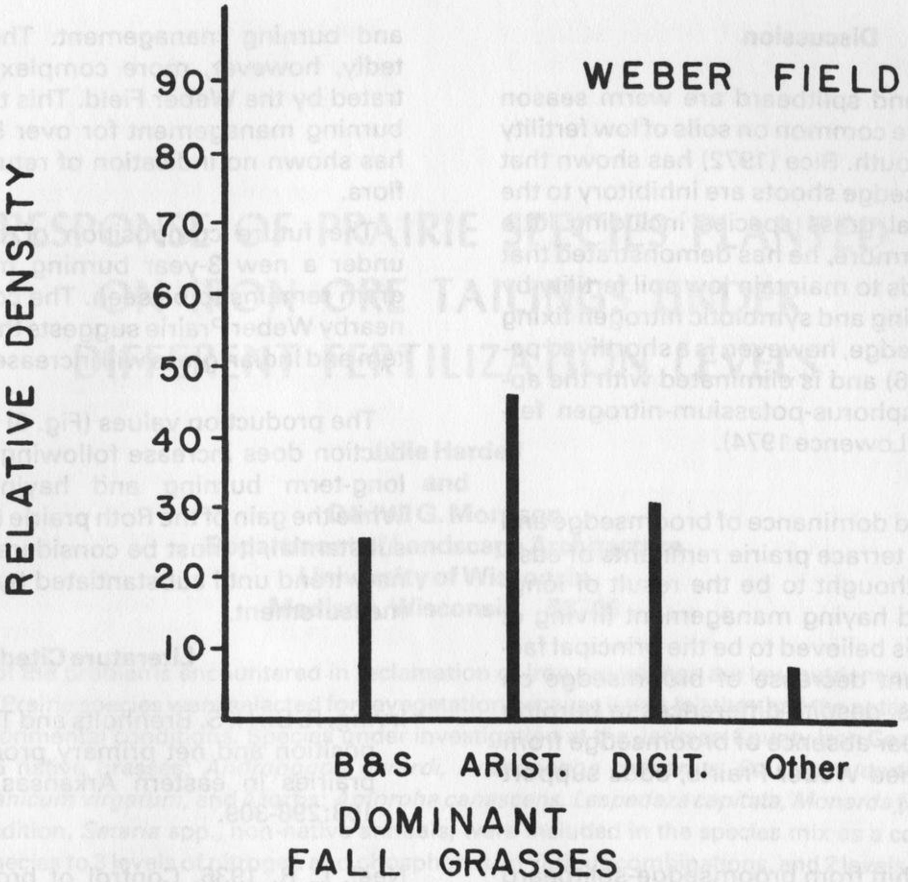


Fig. 5. Relative density of dominant fall grasses on the Weber field. B & S = broomsedge and splitbeard, ARIST. = *Aristida longespica,* DIGIT. = *Digitaria filiformis.*

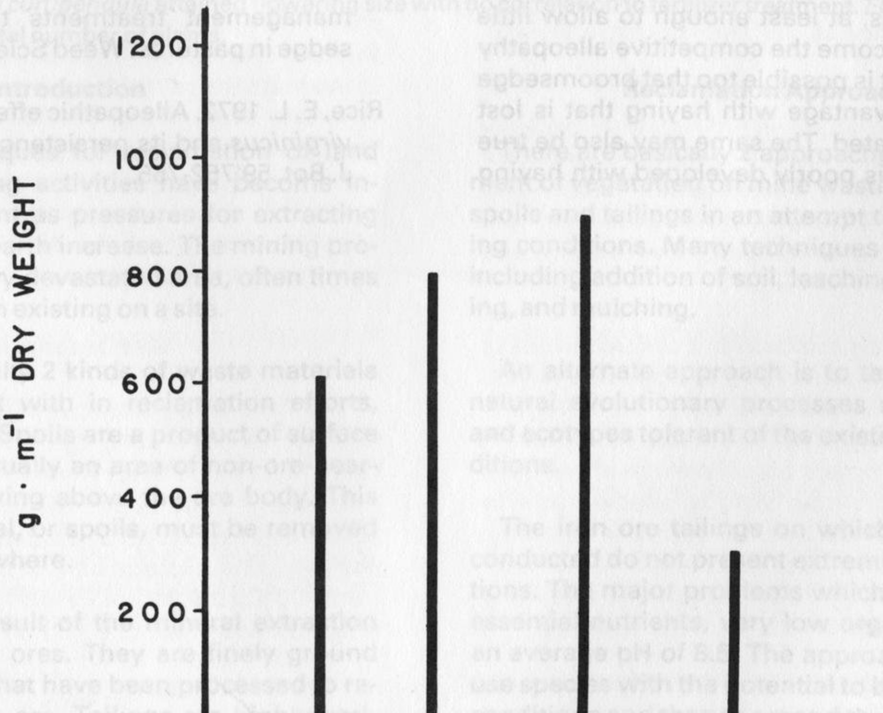


Fig. 6. Annual harvest of above ground production for all study areas.

Discussion

Broomsedge and splitbeard are warm season perennials that are common on soils of low fertility throughout the south. Rice (1972) has shown that decaying broomsedge shoots are inhibitory to the growth of several grass species including little bluestem. Furthermore, he has demonstrated that broomsedge tends to maintain low soil fertility by inhibiting free-living and symbiotic nitrogen fixing bacteria. Broomsedge, however, is a shortlived perennial (Neel 1936) and is eliminated with the application of phosphorus-potassium-nitrogen fertilizer (Peters and Lowence 1974).

The widespread dominance of broomsedge and splitbeard on the terrace prairie remnants of eastern Arkansas is thought to be the result of long-term burning and haying management (Irving et al. 1980). Haying is believed to be the principal factor. The significant decrease of broomsedge on both Roth prairies, despite differences in burning history and the near absence of broomsedge from the annually burned Weber Prairie, adds support to this supposition.

The dramatic shift from broomsedge-splitbeard dominance to that of little bluestem is perhaps the result of several factors. While speculative, the cessation of haying may well have increased available soil nutrients, at least enough to allow little bluestem to overcome the competitive alleopathy of broomsedge. It is possible too that broomsedge may have an advantage with haying that is lost when it is terminated. The same may also be true for mulch which is poorly developed with haying and burning management. There are undoubtedly, however, more complex factors as illustrated by the Weber Field. This tract has had only burning management for over 50 years, and yet has shown no indication of returning to a prairie flora.

The future composition of the Roth prairies under a new 3-year burning management program remains to be seen. The composition of the nearby Weber Prairie suggests that both big bluestem and Indian grass will increase in importance.

The production values (Fig. 6) suggest that production does increase following the cessation of long-term burning and haying management. While the gain of the Roth prairie (200 $g/m^2/yr$) was substantial, it must be considered only a preliminary trend until substantiated by several years of measurement.

Literature Cited

Irving, R. S., H. S. Brenholts and T. Foti. 1970. Composition and net primary production of native prairies in eastern Arkansas. Am. Mid. Nat. 103:298-309.

Neel, L. R. 1936. Control of broomsedge. Tenn. Agri. Exp. Sta. Circ. 57, 4 pp.

Peters, S. J. and S. A. Lowance. 1974. Fertility and management treatments to control broomsedge in pastures. Weed Science 22:201-205.

Rice, E. L. 1972. Alleopathic effects of *Andropogon virginicus* and its persistence in old fields. Am. J. Bot. 59'752-755.

RESPONSE OF PRAIRIE SPECIES PLANTED ON IRON ORE TAILINGS UNDER DIFFERENT FERTILIZATION LEVELS

Julie Hardell
and
Darrell G. Morrison
Department of Landscape Architecture
University of Wisconsin
Madison, Wisconsin 53706

Abstract. Two of the problems encountered in reclamation of iron ore tailings are low nutrient availablity and lack of organic matter. Prairie species were selected for revegetation because it was felt they had the potential to be adapted to the harsh environmental conditions. Species under investigation at the Jackson County Iron Company mine, Wisconsin included 5 native grasses: *Andropogon gerardi, Andropogon scoparius, Bouteloua curtipendula, Elymus canadensis* and *Panicum virgatum,* and 4 forbs: *Amorpha canescens, Lespedeza capitata, Monarda fistulosa,* and *Rudbeckia hirta.* In addition, *Setaria* spp., non-native annuals, were included in the species mix as a cover crop. The response of these species to 3 levels of nitrogen and phosphorus, in various combinations, and 2 levels of sewage sludge has been assessed. The number of plants established in the field after the first growing season has been very encouraging. In general, the grasses performed much better than the forbs. The native species showed little response to fertilizer treatments, while *Setaria* spp. gave the best response only when the high rates of fertilizer were applied. Some individuals of *Bouteloua curtipendula* attained flowering size with no correlation to fertilizer treatment. *Elymus canadensis* performed best in total number of plants.

Introduction

Improved techniques for reclamation of land disturbed by mining activities have become increasingly important as pressures for extracting minerals from the earth increase. The mining process results in a very devastated area, often times with little vegetation existing on a site.

-There are generally 2 kinds of waste materials that must be dealt with in reclamation efforts, spoils and tailings. Spoils are a product of surface mining. There is usually an area of non-ore-bearing rock and soil lying above the ore body. This overburden material, or spoils, must be removed and deposited elsewhere.

Tailings are a result of the mineral extraction process of metallic ores. They are finely ground rock and minerals that have been processed to remove the desirable ore. Tailings are highly variable in physical and chemical characteristics, influenced by the kind of mining operation as well as the ore body itself. The harsh environmental conditions encountered by plants on tailings sites make growth difficult. Natural invasion onto these sites is extremely slow, and therefore, intervention may be necessary.

Reclamation Approaches

There are basically 2 approaches to reestablishment of vegetation on mine wastes. One is to treat spoils and tailings in an attempt to improve growing conditions. Many techniques have been tried, including addition of soil, leaching, liming, fertilizing, and mulching.

An alternate approach is to take advantage of natural evolutionary processes and use species and ecotypes tolerant of the existing growing conditions.

The iron ore tailings on which this study was conducted do not present extremely severe conditions. The major problems which exist are lack of essential nutrients, very low organic matter, and an average pH of 8.5. The approach taken was to use species with the potential to be adapted to site conditions and then to amend the tailings with nitrogen and phosphorus fertilizer and also sewage sludge in an attempt to maximize the chance of successful revegetation.

Native species are appropriate for mining reclamation studies for several reasons. Federal and state legislation regulating reclamation stress the importance of promoting a natural succession of plants that will eventually lead to vegetation similar to that originally covering the site (Public Law 95-87, Sec. 515 (b) (19); Wisconsin State Statues, Chapter 421, Sec. 144.83 (2) (c).

According to Dean et al. (1970, 1974) vegetative stablization should produce a self-perpetuating community in harmony with the environment. Once established, the area should not require any special maintenance care if the species are adapted to the climate of the region (Hunter & Whiteman 1974). It is this viewpoint which has led, in part, to the use of prairie species in the present reclamation study.

There are others who ascribe to this "successional" approach. DePuit and Coenenburg (1979) worked with native plant communities on coal spoils in Montana; Wagner et al. (1978) used natives on the strip-mined lands of New Mexico, and James (1966) studied the establishment of native species on gold tailings in South Africa. Miller (1978) felt estabishment of colonizing grasses followed by the introduction of more persistent trees and shrubs was an appropriate reclamation techique. Walker et al. (1978) worked with native grass ecotypes in search of more highly adapted plants. Schramm and Kalvin (1976) evaluated the use of prairie in strip mine reclamation in Illinois. Wali and Alden (1977), Riley (1974), and Coates (1973) discuss the advantages of encouraging a natural succession of species in lieu of experimental studies.

Prairie species were selected for study because of their tolerance to exposed conditions, and their ability to withstand a limited water supply and high temperatures. Other factors taken into consideration include a tolerance of low nutrient and alkaline soils.

Prairie vegetation is known to build up humus in the soil faster than woodland species and would therefore play an important role in the revegetation of iron ore tailings which are extremely low in organic matter. Grasses are also more effective in controlling erosion than woody species due to their highly branched and fibrous root systems. Prairie species may be compatible with other indigenous species of particular geographic areas and may be well-suited to certain climatic regimes.

Work has been done on tailings with various application rates of fertilizer. However, results have not been very conclusive, especially where native species were used. According to Dickinson (1975), without fertilization it will take many years until vegetation will establish itself on iron ore tailings. Others contend it is almost impossible to establish vegetative cover on mine wastes without adding fertilizers. Native species have been found to invade fertilzed tailings sites planted with other species (Dickinson 1975, Berg 1972, Knudson 1971, Dean and Haven 1970, James 1966). Sewage sludge has also been recommended as a soil amendment for renovating drastically disturbed land. However, Halderson and Zenz (1978) claim that most reclamation sites using sewage sludge have not adequately documented the correlation between sludge application and a particular response.

The major study leading to the present one was that of Dinsmoor (1977) who planted 10 prairie species on iron ore tailings in Wisconsin. He tested 3 treatments, but no fertilizer was applied. Species were planted in furrows, mulched, or scattered and raked in. The summer of Dinsmoor's research, 1976, was abnormally dry. It was felt that perhaps with less extreme conditions, results might have been more favorable. The slow growth and low survival of species following planting suggested that these species might respond to fertilizer applications, especially since the nutrient content of the tailings is quite low. Greenhouse studies were conducted during the winters of 1978 and 1979 in preparation for the present field study to help determine suitability of fertilizer rates.

This study evaluates the performance of prairie species grown on iron ore tailings under different fertilization rates. The objectives were 1) to determine if fertilization made a significant difference in the response of the 10 species selected and, if so, 2) evaluate the performance of these species at the different levels of fertilization. The establishment and growth of species during the first growing season is addressed in this paper, along with comments on visual observations made the second year. Monitoring of the site is continuing since long-term survival is important.

Site Description

The field study was conducted at the Jackson County Iron Company open-pit surface mine located just east of Black River Falls, Wisconsin. Presettlement vegetation in this area was oak savanna. Precipation averages 76 cm (30 inches) per year. The average annual temperature ranges from 4.9^{0}C to 9.3^{0}C (41^{0}F-49^{0}F) with an absolute range between -46^0 to 42^{0}C (-51^{0}F-108^{0}F).

Methods

Experimental plots were set up on the western side of the tailings dike. Road building equipment was used to grade and prepare a bed which was level and quite compacted. Plots of 2 different sizes were alternately staked out with 1 m between plots. The size of the larger permanent plots was

$4m^2$; plots to be harvested after the first year were $1m^2$. Treatments were set up in a completely randomized design. There were 4 replications of each treatment for a total of 44 large and 44 small plots. A border planted with the test species, was included around the periphery of the plots.

The tailings are sandy loam in texture with an average pH of 8.5. The tailings analyses pointed to a low phosphorus content, marginal potassium and magnesium, and sufficient calcium. From previous studies it was known that there is virtually no nitrogen present and that the organic matter content is very low (Dinsmoor 1977, JCIC 1977). Averages of values obtained from the 88 plots prior to planting can be compared with values of Wisconsin prairies and sand barrens (Table 1.). The average tailings value for Mg was 167 lbs/acre.

Each plot was planted with a mix of 10 species in June 1979 at the rate of 22 kg/ha (20 lbs/acre). The prairie grasses included *Andropogon gerardi, Andropogon scoparius, Bouteloua curtipendula, Elymus canadenis,* and *Panicum virgatum.* Each was included in the mix as 10% by number of seeds rather than percent weight due to variability of seed sizes. Two legumes, *Amorpha canescens* and *Lespedeza capitata,* were included at the rate of 15%. The other forbs, *Monarda fistulosa* and *Rudebeckia hirta,* were planted at 5% by number. In addition, non-native annual *Setaria* spp., foxtail, were included as a cover crop at the rate of 10%. Previous experience has indicated that *Setaria* spp. do not tend to persist in prairie plantings for more than a few years.

Seed was broadcast by hand and raked in. A pelletized mulch of grass hulls was applied approximately 2.2 cm (1 in) thick. No artificial watering or weeding was done during the growing season.

Table 1. Soils analysis from Wisconsin prairies and sand barrens (Curtis 1959) and JCIC iron ore tailings

Community	pH	P (lbs/acre)	K (lbs/acre)	Ca (lbs/acre)
Dry prairie	7.8	42	47	2712
Dry-mesic prairie	7.1	24	56	1837
Mesic prairie	6.2	18	65	1350
Sand barrens	6.2	15	8	25
Iron ore tailings	8.5	3	125	2569

Phosphorus, added as triple superphosphate, was rototilled into the tailings. Nitrogen, added as ammonium nitrate, was applied to the tailings surface and raked in. Nine chemical fertilizer treatments, N_0P_0, N_0P_1, N_0P_2, N_1P_0, N_1P_1, N_1P_2, N_2P_0, N_2P_1, and N_2P_2, were applied. Rates are shown in Table 2. Two levels of sewage sludge, obtained from Wisconsin Rapids, were applied as separate treatments. The sludge was rototilled into the tailings 10 days prior to planting at rates of 85 mt/ha and 42 mt/ha.

The above-ground parts of plants in the small plots were harvested in September following the first growing season. Dry weight was of primary importance in evaluating fertilizer treatments. Total dry weight per plot was determined. The total dry weight of *Setaria* spp. and that of all native species combined were also analyzed separately. The average dry weight per plant on a plot basis was also analyzed for selected species.

Of secondary importance was percent cover, plant height, and the number of plants per plot. Tissue analysis information was obtained from *Elymus canadensis.* Statistical analyses included factorial analysis of variance and one-way analysis of variance, considering tranformations. Dunkin's multiple-range was used to compare means.

Results and Discussion

Certain species were more easily established on the iron ore tailings than others. Table 3. gives the percentage of seedlings produced the first growing season from viable seed planted. The number of plants established in the field has been very en-

Table 2. Fertilizer rates applied

Fertilizer	Symbol	kg/ha	lbs/acre
Ammonium nitrate (NH_4NO_3)	N_2	175	156
	N_1	88	79
	N_0	–	–
Triple superphosphate ($Ca(H_2PO_4)_2$)	P_2	112	100
	P_1	28	25
	P_0	–	–
Sewage sludge	SS_2	85 mt/ha	38 t/a
	SS_1	42 mt/ha	19 t/a

couraging and appears comparable to prairie restorations on less severely disturbed sites. The number of plants per square meter ranged from 33-161 with the average over all treatments being 84. Of these 84 seedlings, 20 were non-native *Setaria* spp. In the general the grasses performed much better than the forbs. The 4 species present in large enough numbers to be statistically analyzed include: *Andropogon* spp., *Bouteloua curtipendula, Elymus canadensis,* and *Setaria spp.*

The native species showed very little response to fertilizer treatments, while foxtail gave the best response only when the high rates of fertilizer were applied. There are a few possible explanations as to why the prairie species responded very similarly to all treatments: 1) nutrient requirements of these species are low; 2) these species are very efficient at extracting available nutrients possibly due to their extensive root systems; 3) in its rapid growth, *Setaria* spp. may have utilized the nutrients to the disadvantage of the slower growing prairie species. *Bouteloua curtipendula* was the prairie species which gave the most encouraging results. It showed favorable germination and grew quickly achieving the greatest average dry weight per plant and height for each treatment. Some individuals attained flowering size, with no correlation to fertilizer treatment.

Elymus canadensis showed exceptional germination in the field (Table 3). The first growing season, growth was slower than expected. It was felt that since planting was not done until the middle of June, the weather became too hot for substantial growth to occur. This appears to have been the case since this species has attained an average height of nearly 1 m, with considerable flowering by mid-summer of 1980.

Andropogon gerardi and *A. scoparius* could not be separately identified at the time of harvest and were grouped together for analysis because they were so small. These 2 species are known to be slower growing than the other grasses under consideration. However, substantial growth has not occurred this second growing season although no analyses have been done at this time.

The other prairie species exhibited very low germination in the field. *Panicum virgatum* is considered a relatively fast growing prairie species and has been satisfactorily established in other reclamation studies (Bennett et al. 1978). However, in the present study, average dry weight per plot was in the low range compared with other grasses.

The 2 legumes, *Amorpha canescens* and *Lespedeza capitata,* did not meet with much success. Besides low germination, growth was slow. There are native legumes, such as *Petalostemum purpureum,* which are known to be more easily established than these 2 species and it is recommended they be tested on the tailings site.

Monarda fistulosa and *Rudbeckia hirta* gave similar germinaton results as the other forbs. However, by the second growing season, many of the plants were flowering.

Setaria spp., foxtail, performed very well on the tailings site. Germination was good and growth was rapid, with all plants flowering by the end of the season. It is possible that *Setaria* spp. exerted beneficial as well as detrimental effects upon the prairie species. This fast-growing annual provided good cover for the slower growing perennials as well as erosion control. It protected the prairie species from the sand blasting and desiccating effects of the wind, and shaded them from the sun which may also have helped to conserve moisture. However, the *Setaria* spp. also competed with the natives for water and nutrients. The greatest average dry weight of *Setaria* spp. per plot was obtained at the highest rate of the chemical fertilizers, N_2P_2 (175 kg/ha N, 11 kg/ha P). When analyzing the

Table 3. The number of seedlings produced in 44 one-square meter plots

Seedlings Species	Seedlings produced	Seedlings as % of viable seed	Seedlings as % of total no. established
Grasses			
Andropogon spp.	504	22.9	13.8[1/]
Bouteloua curtipendula	658	59.8	18.0[1/]
Elymus canadensis	1452	132.0	39.8[1/]
Panicum virgatum	54	4.9	1.5
Setaria spp.	874	79.4	23.9[1/]
Forbs			
Amorpha canescens	28	1.7	0.77
Lespedeza capitata	34	2.0	0.93
Monarda fistulosa	12	2.3	0.33
Rudbeckia hirta	36	6.8	0.98

1/ Species statistically analyzed

total dry weight of *Setaria* spp. per plot, N_2P_2, N_1P_2, and SS_2 gave comparable results. Thus, it can be seen that *Setaria* spp. does best under high fertility levels. Its requirement for large amounts of nutrients may be to the detriment of the native species.

The aggressiveness of these non-native species in the following years will help determine its value as a cover crop. It would be desirable for the *Setaria* spp. to phase out as the prairie species increase in size. The *Setaria* spp. have reseeded the second year but plants were far less numerous in the second growing season.

Conclusions

The establishment of certain prairie species on iron ore tailings was satisfactorily achieved. Based on 1 growing season, the effectiveness of fertilization on prairie species appears questionable. Fertilization of these species cannot be recommended at this time. The use of *Setaria* spp. as a cover crop appears feasible although this group responded best to high rates of fertilization.

Acknowledgements

Thanks are extended to the Jackson County Iron Company for use of the site and its preparation before planting. The project was made possible through funding provided by the Graduate School, University of Wisconsin, Madison, and Hatch funding for agricultural research, USDA.

Literature Cited

Bennett, O. L., E. L. Mathias, W. H. Armiger, and J. H. Jones, Jr. 1978. Plant materials and their requirements for growth in humid regions. In F. W. Schaller and P. Sutton, eds., pp. 285-306, Reclamation of Drastically Disturbed Lands. ASA, CSSA, and SSA, Madison, Wisconsin.

Berg, William A. 1972. Vegetational stabilization of mine wastes. 1972 Mining Yearbook. Colorado Mining Assoc., Denver.

Coates, William E. 1973. Landscape architectural approach to surface mining reclamation. In James R. Garvey, ed., pp. 26-41, Research and Applied Technology Symposium of Mined-Land Reclamation. National Coal Asso., Pittsburgh, Pennsylvania.

Curtis, J. T. 1959. The Vegetation of Wisconsin. The University of Wisconsin Press, Madison.

Dean, K. C. and R. Havens. 1970. Stablization of mineral wastes from processing plants. Proc. Second Mineral Waste Utilization Symposium, pp. 206-213. U. S. Bureau of Mines and IIT Research Institute.

Dean, K. C., R. Havens, and M. T. Glantz. 1974. Methods and cost for stabilizing fine-sized mineral wastes. U. S. Bureau of Mines, Report of Investigations, 7896. Salt Lake City Metallurgy Research Center, Salt Lake City, Utah.

Depuit, E. J. and J. G. Coenenburg. 1979. Methods for establishment of native plant communities on topsoiled coal strip mine spoils in the northern Great Plains. Reclamation Review, 2:75-83.

Dickinson, Sam. 1975. Revegetation of taconite tailings. Duplicated copy of paper presented at Mineral Waste Stablization Liasion Committee, Vail, Colorado, August 7-8.

Dinsmoor, Philip C. 1977. An evaluation of the performance of some native plants on iron mine wastes in Wisconsin. Master's thesis, Dept. of Landscape Architecture, University of Wisconsin, Madison.

Halderson, James L. and David R. Zenz. 1978. Use of municipal sewage sludge in reclamation of soil. In F. W. Schaller and P. Sutton, eds., pp. 645-652, Reclamation of Drastically Disturbed Lands. ASA, CSSA, SSSA, Madison, Wisconsin.

Jackson County Iron Company. 1977. Mining permit application and reclamation plan for Black River Falls Mine. Black River Falls, Wisconsin.

Knudsen, J. F., K. B. Hall, and J. K. Horner. 1971. Vegetative stabilization of tailings ponds at Kennecott Copper Corp. Proc. AIME Environmental Quality Conference, pp. 181-192. Am. Inst. of Mining, Metal. and Petrol. Engr., New York.

Miller, G. E. 1978. A method of establishing native vegetation on disturbed sites consistent with the theory of nucleation. Abstract in Reclamation Review, 1:176.

Riley, Charles V. 1974. Ecology--Ally of mined land restoration. In Second Research and Applied Technology Symposium of Mined-Land Reclamation, Louisville, Kentucky. pp. 54-68.

Schramm, Peter and R. L. Kalvin. 1976. The use of prairie in strip miner reclamation. Proc. Fifth Midwest Prairie Conf., pp. 151-153, D. C. Glenn-Lewin and R. Q. Landers, Jr., eds. Iowa State University, Ames.

Wagner, Warren L., W. C. Martin, E. F. Aldon. 1978. Natural succession on strip-mined lands in northwestern New Mexico. Reclamation Review 1:67-73.

Wali, Mohan K. and Alden L. Kollman. 1977. Ecology and mining or mining ecology? In J. L. Thames, ed., pp. 108-115, Reclamation and Use of Disturbed Land in the Southwest. The University of Arizona Press, Tucson.

Walker, D., R. S. Sadasivaiah and J. Weijer. 1978. The selection and utilization of native grasses for reclamation in the Rocky Mountains of Alberta. Abstract in Reclamation Review 1:97-98.

ISLAND BIOGEOGRAPHY AND THE CONSERVATION OF PRAIRIE BIRDS

Fred B. Samson
Missouri Cooperative Wildlife Research Unit
U. S. Fish and Wildlife Service
School of Forestry, Fisheries and Wildlife
University of Missouri
Columbia, Missouri 65211[1/]

Abstract. During the last decade, the theory of island biogeography proposed by MacArthur and Wilson in 1967 has emerged as the conceptual focal point in the design of preserves for wildlife. The theory proposes the relatively constant number of species held by an island reflects a dynamic equilibrium between rates of immigration and extinction influenced by island area and distance between islands. An important achievement has been the extensive application of the insular theory to the design of refuges for tropical birds to include which species will be maintained and for how long. Many aspects of avian use of prairies have been examined in detail. Others, however, including the effect of prairie area, isolation between prairie relicts, and rates of extinction and immigration are not well known. This study, conducted in the spring and summer of 1978 to 1980, found the number of bird species breeding on 15 tall grass prairie relicts in southwest and central Missouri correlated to the size of the relict, isolation influenced the number of breeding species, and immigrations and extinctions were observed; thus results in general agree with insular theory. Emerging from this and similar studies in other ecosystems are two concepts important to the conservation of birds, the hatitat size-dependency of many species, and geometric recommendations in the design of preserves to minimize losses due to extinction. Several prairie species, the upland sandpiper, Henslow's sparrow, and greater prairie chicken among others, appear to possess critical area requirements. A species-centered management approach incorporating the concept of habitat size-dependency is supported for prairie birds and has application in land use planning. Generally preferred are a large versus a small prairie and the clustering of smaller relicts when intact units are unavailable.

Introduction

During the last decade, the theory of island biogeography (MacArthur and Wilson 1967) has emerged as the conceptual focal point in the design of preserves for the conservation of plant and animal species (Terborgh 1974, Wilson and Willis 1975, May 1975). Most discussion has centered upon the size and isolation of preserves (Diamond 1975, 1976, Whitcomb et al. 1976, Diamond and May 1976), and several authors have attempted, with varying techniques and success, to solve immediate conservation needs of single species and communities (Miller 1979, Faaborg 1979, Goeden 1979, Picton 1979).

The tallgrass prairie is a declining resource. In Missouri, only 30,350 ha (0.5%) of a presettlement prairie of 6,070,000 ha now remain, and only 1,280 ha are under the management of public or private conservation organizations (Christisen 1972). These remaining isolated prairie islands are clearly distinguished from the surrounding habitat. This paper discusses the conservation of birds of the open tallgrass prairie in terms of island biogeography.

Equilibrium Model of Island Biogeography

The equilibrium model of MacArthur and Wilson (1967) proposes that the number of species held by an oceanic or inland habitat island reflects a dynamic equilibrium between immigration rates and extinction rates influenced by island area and isolation between islands. (Fig. 1). Generally large islands have low extinction rates and high immigration rates; small islands the converse. Observations on greater prairie chicken (*Tympanucus cupido*) use of isolated tall grass prairies of varying size in Missouri permit testing of predictions from island biogeographical theory, and, thus, judgements about the usefulness of the concept of management.

The equation of MacArthur and Wilson (1967),

$$P \simeq 1 - (\mu/\lambda)^k,$$

provides the survival probability (P) for an island population where μ is the per capita death rate, λ

[1/] Present address, Colorado Cooperative Research Unit, Colorado State University, Fort Collins, Colorado. 80523.

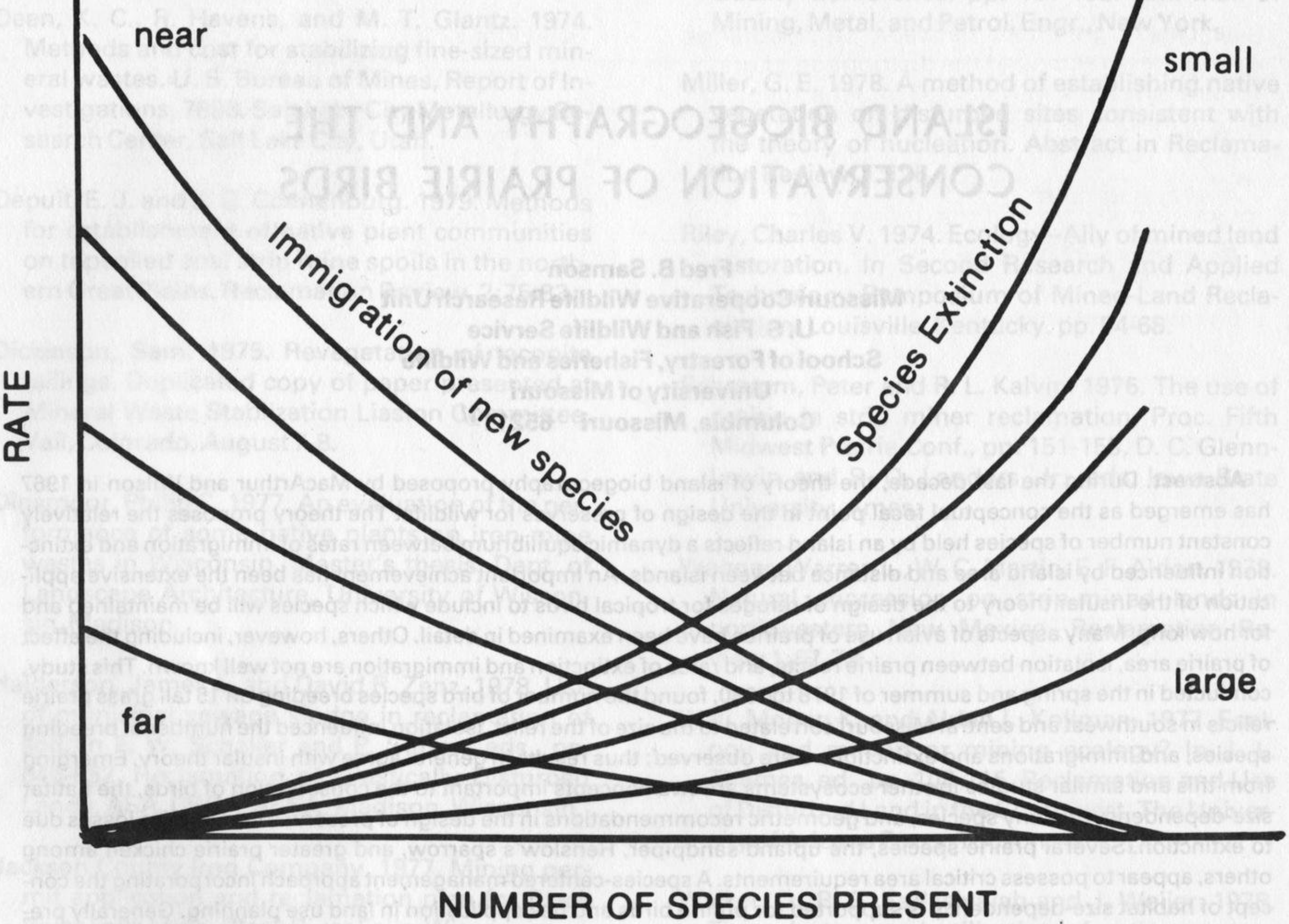


Fig. 1. The equilibrium model of island biogeography explains species numbers in terms of immigration rates, extinction rates, island isolation, and area. Large islands have high immigration rates and low extinction rates, as do islands near mainland (after MacArther and Wilson 1967).

is the per capita birth rate, and k is the carrying capacity. I compiled estimates of greater prairie chicken density and per capita birth and death rates form reviews or studies by Hamerstrom and Hamerstrom (1973) and Johnsgard (1973) to compute P. This yielded a k of 3 females per 100 ha. and a μ/λ of 0.7. I assume μ and λ are constant and independent of prairie size, but k corresponds to size of a prairie island.

The predicted success (i.e., annual prairie occupancy) of populations of the greater prairie chicken on prairie relicts of size 15, 60, 120 and 360 ha is plotted in Fig. 2. There is relatively close agreement between predicted and observed prairie occupancy on 17 prairie relicts (Appendix 1) in central and southwest Missouri, 1976 to 1978 (Christisen 1977, 1978, 1979). Size of occupied prairie island ($\bar{x}$ = 171.7 ha is signigicantly different (Mann Whitney U = 62, P ‹ .05) from unoccupied relicts (x = 32.8 ha). The high proportion of small unoccupied patches may in part be accounted for by high rates of extinction. Populations of many species exploiting small habitat islands frequently become extinct unless regularly reestablished by immigration (Smith 1974, Lynch and Whitcomb 1978, Fritz 1979). Although mortality in the greater prairie chicken was not observed, the recurrent disappearance of birds from small prairie relicts suggest localized extirpations.

Prairie isolation, as an influence on immigration, is important to the distributin of the greater prairie chicken in central and southwest Missouri (Fig. 2). Distances between unoccupied prairies ($\bar{x}$ = 81.1 km) are significantly (Mann Whitney U = 55, P ‹ .05) different from those between occupied relicts ($\bar{x}$ = 14.1 km). Greater prairie chicken dispersal distances are limited, ranging from 0.58 to 1.22 km for juveniles; movements in adults are generally less (Bowman and Robel 1977). In contrast to the distance of dispersal, however, we know very little about the population density, social structure, or environmental factors that influence the number of dispersing birds.

The close agreement between predictions of island biogeography and the distribution of greater prairie chickens in Missouri has the following practical messages for management: 1) increased accuracy of predicting prairie chicken survival on a relict of a certain size, an important consideration in prairie acquisition and restocking programs, 2) the need to preserve tracts of about 300 ha to minimize localized extinctions, and 3) if such dimensions are unavailable, to cluster small prairies within a distance of 20 km, considering the limited dispersal abilities of the bird.

Minimum Area

Emerging from studies involving the concept of island biogeography is an alternate approach to determine the minimum size of the habitat required to maintain a viable breeding bird population. The approach involves computing the incidence function (J), the probability that a given size

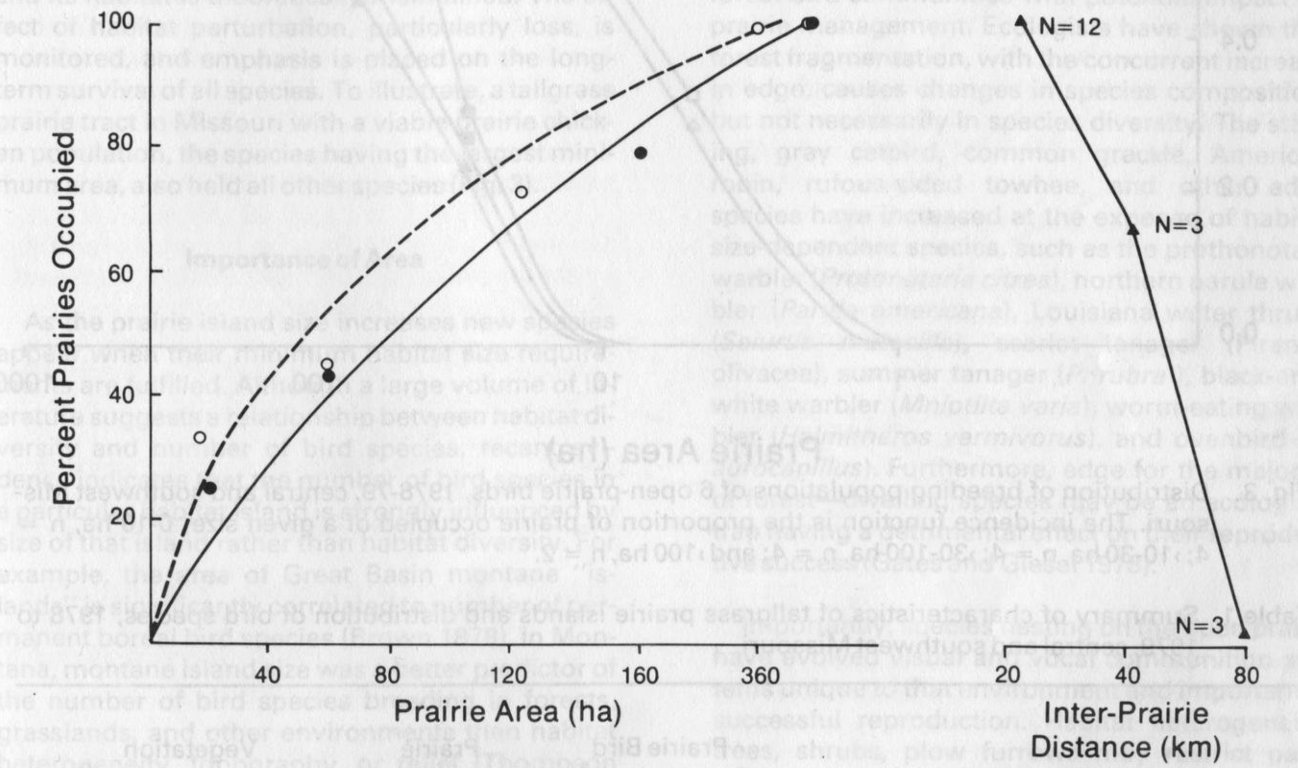


Fig. 2. The predicted (dotted line) and observed (solid line) occupancy by the greater prairie chicken of prairie islands and the percent of prairies occupied by 3 interprairie intervals, 0-25 km, n = 12; 26-50 km, n = 3; 51-100 km, n = 3; central and southwest Missouri, 1976-78.

habitat will annually hold a breeding population of a species (Diamond 1978).

In the spring and summer of 1978 and 1979, I visited 14 prairies in central and southwest Missouri and recorded the number of open prairie breeding birds (Table 1). The incidence function (J) was calculated for 6 species (Fig. 3). Minimum area (j = 0) for a population to breed ranged from less than 1 ha for the eastern meadowlark, greater than 1 ha for the horned lark and grasshopper sparrow, to greater than 10 ha for the Henslow's sparrow, upland sandpiper and greater prairie chicken. The size of prairie island regularly able to hold a breeding population (J = 1), however, ranged from greater than 1 ha for the eastern meadowlark to 160 ha for the upland sandpiper and greater prairie chicken.

Importantly, there are clear biological correlates to the habitat size-dependent concept. The nonpasserines of the open prairie (upland sandpiper and greater prairie chicken) and the eastern deciduous forest (Galli et al. 1976) require larger minimum-sized habitat islands than do the passerines. Furthermore, the former species have relatively large bodies, tend to raise a single brood, and nest on or near the ground often near the center of a habitat island. Habitat size-independent species of the open prairie and eastern forest such as the eastern meadowlark, starling (*Sturnus vulgaris*), gray catbird (*Dumetella carolinensis*), common grackle (*Quiscalus quiscula*), American robin (*Turdus migratorius*), rufous-sided towhee (*Pipilo erythrophthalmus*) differ biologically. They are permanent residents or short distance migrants, have 2 or more broods per year, select the edge, and generally have a greater chance for reproductive success (Robbins 1979).

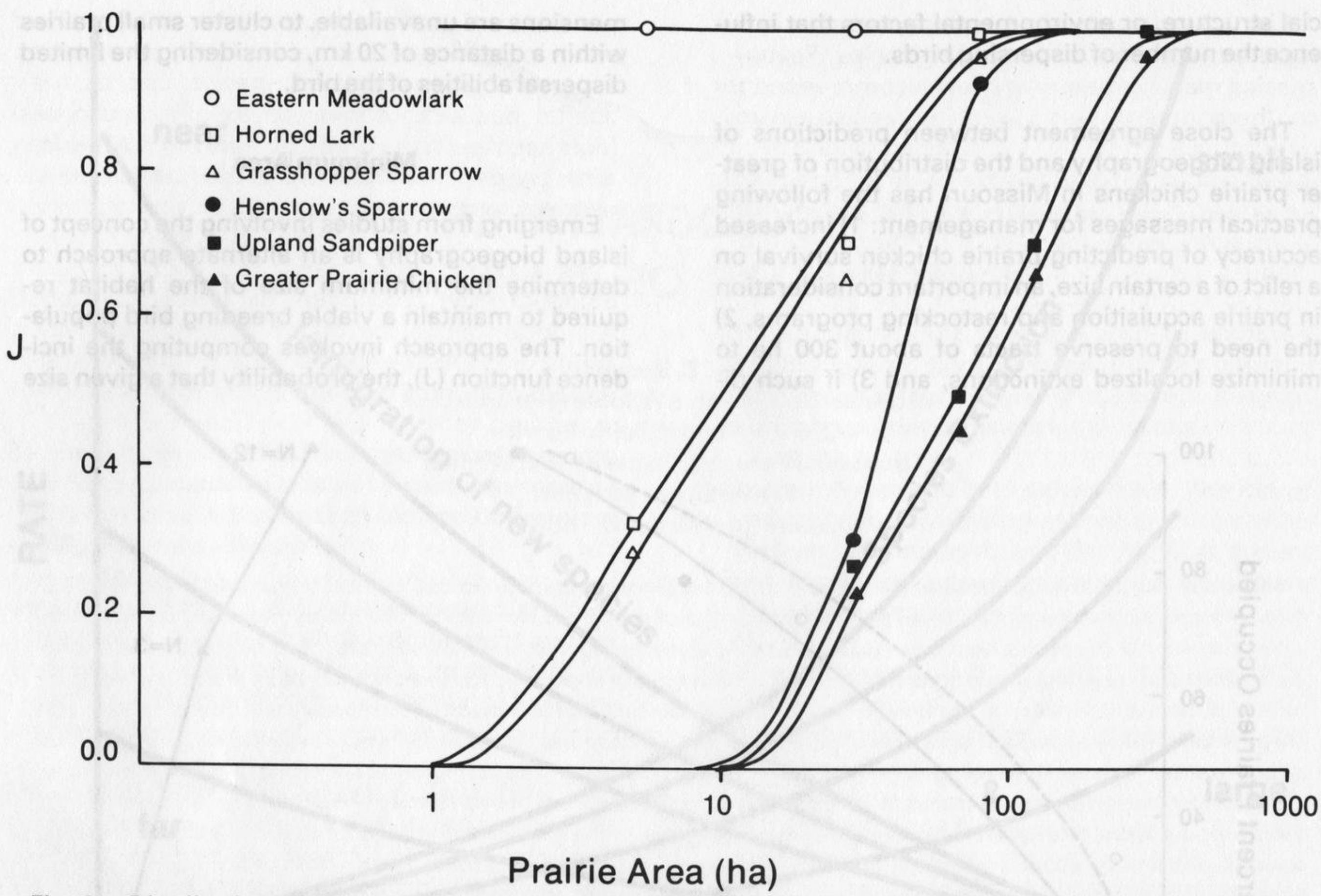


Fig. 3. Distribution of breeding populations of 6 open-prairie birds, 1978-79, central and southwest Missouri. The incidence function is the proportion of prairie occupied of a given size; 0-10 ha, n = 4; ›10-30 ha, n = 4; ›30-100 ha, n = 4; and ›100 ha, n = 2.

Table 1. Summary of characteristics of tallgrass prairie islands and distribution of bird species, 1978 to 1979, central and southwest Missouri

Prairie Island	Location	Prairie Bird Species (no.)[1/]	Prairie Area (ha)	Vegetation Heterogeneity (D)[2/]
Taberville	30°01′,93°98′	11	510.0	1.31
Golden	37°28′,94°08′	7	125.9	1.41
Monegaw	37°50′,93°18′	8	73.4	1.46
Wa-Sha-She	37°21′,94°21′	6	62.8	0.91
Little Osage	37°50′,94°20′	6	31.4	0.16
Pawhuska	37°32′,94°08′	5	30.2	0.87
Le Petite Gemme	37°46′,93°25′	5	28.0	0.42
Friendly	38°31′,93°16′	5	15.7	0.21
Mount Vernon	37°12′,93°37′	4	15.7	0.06
Lawrence	37°12′,93°39′	3	12.1	0.19
Fenced	37°50′,94°20′	3	10.0	0.31
No. 33	37°49′,94°18′	2	4.0	0.08
Railroad	37°50′,94°17′	2	1.0	0.08
HW 24	37°52′,94°19′	2	0.5	0.16

1/ Greater prairie chicken, upland sandpiper *(Bartramia longicauda)*, horned lark *(Eremophila alpestris)*, eastern meadowlark *(Sturnella magna)*, western meadowlark *(S. neglecta)*, dickcissel *(Spiza americana)*, Savannah sparrow *(Passerculus sandwichensis)*, grasshopper sparrow *(Ammodramus savannarum)*, Henslow's sparrow *(A. henslowii)*, vesper sparrow *(Pooecetes gramineus)*, and lark sparrow *(Chondestes grammacus)*.

2/ D is calculated by the formula of Roth (1976) (Samson unpub. data).

Lastly, land management often centers on either featured, sensitive or indicator species. Featured species management has been recommended for southern forest (Gould 1977). The species sensitivity approach (Webb 1977) is directed toward avoiding drastic consequences for selected songbirds. An indicator species is often used by land management agencies to monitor the effect of land use changes. To identify this species, I have suggested that the habitat size-dependent species requiring the largest minimum area in the habitat under consideration should be selected (Samson 1980). By doing so, the integrity of an entire bird community and its habitat is theoretically maintained. The effect of habitat perturbation, particularly loss, is monitored, and emphasis is placed on the long-term survival of all species. To illustrate, a tallgrass prairie tract in Missouri with a viable prairie chicken population, the species having the largest minimum area, also held all other species (Fig. 3).

Importance of Area

As the prairie island size increases new species appear when their minimum habitat size requirements are fulfilled. Although a large volume of literature suggests a relationship between habitat diversity and number of bird species, recent evidence indicates that the number of bird species in a particular habitat island is strongly influenced by size of that island rather than habitat diversity. For example, the area of Great Basin montane "islands" is significantly correlated to number of permanent boreal bird species (Brown 1978). In Montana, montane island size was a better predictor of the number of bird species breeding in forests, grasslands, and other environments than habitat heterogeneity, topography, or relief (Thompson 1978). On a local scale, island area but not internal heterogeneity of mixed oak patches of varying size in New Jersey was a significant factor in predicting number of breeding bird species (Galli et al. 1976). Avian use of Illinois lowland hardwoods (Graber and Graber 1976), Wisconsin northern hardwoods (Tilghman 1977), Seattle urban parks (Gaverski 1976), Chicago cemeteries (Lussenhopp 1977), and South Dakota shelterbelts (Martin 1978) is influenced by size of habitat island. In my study, the prairie island area ($r^2 = .97$, $P < .05$) and not habitat heterogeneity ($r^2 = .38$, $P > .10$) had a significant influence on number of breeding bird species (Table 1).

Support for the importance of size of habitat also comes form a second source, the observed localized extirpations of species. Declines of 20-92% in numbers of size-dependent warblers and vireos occurred during the last 4 decades as large eastern forests have been fragmented (Lynch and Whitcomb 1978). Formerly widely disturbed prairie species, the Henslow's sparrow, upland sandpiper, and greater prairie chicken, are now on state rare or endangered species lists as their habitat has been converted to other purposes. Most species on the Blue List reported in *American Birds* are either colonial nesters or habitat size-dependent species.

As shown in this paper, concepts in island biogeography, particularly with respect to area, are important to the distribution and long-term survival of forest and prairie birds. There is also important information emerging from studies of forest bird communities with potential impact on prairie management. Ecologists have shown that forest fragmentation, with the concurrent increase in edge, causes changes in species composition, but not necessarily in species diversity. The starling, gray catbird, common grackle, American robin, rufous-sided towhee, and other edge species have increased at the expense of habitat size-dependent species, such as the prothonotary warbler (*Protonotaria citrea*), northern parula warbler (*Parula americana*), Louisiana water thrush (*Seiurus motacilla*), scarlet tanager (Piranga olivacea), summer tanager (*P. rubra*), black-and-white warbler (*Mniotilta varia*), worm-eating warbler (*Helmitheros vermivorus*), and ovenbird (*S. aurocapillus*). Furthermore, edge for the majority of forest—dwelling species may be an ecological trap having a detrimental effect on their reproductive success (Gates and Giesel 1978).

Importantly, species nesting on the open prairie have evolved visual and vocal communition systems unique to that environment and important to successful reproduction. Habitat heterogeneity-trees, shrubs, plow furrows–may restrict pathways of visual and vocal communication, thus reducing reproductive success or causing abandonment of a prairie. Recommendations to increase habitat heterogeneity on open prairies should be viewed with caution. The prairie should be as Weaver (1968:48) stated: "almost monotonous in the general uniformity of its plant cover. Its main features are the absence of trees, the scarcity of shrubs and the dominance of grasses." It is within this environment that prairie birds evolved and upon which their future depends.

Summary

Habitat for birds is becoming increasingly isolated by agriculture or other human activities and thus more insular in character. The distribution of the greater prairie chicken on prairie islands in central and southwest Missouri is influenced by island area and isolation and is in agreement with predictions of the equilibrium model of island biogeography. The number of open prairie species breeding on prairie islands is influenced greatly by size

of habitat, and less by habitat heterogeneity. These factors should be considered in the conservation of prairie birds. The need is urgent because the process of habitat fragmentation is escalating and generally irreversible.

Acknowledgments

Financial support was provided by the Missouri Cooperative Wildlife Research Unit (U. S. Fish and Wildlife Service; Missouri Department of Conservation; School of Forestry, Fisheries and Wildlife, University of Missouri; and Wildlife Management Institute, cooperating). I thank T. S. Baskett, C. F. Rabeni, U. S. Fish and Wildlife Service; K. E. Evans, U. S. Forest Services; T. R. Finger and J. Faaborg, University of Missouri, who provided helpful criticism on the manuscript and S. S. Clark and J. K. Gerhard for typing and styling the manuscript.

Literature Cited

Bowman, T. J. and R. J. Robel. 1977. Brood break-up, dispersal, mobility and mortality of juvenile prairie chickens. J. Wildl. Manage. 41:27-34.

Brown, J. H. 1978. The theory of insular biogeography and the distribution of boreal birds and mammals. In K. T. Harper and J. L. Deveal eds., pp. 209-227, Intermountain Biogeography: A Symposium. Great Basin Naturalist Memoirs No. 2.

Christisen, D. M. 1972. Prairie preservation in Missouri. Proc. Third Midwest Prairie Conf., pp. 42-46, L. C. Hulbert, ed. Kansas State University, Manhattan.

____. 1977. Annual prairie chicken inventory. Fed. Aid Project No. W-13-R-30 (1976). 15 pp.

____. 1978. Annual prairie chicken inventory. Fed. Aid Project No. W-13-R-31 (1977). 8 pp.

____. 1979. Annual prairie chicken inventory. Fed. Aid Project No. W-13-R-32 (1978). 8 pp.

Diamond, J. M. 1975. The island dilemma: lessons of modern biogeographic studies for the design of natural reserves. Biol. Conserv. 7:129-146.

____. 1976. Island biogeography and conservation: strategy and limitations. Science 193:1027-1029.

____. 1978 Critical areas for maintaining viable populations of species. In M. W. Holdgate, ed., pp. 27-40, The Breakdown and Restoration of Ecosystems. Plenum Press, New York.

____ and R. M. May. 1976. Island biogeography and the design of natural reserves. In R. M. May, ed., pp. 163-186, Theoretical Ecology: Principles and Applications. W. B. Saunders Co., Philadelphia.

Faaborg, J. 1979. Qualitative patterns of avian extinction on neotropic land-bridge islands: lessons for conservation. J. Appl. Ecol. 16:99-107.

Fritz, R. S. 1979. Consequences of insular population structure: distribution and extinction of spruce grouse populations. Oecologia 42:57-65.

Galli, A. E., C. F. Leck and R. R. T. Forman. 1976. Avian distribution patterns in forest islands of different sizes in New Jersey. Auk 93:356-364.

Gates, J. E. and L. W. Gysel. 1978. Avian nest dispersion and fledgling success in field-forest ecotones. Ecology 59:871-883.

Gaverski, G. A. 1976. Relation of park size and vegetation to urban bird populations in Seattle, Washington. Condor 78:375-382.

Goeden, G. B. 1979. Biogeographic theory as a management tol. Environ. Conserv. 6:27-32.

Gould, N. E. 1977. Featured species planning for wildlife on southern natural forests. Trans. N. Am. Wildl. Nat. Resour. Conf. 42:435-437.

Graber, J. W. and R. R. Graber. 1976. Environmental evaluations using birds and their habitats. Biol. Notes No. 297. Illinios Nat. Hist. Surv., Urbana. 39 pp.

Hamerstrom, F. and F. Hamerstrom. 1973. The prairie chicken in Wisconsin. Dept. Natur. Resour. Tech. Bull. No. 64. 52 pp.

Johnsgard, P. A. 1973. Grouse and Quails in North America. University of Nebraska Press, Lincoln.

Lussenhop, J. 1977. Urban cemeteries as bird refuges. Condor 79:456-461.

Lynch, J. F. and R. F. Whitcomb. 1978. Effects of the insularization of the eastern deciduous forest on avifaunal diversity and turnover. In Classification, Inventory, and Analysis of Fish and Wildlife Habitat, pp. 461-489. U. S. Fish and Wildl. Ser. OBS/78/76.

MacArthur, R. H. and E. O. Wilson. 1967. The Theory of Island Biogeography. Princeton University Press, Princeton, New Jersey.

Martin, T. E. 1978. Diversity and density of shelterbelt bird communities. M.S. Thesis, South Dakota State University, Brookings.

May, R. M. 1975. Island biogeography and the design of wildlife preserves. Nature 257:177-178.

Miller, R. I. 1978. Applying island biogeographic theory to an East African reserve. Environ. Conserv. 5:191-195.

Picton, H. D. 1979. The application of insular biogeographic theory to the conservation of large mammals in the northern Rocky Mountains. Biol. Conserv. 15:73-79.

Robbins, C. S. 1979. Effect of forest fragmentation on bird populations. In R. M. DeGraaf and K. E. Evans, eds., pp. 198-212, Management of North Central and Northeastern Forests for Nongame Birds. Forest Service Tech. Rep. NC-51, U. S. Dept. Agri., Wash., D. C.

Roth, R. R. 1976. Spatial heterogeneity and bird species diversity. Ecology 57:773-782.

Samson, F. B. 1980. Island biogeography and the conservation of nongame birds. In Trans. N. Am. Wildl. Nat. Res. Conf. (in press).

Smith, A. T. 1974. The distribution and dispersal of pikas: consequences of insular population structure. Ecology 55:1112-1119.

Terborgh, J. 1974. Faunal equilibria and the design of wildlife preserves. In F. B. Golley and E. Medina eds., pp. 369-380, Tropical Ecological Systems. Springer-Verlag, New York.

Thompson, L. S. 1978. Species abundance and habitat relations of an insular montane avifauna. Condor 80:1-14.

Tilghman, N. G. 1977. Problems in sampling songbird populations in southeastern Wisconsin woodlots. M.S. Thesis, University of Wisconsin, Madison.

Weaver, J. E. 1968. Prairie Plants and Their Environment. University of Nebraska Press, Lincoln.

Webb, W. L. 1977. Songbird management in a northern hardwood forest. Trans. N. Am. Wildl. Nat. Res. Conf. 42:438-448.

Wilson, E. O. and E. O. Willis. 1975. Applied biogeography. In M. L. Cody and J. M. Diamond eds., pp. 522-534, Ecology and Evolution of Communities. Harvard University Press, Cambridge.

Whitcomb, R. F., J. F. Lynch, P. A. Opler, and C. S. Robbins. 1976. Island biogeography and conservation: strategy and limitations. Science 103:1027-1029.

Appendix 1. Names, counties, and size of Missouri prairies included in calculations

Prairie	County	Size (ha)[1/]
Taberville	St. Clair	510.0
Wah-Kon-tah	St. Clair	250.0
Mo-Ko	Cedar	165.3
Golden	Barton	125.9
Monegaw	Cedar	73.4
Niawathe	Dade	94.5
Tzi-sho	Barton	94.5
Tucker	Callaway	78.7
Wa-Sha-She	Jasper	62.8
Penn-Sylvania	Dade	63.0
Hunkah	Barton	63.0
McNary	Catlin	63.0
Little Osage	Vernon	31.5
Pawhuska	Barton	30.0
Opolis	Jasper	23.6
Mount Vernon	Lawrence	15.7
Friendly	Pettis	15.7

1/ Adjusted to exclude non-prairie habitat or include adjoining prairie.

[illegible]
vation of prairie birds. Th[illegible]
the process of habitat fragmentation is escalating

Acknowledgments

[illegible]
[illegible] conser-
vation; School of Forestry, Fisheries and Wildlife,
University of Missouri, and Wildlife Management
[illegible]
[illegible]ments,
U. S. Forest Service; T. R. Finger and J. Faaborg,
[illegible]
[illegible]
Gerhard for typing and [illegible]

Literature Cited

[illegible] 1977. Brood break-up, dispersal, mobility and mortality of juvenile prairie chickens. J. Wildl. Manage. 41:27-34.

Brown, J. H. 1978. The theory of insular biogeography and the distribution of boreal birds and mammals. In K. T. Harper and J. L. Reveal, eds., pp. 209-[illegible], Intermountain Biogeography: A Symposium. Great Basin Naturalist Memoirs No. 2.

Christisen, D. M. 1977. Prairie preservation in Missouri. Proc. Third Midwest Prairie Conf., pp. 42-46, L. C. Hulbert, ed., Kansas State University, Manhattan.

______ 1977. Annual prairie chicken inventory. Fed. Aid Project No. W-13-R-[illegible] (1976). 15 pp.

______ 1978. Annual prairie chicken inventory. Fed. Aid Project No. W-13-R-[illegible] (1977). 8 pp.

______ 1979. Annual prairie chicken inventory. Fed. Aid Project No. W-13-R-[illegible] (1978). 8 pp.

Diamond, J. M. 1975. The island dilemma: lessons of modern biogeographic studies for the design of natural reserves. Biol. Conserv. 7:129-146.

______ 1976. Island biogeography and conservation: strategy and limitations. Science 193:1027-1029.

______ 1978. Critical areas for maintaining viable populations of species. In M. W. Holdgate and [illegible] pp. 27-40, The Breakdown and Restoration of Ecosystems. Plenum Press, New York.

______ and R. M. May. 1976. Island biogeography [illegible] and Applications. W. B. Saunders Co., Philadelphia.

Faaborg, J. 1979. Qualitative patterns of avian extinction on neotropic land-bridge islands: les-[illegible]

[illegible] tion structure: [illegible] of spruce grouse populations. Oecologia 42:57-65.

[illegible] 1976. [illegible] of [illegible]

Gates, J. E. and L. W. Gysel. 1978. Avian nest dispersion and fledging success in field-forest [illegible]

Gavareski, C. A. 1976. Relation of park size and vegetation to urban bird populations in Seattle, Washington. Condor 78:375-382.

Gilbert, G. B. 1979. Biogeographic theory as a [illegible]

Gould, N. E. 1977. [illegible] for wildlife on southern natural forests. Trans. N. [illegible]

Graber, J. W. and R. R. Graber. 1976. Environmental evaluations using birds and their habitats. Biol. Notes No. 297. Illinois Nat. Hist. Surv., Urbana. 39 pp.

Hamerstrom, F. and F. Hamerstrom. 1973. The prairie chicken in Wisconsin. Dept. Natural Resources Tech. Bull. No. 64. 52 pp.

Johnsgard, P. A. 1973. Grouse and Quails of North America. University of Nebraska Press, Lincoln.

Lussenhop, J. 1977. Urban cemeteries as bird refuges. Condor 79:456-461.

Lynch, J. F. and R. F. Whitcomb. 1978. Effects of the insularization of the eastern deciduous forest on avifaunal diversity and turnover. In Classification, Inventory, and Analysis of Fish and Wildlife Habitat, pp. 461-489. U. S. Fish and Wildl. Serv. OBS-78/76.

MacArthur, R. H. and E. O. Wilson. 1967. The Theory of Island Biogeography. Princeton University Press, Princeton, New Jersey.

Martin, T. E. 1978. Diversity and density of shelterbelt bird communities. M.S. Thesis, South Dakota State University, Brookings.

PERENNIAL GRAIN CROP RESEARCH: RATIONALE AND BASIC BIOLOGICAL QUESTIONS

Wes Jackson
and
Marty Bender
The Land Institute
Route 3
Salina, Kansas 67401

Abstract. Even though crop yields are higher than ever, what is probably our worst environmental problem, soil loss, has not been decreased by the earnest efforts of the Soil Conservation Service. With the prairie (a perennial polyculture) as a standard against which we judge our agricultural practices, it appears that the solution to the soil loss problem requires a "technical fix", that is, perennial grain crops. This idea encounters 2 basic biological questions: 1) are perennialism and high seed yield mutally exclusive, and 2) can a temperate polyculture have a higher seed yield than its separate monocultures?

Introduction

The major underlying assumption of this paper is that till agriculture destroys. There are places, to be sure, where sustainable till agriculture is being practiced and other places where it has been in the past, but these appear as small pockets scattered over the globe or as anomalies in time. So sweeping and destructive has the agricultural revolution been that, geologically speaking, it surely stands as the most significant and explosive event to appear on the face of the earth, changing the earth even faster than did the origin of life. Volcanoes erupt in small areas, and mountain ranges require so long in their uplift that adjustments to changing conditions by the life forms are smooth and easy. Till agriculture has come on the global scene so rapidly that the life-support system has not had time to adjust to the changing circumstances. In this sense, then, till agriculture is a global disease, which in a few places has been well-managed, but overall has steadily eroded the land. In some areas, such as the United States, it is advancing at an alarming rate. Unless this disease is checked, the human race will wilt like any other crop.

A second assumption is that not only does agriculture destroy but it has been given every chance to prove itself as **a viable experiment for continuously sustaining a large standing crop of humans.** Its failure to do so is difficult for most of us North Americans to comprehend because since Jamestown, we have harvested more and more food. In spite of all our scientific and technological cleverness of recent decades, **not one significant breakthrough** has been advanced for a truly **sustainable** agriculture that is at once assuredly healthful and sufficiently compelling to be employed by a stable population, let along an exploding one.

A Proposal for a New Agriculture

Counter-responses. People in all sectors of agricultural production are understandably conservative or suspicious of proposed changes in the way we grow food. It is understandable for it does involve fooling with our most basic need. Therefore, when there is a call for a bio-technical fix (based on perennials), it is not surprising that some version of 1 or more of the following counter-responses is offered in turn:

1) In the entire array of soil conservation measures there are some easily copied traditional applications which require litle if any research and development.

2) The problem is a spiritual one involving stewardship. We need a stronger appeal to the old fashioned stewardship such as practiced by the Amish and Mennonite farmers.

3) Enlightened self-interest will result with more education for the farmer and he, in turn, will take the necessary measures.

4) Minimum or no-till methods will save the soils.

5) Government policy which employs both the

"carrot" and the "stick" approach will encourage sound soil conservation practices.

For centuries we have been aware of many soil conservation measures which, if appropriately applied, the soil loss problem would cease to exist. The problem is that many of these measures must be practiced at once and there are few farmers that will stay with these practices diligently either because they are pressed for time or the immediate economic situation causes them to forego some of their practices. The problem may be a spiritual one, as Wendell Berry suggests (1977), but the reality of the situation suggests that good stewardship is practiced best by a God-fearing minority who regard farming as the highest calling. Even so, at least on Mennonite farms in Kansas, soil erosion is serious. Enlightened self-interest seldom works either. There are many examples where it doesn't pay to conserve the soil. Pimentel et al. (1976) reports on Northeastern Illinois farmers whose conservation measures penalized them $39/acre per year.

For these first 3 contentions, there is a major consideration worth mentioning. It has to do with our very nature which is the result of the way we probably spent most of our evolutionary history. We usually forget or ignore that tiny percentage of our time on earth has been devoted to intensive ecosystem management - farming. It is any wonder that farming is so alien to us when scarcely 5% of our evolutionary history with the big brain, 10,000 of the last 200,000 years, has been devoted to agriculture? For the balance of this time and extending backward another couple of million years or so, we took from nature by hunting and gathering, probably gathering more than hunting. What is important is that we took without thought for the morrow. The concepts of leisure and work likely did not exist. If life in this past was like what we find in primitive tribes today, sustenance and health were managed in a work week that was scarcely half that of current industrialized societies.

When agriculture came onto the scene, when we took more control of our provision, we had to be concerned about our livelihood, not just for the day, but over the period of an entire year. As populations increased, the succesful ones were those who thought ahead, probably as much as a year or more. Recall the Biblical Joseph's recommendation for a 7-year grain storage program for the Egyptians. When we think of it, this must have involved a tremendous stretch of our paleolithic predispositions tuned more to the moment than to the year. What is even more amazing is that the problems which confront us now–and we elaborate here because the soil loss problem is among them--do not involve1-7 days or even 1-7 years but 1-7 decades and more. The difference between 1 day and 1 decade of days is a jump of 3 orders of magnitude. We should not be so surprised at our strong propensity to discount such a "distant" future. The first 3 considerations mentioned earlier all involve taking action in order to avoid problems certain to develop from 10 years to half a century down the line—when most of us are gone.

The fourth consideration, the one pertaining to minimum or no till methods and the reliance on the application of chemicals, is of crucial concern here. We are not concerned that these are fossil oil-based, for the total annual application of herbicide and insecticide amounts to less than 0.4% of our 1980 oil consumption. Furthermore, we do not hinge our argument or concern about chemicals on the fact that these methods invite changes in the weed flora and eventually a decreased effectiveness of the herbicide. We believe there is a much deeper problem which the scientific community needs to face. It is a philosophical problem and has to do with the way we perceive ourselves in relation to the environment.

Western civilization carries a religious legacy, for however unwitting, and however secularized, it has religious roots. This is the notion that the environment is "out there". Part of that legacy at least is rooted in the Genesis myth of the Creation in which all life forms were created almost at once, **except humans.** After this creation, God paused and then invented us. It is a 2-stage creation myth. What molecular biology has given us, on the other hand, is the powerful evidence that we are of one creation, for all of us—redwood, whale, sunflower, osprey, human—consist of the same 20 amino acids. All life forms, furthermore, with a few unimportant exceptions, consist of the same four nucleic acid bases.

The implication of these relatively recent findings is that a willful pollution of the environment is potentially a willful pollution of ourselves. It is not chemistry which should scare us, for nature provides an amazing array of chemical protectors for this organism and that. The first question is whether we are introducing a chemical into the environment with which our cells have had no evolutionary experience. Secondly, if we are introducing a chemical that has been around for over eons, is it being introduced at a level beyond the evolutionary experience of our cells? This is not to say that every chemical with which our cells have had no evolutionary experience is automatically a danger. Some human-devised chemicals may be structurally close enough that our cells can deal with them. We should remember also there are some ancient chemicals around which are lethal or damaging. They are either so toxic our cells haven't had a chance to deal with them or they are such infrequent confronters they haven't been worth fooling with in terms of our genetic response.

Once all the exceptions have been acknowledged, we at last conclude that ours is a philosophical stance that we have assumed to be necessarily prudent before we allow nature's life forms to become guinea pigs more than ever. It isn't just nature "out there" that would be the guinea pig in this empirical experiment, it is we ourselves as part of nature.

Finally, "carrot" and "stick" approaches have long been a part of government policy through such vehicles as the various cost-sharing programs for farmers who participate in some SCS or ASCS program. They may have contributed to a slowing of soil loss, but soil still runs to the sea.

Rationale for change. We are promoting research into high-yielding perennial grain crops which grow in mixtures, and on the eventual curtailing of annual monoculture because:

1) Stewardship has failed except in a few places in the world.

2) Enlightened self-interest appeal assumes the economic system is sensitive to long-term consideration when in fact it is not. Part of the personality of inflation and high interest rates is that more and more of the future is discounted.

3) The array of soil conservation measures may be large, but the extra thought and effort necessary to make them effective has not been, and probably won't be, very compelling.

4) No-or minimum-tillage, besides having other serious flaws, is chemically-dependent and highly suspect.

5) A reward and punishment system imposed on farmers sufficiently powerful to take up the slack of an economic system almost totally insensitive to ecological necessity is probably unworkable.

Perhaps most of the failures in agriculture involve the failure of humans to force themselves into alien activity. When we were gatherers and hunters what one might call appropriate management of ourselves must have been unnecessary—it naturally flowed. The successful development of herbaceous perennial seed-producing polycultures allows for re-establishment of a vegetative structure similar to the vegetative structure which existed before an area was first tilled and is therefore a good beginning for rehealing the long discussed split between humans and nature.

Even when we do think deeply about the problems, we are inclined to accept the eventual decline of agriculture as being in the nature of what the noted philosopher, Alfred North Whitehead, called the essence of dramatic tragedy—inevitable (quoted by Garrett Hardin, p. 118, 1968).

In *The Unsettling of America,* Wendell Berry (1977) raises our sights on the agriculturl problem by dealing with most of the problems in agriculture. Berry sees that the problem basically comes from a failure of the human spirit. There is a religious dimension to the agricultural problem which needs to be addressed and there is a profound need for all of us to examine the advisibility of regardng the farm as a food factory rather than as a hearth. After an examination of the many areas in which humans have failed over the centuries to adequately deal with the agricultural problem, we think agriculture needs this bio-technical fix described here. We are not entirely comfortable with such a proposal, not because we don't believe in its premise, but because of what technical fixes promote even if they are of a "bio" variety. They feed the modern day zealot who sees all of our problems to be materially or technically soluble. Such an attitude prevents us from facing the deeper moral and spiritual problems Berry so eloquently considers. Nevertheless, it is the biotechnical fix we will discuss here for Berry's important topic is outside our scope.

Major Considerations of the Argument

The argument presented here involves 3 basic considerations. First, we believe there is a need for a future agriculture based on herbaceous perennial polycultures where the desired product is grain or seed. Second, these perennial mixtures of the future would likely be derived from plants now regarded as possessing little promise for meeting human needs or demands. Lastly, because of advances in biology over the last half-century, we believe the scientific-technological community has the know-how to develop a truly sustainable agriculture.

The need for herbaceous perennial seed-producing polycultures. We believe such a bio-technical fix would make it easier for humans to solve many problems in agriculture at once. But in a less speculative view there are 2 major reasons why there is a need for such an agriculture. First of all, we need to think very hard about meeting the **needs of the land,** if unborn generations are to inherit a chance to live healthful and productive lives. Right now, our agricultural lands are experiencing severe soil loss nation-wide. The Soil Conservation Service recently set the average of 5 tons of lost soil per each year, but the General Accounting Office study (1977) indicated we were losing around 15 tons per acre each year. An engineering approach to soil conservation has failed to adequately prevent soil loss. The biological approaches of stripcropping and rotation have not been sufficiently compelling for widespread application and even where tried have been poor substitutes for nature's incomparably more effective means of soil retention.

The second major reason why we need such an agriculture is energy-related. Our current high production is managed by excessively high increases in fossil fuels, particularly the portable liquid fuels. The energy crisis is most acute due to the scarcity of the portable liquid segment of global fossil fuel reserves. It may be that it is within the area of agriculture that our current energy path is most "hard." A "soft" agriculture path is at least as necessary as a "soft energy path." If we are to feed people in an oil-less future at anywhere near our current level of grain consumption, an agriculture many times more energy efficient than our present one will be necessary. Such an agriculture offers promise in huge fossil fuel savings for it would rely more on dispersed solar energy to do jobs managed by an array of life forms at low thermal levels, jobs the agriculturist pays to have done by fossil fuel units at high thermal levels.

In the long run, soil and water are more important than oil. We currently have a cushion or a time period of perhaps 50 years to make the transition from oil back to soil and an agriculture which includes a sound water management policy.

New crops from wild species. The second major contention that these perennial mixtures of the future will likely be derived from plants now regarded as possessing little promise for meeting human needs or demands, needs some elaboration. Essentially all of our high-yielding grain crops are annuals and where they are not, as in the case of the sorghums, they are treated as such. There has been extensive research to develop perennial wheats and yet not a single strain has been sufficiently compelling to be successful on the market. The introduction of perennial germ plasm into crops in which the annual condition is well-fixed will likely be disappointing simply because thousands of plants generations have passed in which we humans worked on the annual theme.

It is not just the annual condition for which the genes of our major crops are tuned; they are also tuned, particularly in the temperate regions, to exist as a part of a monoculture. Even under conditions which are technically referred to as following under the umbrella of polyculture, many of these plants are in rows or strips not mixed or dispersed as are the wild and "useless" plants in nature's array.

It seems to make more sense, therefore, for us to begin with plants whose genetic ensembles have been tuned to getting along with other species in a living community but which at the same time show promise for meeting some of the human-defined needs. It seems more sensible to start with the complexity which nature presents to us and keep track of what we lose in our selection program than to impose a wide array of unknowns on high-yielding crop species which have long since lost the systems necessary, not just to survive, but to contribute to a polyculture.

Agricultural science and technology can do it. Finally we come to our third pre-supposition which holds that the scientific-technological community possesses the know-how to make this agricultural revolution possible. Since the work of Gregor Mendel was rediscovered in the first year of this century, an enormous amount of scientific knowledge and technical skill has developed, much of which has already been applied to yield increases in agriculture. But there is an even greater wealth of knowledge and skill which has accumulated as scientists sought to relate Darwin's theory of evolution to Mendel's elements of heredity. Dozens of investigators put their imaginations and equipment to the task of proving or disproving the chromosome theory of heredity. Later, classical taxonomists used these new tools and the new knowledge to modernize their thinking about relationships between plant and animal groups and routinely make numerous side crosses. Chromosomes were counted, artificially doubled and redoubled again. Chromosomes were introduced and taken away. The chromosomal gymnastics which preceded sex cell formation were observed and recorded. Most of this basic research was not used for the improvement of major crops. Most crop improvement came with the invention of and explosion within the field of statistics through the efforts of R. A. Fisher and his disciples. Here the emphasis was on analysis and the fine-tuning of the plants and animals which were already proven. Nevertheless, there is a reservoir of knowledge, much of it largely forgotten since the era of biochemical genetics introduced in the 1940's. And though much of this knowledge and technology has cooled and been forgotten, it is in the literature and available for resurrection.

Our Hopes for Such an Agriculture

The proposal for such a dramatic agricultural change invites examination of how realistic are the proponents' hopes and claims. Though based on knowledge and numbers, we believe to be realistic, our vision is utopian, or perhaps more precisely, ecotopian. There are 9 considerations or categories:

1) We expect perennial agriculture to gradually accumulate soil soon after the new loss has been cut to zero. The fossil energy saving for fertilizer to replace this lost soil is significant.

2) The direct consumption of fossil energy at the field level would be cut to zero and biofuels amounting to some 30% of the current on-farm liquid fuel use would power the farm machinery.

3) The indirect consumption of fossil energy would be substantially reduced. For example, the application of commercial fertilizer would be a small fraction of the current level of consumption.

4) Human-made pest control chemicals, especially those with no close chemical relatives in nature would be absent or nearly so. Besides the reduction in chemical contamination, this is a minor fossil energy saving.

5) The efficiency of water utilization and water conservation by the perennial ecosystem would be near maximum and springs, long since dry or short-lived during the year, would return. Where there is irrigation, this would reduce fossil energy use, both indirectly and on farm.

6) Long before such an agriculture is completely in place, because of efficiency in water usage, major policy questions surrounding irrigation projects which promote aquifer mining or water diversions which lead to soil salting and silting problems become more manageable.

7) Policy considerations which include equitable landownership rather than major corporate control of land become more manageable because of the reduced need for high capitalization on machinery, energy, farm chemicals, irrigation and seed.

8) Over 100 million acres, currently set aside as marginal land, largely because of serious erosion potential under current cropping systems could be brought into production reducing the pressure or need for excessively high yields and, just as importantly, reduces the pressure on ever-increasing land prices. This increases the opportunity for more people to have a farm as a hearth, reducing the trend of the hearth giving way to the food factory.

9) The time spent in the fields over the course of a year would about equal the time spent in the food procurement process of "primitive" tribes today — 20 hours or less per person.

Literature Cited

Berry, Wendell. 1977. The Unsettling of America. Avon Books, New York.

General Accounting Office. 1977. "To protect tomorrow's food supply, soil conservation needs priority attention." CED-77-30. Washington, D. C.

Hardin, Garrett. 1968. Exploring New Ethics for Survival. Viking Press, New York.

Pimentel, David, E. C. Terhune, R. Dyaon-Hudson, S. Rochereau, R. Samis, E. A. Smith, D. Denmen, D. Reifschneider and M. Shepard. 1976. Land degradation: effects on food and energy resources. Science 194:149-155.

[illegible] Soil Conservation [illegible] of 5 [illegible] Accounting Office [illegible] were losing around [illegible] engineering approach to soil conservation has failed [illegible] not [illegible] application [illegible] sub- [illegible] effective [illegible] an [illegible] pro- [illegible] in fossil fuels, particularly the portable [illegible] fuels. The energy crisis is most acute due to the scarcity [illegible] most "hea[illegible] necessary as a "soft energy path." If we are to feed people in an oil-less future at anywhere near our current level of grain consumption, an agriculture many times more energy efficient than our present one will be necessary. Such an agriculture offers [illegible] make on dispersed solar energy to do [illegible] managed by an array of life forms at low thermal levels, jobs [illegible] fossil fuel [illegible] thermal levels.

In the long run, soil and water are more important than oil. We currently have a cushion or a time period of perhaps 50 years to make the transition [illegible] cludes a sound [illegible] human needs or [illegible] tion. Essentially all of our high-yielding grain crops are annuals and where they are not, as in the case of the sorghums, they are treated as such. There has been extensive research to develop perennial wheats and yet not a single strain has been sufficiently compelling to be successful on the market. The introduction of perennial germ plasm into crops in which the annual condition is well-fixed will likely be disappointing simply because thousands of plants generations have passed in which we humans worked on the annual theme.

It is not just the annual condition for which the genes of our major crops are tuned; they are also tuned, particularly in the temperate regions, to [illegible] array.

[illegible] same time show promise for meeting some of the [illegible] on high-yielding crop species [illegible] long since lost the systems necessary, not just to survive [illegible] which holds that the scientific-technological community possesses the know-how to make this agricultural [illegible] in agriculture. But there is an even greater wealth [illegible] taxonomists used these [illegible] new knowledge to modernize their thinking about relation[illegible] and recorded. Most of [illegible] not used for the improvement of major crops. Most crop improvement came with the invention of and explosion within the field of statistics through the efforts of R. A. Fisher and his disciples. Here the emphasis was on analysis and the fine-tuning of the plants and animals which were already proven. Nevertheless, there is a reservoir of knowledge, much of it largely forgotten since the era of biochemical genetics introduced in the 1940's. And though much of this knowledge and technology has cooled and been forgotten, it is in the literature and available for resurrection.

Our Hopes for Such an Agriculture

The proposal for such a dramatic agricultural

PERENNIAL GRAIN CROP RESEARCH

Marty Bender
Research Associate
The Land Institute
Route 3
Salina, Kansas 67401

Abstract. An herbary has been initiated at the Land Institute to develop an inventory of herbaceous plants as candidates for perennial grain crop research. The physical set-up and present inventory are described. Other present uses, as well as future plans, with respect to our perennial grain crop research and educational programs are discussed. In order to assess the feasibility of developing perennial crops, a review of herbaceous perennial seed yields is presented. Data from the literature are organized into several categories, each containing the top seed yielders. A table is also available which compares seed protein yields of some herbaceous perennials versus those of our major annual crops. Suggestions are made for standard listing of seed yield data and for further research in seed yields of perennials.

Introduction

The Land Institute is establishing an herbary containing native and non-native herbaceous perennials of the prairie and the plains. Observation of each perennial, supplemented with notes from scientific literature, enables us to choose candidates for various experiments in our perennial grain crop. But we can undertake research that we hope will convince land grant colleges and private institutions, which have the necessary staff, equipment, knowledge, and money, that it is worthwhile to pursue untried methods for breeding perennial grain crops. Since the Land Institute is an environmental resource center for students and the community, the herbary will be used for many educational purposes. It will also serve as a germplasm nursery from which we can expand seed supplies when desired.

Current Progress and Future Developments

Located on Niles silty clay loam, which is an Ustoll soil, the herbary presently covers one-third of an acre. In the spring of 1979, the seeds of 42 species obtained from the Soil Conservation Service Plant Materials Center in Manhattan, Kasas (PMK), were planted in separate rows 5-m long. With an annual rainfall of 26.5 inches and occasional irrigation, 37 species were established. In the spring of 1980, 200 rows were planted with seeds obtained from PMK and from field collections in Kansas, Oklahoma, Nebraska, Texas, New Mexico, Missouri, Ohio, and Mexico. One-hundred and five (105) rows became established for a total of 142 rows from both planting years. Seedlings of 20 additional species were donated by Bill and Jan Whitney of the Prairie/Plains Resource Institute in Aurora, Nebraska. We appreciate donations of seeds, since field collections in unfamiliar locations depend more often than not on an eagle eye from the driver's seat.

For our perennial grain crop research, herbary allows us to record observations on the growth habits, the water requirements, the times of flowering and the seed maturity, seed shattering, etc. By collecting the seeds from the 5-m rows, relative yeilds can be determined. Extrapolation on a per-acre basis for absolute seed yields is made by assuming a stand of rows spaced 30 inches apart.

Will it be possible for the scientists of this century to breed high-yielding perennial grain crops? This question addresses the superfluous premise that perennialism and high yield are mutually exclusive. The validity of this concept depends partly upon what constitutes high seed yield. So we sought the experience of highly respected plant geneticists who have worked on the problem and have thought about it. Some of them felt it would not be possible to breed high-yielding perennials; whereas, some said it might be possible. With this bit of encouragement, we decided that a review of the scientific literature on herbaceous perennial seed yields was needed to assess the principle that perennialism and high seed yield are mutually exclusive.

From 32 references, the data from selected sources have been organized as the top seed yielders: 1) irrigated grass yields, 2) dryland grass yields, and 3) yields of several Compositae and species of legumes (Table 1, 2). Field conditions are also reported. Unless specified for a given year, yields represent the upper limit recorded over many years. It assumed that all species were cultivated in rows.

To assess the principle that perennialism and high seed yield are mutually exclusive, we define a high seed yield as 30 bushels (1800 pounds) per acre, a good yield for a wheat crop, and an average yield for corn in the 1930's before the advent of fertilizers, pesticides, and hybrids. As the tables are presented, keep in mind that we are concerned with total seed yield, whether edible or not. First, high seed-yielding perennials should be developed to show that such is possible, with subsequent research and development on edible use. Quite a number of grasses and forbs have seed yields of 1,000 lbs/acre, or more, this prior to selection or breeding for high production.

Table 1. Seed yield of selected grasses grown under irrigated and dryland conditions

Scientific Name	Yield - lbs/acre Irrigated	Dryland	Reference[1/]
Buchloe dactyloides	1,727[2/]	____	Ahring 1964
Festuca arundinacea	1,460	400	a USDA 1964 b Cooper 1957
Dactylis glomerata	1,100	____	Whyte 1959
Eragrostis curvula	1,100	____	Wenger et al. 1943
Sporobolus cryptandrus	1,000	900	a USDA 1948 b Brown 1943
Elymus canadensis	1,000	____	Cooper 1957
Agropyron cristatum	996	____	Wheeler 1957
Bromus inermis	942	500	a Wheeler 1957 b Cooper 1957
Lolium perenne	930	____	Wheeler 1957
Agropyron trachycaulum	930	400	a Klages and Stack 1948 b Thornberg 1971
Agropyron trichophorum	____	500	Thornberg 1971
Agropyron intermedium	____	450	Cooper 1957
Stipa viridula	____	400	Cooper 1957
Agropyron elongatum	____	400	Thornbert 1971
Agropyron spicatum	____	400	Thornberg 1971
Elymus junceus	____	300	Cooper 1957

1/ a,b, reference for irrigated and dryland yields, respectively.
2/ Includes dry weight of 'bur'.

Table 2. Seed yield of selected legumes and composites grown under irrigation

Species	Yield - lbs/acre	References
Leguminosae		
Desmanthus illinoensis	1,189	USDA-SCS Knox City 1978
Astragalus cicer	1,000	USDA-SCS Bridger 1966
Onobrychis viciaefolia	1,000	Thornberg 1971
Medicago sativa	500	Thornberg 1971
Compositae		
Ratibida pinnata	1,600	Ahring 1979
Helianthus maximilliani	1,300	The Land Institute 1979
Liatris aspera	550	USDA-SCS Manhattan 1978

Table 3. Comparison of calculated protein equivalents of selected annual crop plants and perennial grasses and legumes

Species	Percent Protein	Seed Production (lbs/acre)	Total Protein (lbs/acre)
Annual crops			
Corn	9	5,680 (100.8 bu)	511
Wheat	12	1,896 (31.6 bu)	228
Soybeans	42	1,770 (29.5 bu)	743
Perennial species 1/			
Elymus canadensis	27	1,000	270
Festuca arundinacea	22	1,460	321
Astragalus cicer	40	1,000	440
Desmanthus illinoensis	34	1,189	404

1/ Based on irrigated yields (Table 1).

As evidenced from the meager amount of data for field conditions there is a need in the scientific literature for a standard listing of data on seed yields, so that the relative significance of seed yields can be judged. With each production value there should be listed the amount of rainfall and irrigation, the soil condition, the size of the plot, the amount and kind of fertilizers and pesticides applied, the purity of the harvested seed, and whether the plants were in rows or solid stands.

Table 3 compares percent protein and total yield per acre for corn, wheat, and soybeans with data for several perennials. Calculated values for the latter group are based on irrigated dry-matter production.

More data on seed yield of perennials are needed as there may be native species of high potential that are as yet unknown. The seed yields of only a small number of perennial forbs have been collected. Almost all the grass-seed yields are from species that are used for forage and hay. Such grasses allocate much of their energy to the leaves and stems rather than to the seed. Perhaps there are perennial grasses that are poor forage but good seed producers that have not been studied.

In summary, our herbary will not only be used for research, but will also provide a laboratory for public school teachers and students to learn the plants. We also conduct tours of the herbary and present information on the role of plants in developing the ecological capital, the soil, on which American agriculture rests, as a source of future germplasm for a perennial agriculture, and as entities which exist for their own sake, independent of the needs of *Homo sapiens.*

The desire to set aside prairie areas has been motivated by the appreciation of the prairie's natural beauty. At The Land Institute we are also motivated by the important practical value of prairie plants. We see the prairie as a standard against which to judge our agricultural practices, and we seek to understand what elements in the prairie can be adapted to create a sustainable agriculture.

Literature Cited

Ahring, R. M. 1964. The management of buffalograss for seed production in Oklahoma. Agri. Expt. Sta. Tech. Bull. T-109. Oklahoma State University, Stillwater.

Brown, H. Ray 1943. Growth and seed yields of native prairie plants in various habitats of the mixed prairie. Trans. Kansas Acad. Sci. 46:87-99.

Cooper, H. W. 1957. Producing and harvesting grass seed in the Great Plains. Farmers Bull. 2112. U. S. Dept. Agri., Wash, D. C.

Earle, F. R. and Quentin Jones 1962. Analyses of seed samples from 113 plant families. Econ. Bot. 16:221-250.

Jones, Quentin and F. R. Earle. 1966. Chemical analyses of seeds II: oil and protein content of 759 species. Econ. Bot. 20:127-155.

Klages, K. W. H. and R. H. Stark. 1949. Grasses and grass seed production. Agri. Expt. Sta. Bull. 273. University of Idaho, Moscow.

Land Institute, The. 1979. Unpubl. records.

Thornberg, Ashley. 1971. Grass and legume seed production in Montana. Agri. Expt. Sta. Bull. 333. Montana State University, Bozeman.

U.S.D.A. 1948. Grasses Yearbook of Agriculture. U. S. Dept. Agri., Wash., D.C.

——. 1966. Tech. Note 12/1/66. Plant Materials Center, Soil Conservation Service, Bridger, Montana.

——. 1976. Tech. Rept. 1975-6. Plant Materials Center, Soil Conservation Service, Coffeeville, Mississippi.

——. 1978. Annual Report. Plant Materials Center, Soil Conservation Service, Knox City, Tennessee.

——. 1978. Tech. Rept. 1978. Plant Materials Center, Soil Conservation Service, Manhattan, Kansas.

——. 1980. Agricultural Outlook. June, 1980. Economics, Statistics, and Cooperative Service, Wash., D.C.

Wenger, L. E., D. R. Cornelius, J. E. Smith, and A. D. Stoesz. 1943. Methods of harvesting, storing, and processing native grass seeds. Subcommittee Service, U. S. Dept. Agri., Wash., D. C.

Wheeler, Wm. 1957. Grassland Seeds. D. Van Nostrand Co., New York.

Whyte, R. O. 1959. Grasses in Agriculture. FAO, Rome.

PERENNIAL GRAIN CROP RESEARCH: EXPERIMENTAL DESIGN

Marty Bender
Research Associate
and
Wes Jackson
Co-director
The Land Institute
Route 3
Salina, Kansas

Abstract. The experimental designs for perennial grain crop research at the Land Institute fall into 2 categories, monoculture and polyculture. In the monoculture approach, research is or will be conducted on *Tripsacum dactyloides, Zea Diploperennis,* and the response of perennials versus annuals to selection for seed yields. In the polyculture approach, research is being conducted in prairie studies, which are bicultures of grass, and in forb tests, which study the effect of forbs on bicultures of grasses.

Introduction

The Land Institute is conducting experiments in 5 areas of perennial grain crop research:

I. Yield Increase in Eastern Gamagrass
II. Biology and Life History of *Zea diploperennis*
III. Response-to-Selection Experiments
IV Paired Studies
V. Forb Tests.

The first 3 are monoculture designs, while the last 2 are polyculture designs.

I. Yield Increase in Eastern Gamagrass

We want to increase the seed yield of this high protein grain from 1 bushel per acre upward to some unknown limit. We chose this perennial grass rather than one of the high-yielding grasses for the following reasons: 1) since it is a close relative of corn, it has already been extensively studied, 2) its present distribution in the United States is about the same as that of corn, which we hope to replace on the uplands to reduce soil erosion, 3) the female flowers are localized and separate from the male flowers, making it easy for the breeder to emasculate the plant before making crosses, 4) the grain has a protein content of 27% and is high in methionine, which makes it a good complement with legumes, 5) the species has natural immunity against grasshoppers, corn ear worm, and the European corn borer, and 6) having nearly 400 accessions of eastern gamagrass from across the United States from the USDA Southern Great Plains Field Experiment Station in Woodward, Oklahoma through the generous efforts of Range Agronomist Chet Dewald, we can begin to increase the seed yield through breeding efforts to overcome lodging, shattering and indeterminate seed set. About 70 of these accessions were previously examined cytologically and their chromosome numbers determined.

Before we can launch such a yield-increase breeding program several years from now, we need to gather baseline information on the degree of fertility for various crosses with the 2 chromosome race: the diploid with 36 chromosomes and the tetraploid with 72 chromosomes. We need to know the degree of fertility for self-pollinated plants, for plant crosses from the same locality, and for plants from different localities but of the same chromosome numbers.

II. Biology and Life History of *Zea diploperennis*

There is much that we need to know about this potentially important species including the limits of its range and habitat preferences. We would like to build up our seed supply and ask different people and organizations to grow it at latitudes and in climates were the winters are less severe and perhaps gradually pick up the genes for cold resistance. The plants we left outside last winter died, as expected. If we can sychronize flowering with our annual open-pollinated corn which has the same chromosome number, perhaps we can make several crosses. We might even half-heartedly try some crosses between it and its relative eastern gamagrass.

This spring we have established 240 individuals in the garden. Twenty are from seed collected from a 1450-m elevation, 140 from 2000-m, and 50 from a 2400-m elevation. Many of these latter individuals were placed in 5-gallon plastic buckets with holes in them so they can readily be transported to the greenhouse to be protected through winter. From the seeds which Marty Bender collected in Mexico from naturally-occurring hybrids between *Zea diploperennis* and corn, 15 plants have been established. Fifteen plants of this perennial have also been established from crosses Wes Jackson made in the Kansas Wesleyan Greenhouse last winter.

III. Response-to-Selection Experiments

Of the 5 areas in which we are conducting research, this may be the most important in the long run, for it deals with a basic question central to our effort. Can herbaceous perennial grains equal the yield of herbaceous annuals? If our paradigm is "sustainability" first and "yield" second, we should not care in the absolute sense whether the perennial matches the annual. Perhaps the perennial can equal the annual in a given year but can it continue to compare with annuals year in and year out? After all, perennials do have a history of doing pretty well in the second and third year before production heads downward. In thinking about the balance between "sustainability" and "yield", it is a question of emphasis. The conventional plant breeder does not totally dismiss "sustainability", just as the "New Age" plant breeder cannot dismiss "yield".

We will compare the response of a perennial to an annual of the same genus in order to determine which responds the most dramatically to selection for high seed yield over several years. Both now and in the future, plants will be spaced at 1-foot intervals. In the fall, seeds will be collected from each plant and weighed. Seeds of the top performers will in turn be planted out in succeeding years.

To achieve the most meaningful information, the perennial and the annual should be of the same breed mode, i.e., both species should be self-pollinating or both be obligate out-crossers. With this restriction only the following comparisons have been found:

Selfing Perennial	Selfing Annual
Lespedeza cuneata	*Lespedeza striata, L. stipulacea*
Trifolium fragiferum	*Trifolium agrarium, T. dubium, T. procumbens, T. resupinatum, T. striatum*

Outcrossing Perennial	Outcrossing Annual
Pennisetum purpureum	*Pennisetum glaucum*

We were very fortunate to obtain seeds for some of the above legumes through Jack Walstrom, a local SCS plant materials specialist. Unfortunately, germination was poor as most of the seeds were about 15 years old, but we presently have plants for the 2 comparisons in the genus *Lespedeza.*

IV. Paired Studies

It may be difficult to grow a perennial grain crop in monoculture because the same crop would be in the field year after year, making it susceptible to disease and insects, and causing the roots to compete with each other at the same level. By growing a variety of perennial species together in polyculture, the diversity would eliminate these problems. We need to find combinations of perennial species which would give greater seed yield in polyculture than in separate monoculture. Consultation with 2 agricultural statisticians at the University of Nebraska in Lincoln resulted in a simple polyculture design called a paired study. In this approach, 2 perennial grasses are grown separately and in bicultures with 3 ratios. For example, in a paired study involving switchgrass and Indiangrass, there are 4 replications, each replication including separate plots of switchgrass and Indian grass, and combination plots of these species using 50-50, 75-25 and 25-75 ratios. Plot size was 4x20 feet. We chose 3 ratios for the polycultures rather than just the 50-50 ratio to see what effect multiple ratios would have on seed yield. For each replication, the seed yield of the monocultures can be proportionally compared with the seed yield of each of the 3 polycultures.

Depending on the results from many bicultures, research may proceed to studies of tricultures of perennial grasses or even larger groups. When compatible combinations of grasses are found, then research can be done to increase the seed yield of each compatible grass. Five paired studies were initiated this spring: 1) switchgrass and Indian grass, 2) switchgrass and sand lovegrass, 3) Indian grass and sand lovegrass, 4) switchgrass and sand dropseed, and 5) buffalograss and blue grama.

V. Forb Tests

Some of the perennials in a polyculture of perennial grain crops will be forbs, such as legumes. It is well known that legumes fix nitrogen on the prairie, but what is the role of other species? There are numerous families represented on the prairie including mints, composites, milkweeds, borages, etc. Do they contribute to the overall stability of the biotic community or are they just "there"? From the human's point of view we are interested in total production of seed but the prairie did not evolve, necessarily, to meet human purpose. But if we start with prairie plants which have their own emphasis, and shift their purposes to meet human goals, we need to know whether the presence of various forbs can contribute to seed production. Consequently, we have designed several forb tests. In a forb test involving switchgrass, Indian grass, and grayheaded coneflower, there are 4 replications, each containing a plot of switchgrass and Indian grass in a 50-50 ratio, a plot of gray-headed coneflower, and a plot of switchgrass, Indian grass, and gray-headed coneflower in a 37.5-37.5-25 ratio. Switchgrass and Indian grass remain in a 50-50 ratio and make up 37.5 + 37.5 = 75% of the plot while gray-headed coneflower makes up the remaining 25% of the plot. Not only will forb tests determine what forbs are compatible with grasses for seed production, but after many tests, it may be possible to make generalizations about the effect of various plant families on seed and biomass production of such polycultures. Five forb tests were planted this spring. In four, switchgrass and Indian grass together are used in turn with gray-headed coneflower, Maximilian's sunflower, Illinois bundleflower and purple prairie clover. The fifth test combines buffalo grass, blue grama, and purple prairie clover.

These experiments are just a small beginning, so all of us must try to convince the Land Grant colleges, which have the knowledgeable researchers, equipment, and funding, that perennial grain crops are worth developing.

[illegible]

This spring we have established 240 individuals in the garden. Twenty are from seed collected from a 1450-m elevation, [illegible] from 2000 m and 50 from a 2200-m elevation. [illegible] from seed which Marty Bender collected in Mexico from naturally-occurring hybrids between *Zea diploperennis* and corn, 15 plants have been established. Fifteen plants of this perennial have also been established from crosses Wes Jackson made in the Wesleyan greenhouse last winter.

III. Response-to-Selection Experiments

Of the 5 areas in which we are conducting research, this may be the most important in the long run, for it deals with a basic question central to our effort. Can herbaceous perennial grains equal the yield of herbaceous annuals? If our paradigm is "sustainability" first and "yield" second, we should not care in the absolute sense whether the perennial matches the annual. Perhaps the perennial can equal the annual in a given year but can it continue to compete with annuals year in and year out? After all, perennials do have a history of doing pretty well in the second and third year before production heads downward. In thinking about the balance between "sustainability" and "yield", it is a question of emphasis. The conventional plant breeder does not totally dismiss "sustainability", just as the "New Age" plant breeder cannot dismiss "yield".

We will compare the response of a perennial to an annual of the same genus in order to determine which responds the most dramatically to selection for high seed yield over several years. Both now and in the future, plants will be spaced at 1-foot intervals. In the fall, seeds will be collected from each plant and weighed. Seeds of the top performers will in turn be planted out in succeeding years.

To achieve the most meaningful information, the perennial and the annual should be of the same breed mode, i.e., both species should be self-pollinating or both be obligate out-crossers. With this restriction only the following comparisons have been found:

Outcrossing Perennial	Outcrossing Annual
Pennisetum purpureum	*Pennisetum glaucum*

[illegible]

IV. Paired Studies

[illegible] disease and insects, and causing the roots to compete with each other at the same level. By growing a variety of perennial species together in polyculture, the diversity would eliminate these problems. We need to find combinations of perennial species which would give greater seed yield in polyculture than in separate monoculture. Consultation with 2 agricultural statisticians at the University of Nebraska in Lincoln resulted in a simple polyculture design called a paired study. In this approach, 2 perennial grasses are grown separately and in bicultures with 3 ratios. For example, in a paired study involving switchgrass and Indiangrass, there are 4 replications, each replication including separate plots of switchgrass and Indian grass, and combination plots of these species using 50-50, 75-25 and 25-75 ratios. Plot size was 4x20 feet. We chose 3 ratios for the polycultures rather than just the 50-50 ratio to see what effect multiple ratios would have on seed yield. For each replication, the seed yield of the monocultures can be proportionally compared with the seed yield of each of the 3 polycultures.

Depending on the results from many bicultures, research may proceed to studies of tricultures of perennial grasses or even larger groups. When compatible combinations of grasses are found, then research can be done to increase the seed yield of each compatible grass. Five paired studies were initiated this spring: 1) switchgrass and Indian grass, 2) switchgrass and sand lovegrass, 3) Indian grass and sand lovegrass, 4) switchgrass and sand dropseed, and 5) buffalograss and blue grama.

V. Forb Tests

Some of the perennials in a polyculture of pe-

PLENARY SESSION

8 P.M. AUGUST 5, 1980, CARRINGTON HALL

WELCOME BY JIM LEHR, PRESIDENT, MISSOURI PRAIRIE FOUNDATION

I. Richard W. Pohl, Distinguished Professor of Botany, Iowa State University - Modern Grass Classification and the Ecology of Grasses, an illustrated lecture.

II. John W. Voigt, Professor of Botany, Associate Dean, College of Science, Southern Illinois University at Carbondale - J. E. Weaver and the North American Prairie: "Look Carefully and Look Often," reproduced in the Proceedings.

J. E. WEAVER AND THE NORTH AMERICAN PRAIRIE: "LOOK CAREFULLY AND LOOK OFTEN"

John W. Voigt
Professor of Botany
Associate Dean, College of Science
Southern Illinois University
Carbondale, Illinois 62901

The following text is an address delivered at the Seventh North American Prairie Conference, Southwest Missouri State University, Springfield, Missouri, August 4, 1980.

When I was invited to speak at the seventh meeting of the North American Prairie Conference I was told it would be appropriate to say something about J. E. Weaver and about the North American Prairie. It is hard for me to think of one without the other.

Only a short time ago I was young and he was old. I was a student and he was my teacher. Now I am older, and I am the teacher, and he is gone. But there is a continuity...... a lineage that will forever connect me with great figures beyond Weaver into the past. This would include Clements, Bessey, Gray, Torrey, and all the way back to Linnaeus, I suppose.

What do we know of them, these figures of our field? We know what has been gleaned from their published papers, Who's Who, and a photograph or two, but this tells us very little of what they really were like.

Besides being J. E. Weaver's student I was an associate. I worked with him in the field, traveled with him, and published with him. This enabled me to hear his views on many things, and to hear the behind-the-scenes stories revealing the personality and philosophy of his teachers, and his contemporaries. Included would be R. J. Pool, H. L. Shantz, Arthur Sampson, F. E. Clements, Roscoe Pound, and Charles Edwin Bessey. After hearing the professional side and the human side of these stories, I felt that I really knew these people. Weaver provided me an oral history on those whom he had known, and he provided an oral history on J. E. Weaver.

Such oral history needs to be recorded. It is regarded as priceless by the historian. It is with much pleasure that I share some of this history with you at this meeting.

I had heard great stories about the prairies from my mother. Grandfather had homesteaded on the unbroken prairies of South Dakota. Mother had grown up there, but I had never seen a prairie until I began my graduate study.

I stood alone in my first view of prairie. I was drenched in sunshine and heat. A gentle breeze cooled my moist skin. I saw the grasses in their verdant, surging growth. I saw the grasses rippling into countless waves which broke over the gentle slopes and the crests of the hills in an endless repetition. I felt the emotion of the poets who described the land as having the heave and swell of the ocean, and of the prairie being a "sea of grass." I also felt the isolation in Willa Cather's words.....that... "I had the feeling that the world was left behind, that we had got over the edge of it."[1]

I was further entranced, as if in some way I was returning to a place I had known from an earlier time, and yet I had never been there before. I could feel the ghosts of the bison, the Indians, and the early settlers being passed through my being. I also felt a close bond for those living elements of the present. I was gripped by the great vault of blue sky, and the pervading quietness, and the great accent on the horizontal. The prairie had an aura of mystery, and it had a cathedral quality which evoked a considerable amount of reverence. I could not fully understand the unity and integrity of this great vegetation, but one could feel its strength and draw some of it into one's own being.

[1] Willa Cather. 1954. *My Antonia.* Houghton, Mifflin Co., New York and Boston.

I have always enjoyed scenery. Perhaps I like scenery because I like diversity. Perhaps I like scenery because I like things that are old and good scenery is almost always old. All of my life I have liked old things. I like to collect artifacts and antiques. When I view these old things or hold them in my hands I feel something of their past, and I feel something of their strength. I also like old people, who are in a way also antiques. In their journey through life they have gathered a great store of information. I have enjoyed listening to their stories, because they were always rich and useful in the lessons they conveyed. We are once again beginning to realize how important is folklore to our education and in the transmission of culture.

Each scene of the landscape holds its own story. Each scene has its own life history. Every part of Nature has much stored information, and there is much that each part can tell us, but we must be ready to receive. Each scene speaks to us in a different language. To some it is the mathematical order; to some it is the geological process, or in the process of another science. To still others it is the language of the arts. Nature speaks to any of us as much as she does to any other. It behooves us to understand these different languages so as to be able to receive more.

Scenery is like an elderly person in that it is also a repository of information. It represents the collected biological wisdom of the ages. It is the accumulated history of both biological and nonbiological events. Before there were books, schools, and libraries, there were two places where information was stored. These places were Nature, and in the World's great religions. In each of these places information had been gathered, stored, coded, improved upon, and passed on to living creatures.

From the very beginning of life by the formation of small aggregates of membrane-bound proteinaceous substances, which later acquired the genetic apparatus for self-replication, information has been gathered, stored, improved upon, and passed on so that the result was an increasing amount of organization. Because Nature organizes itself at every level we may say that life virtually learned its way into being and up to its present level of complexity by struggle, sacrifice, and discovery. The process of this learning we call evolution. Another self-organizing process, i.e. ecological succession, results in a complex ecosystem. Margalef says that succession learns its way forward.[2]

The ecosystem with which we are primarily concerned at this meeting is the prairie. It is a vegetational entity which has a long history and it has undergone many changes. It is comprised of many parts which have been sorted and improved upon many times over by the environment so that it represents, ultimately, those forms which are best adapted. The present set of parts of the system represents those which "learned" to cope the best. Nature thus, does indeed, represent the collected biological wisdom of the ages.

It is impossible to find suitable answers about ourselves, and about Nature, without asking the questions of: What is this? How did it get here? What good is it? How does it function? As we look, we see; as we see, we understand; we accumulate; we build, and finally we understand the system which supports us, and we realize too that we are a part of it.

I have remarked that the prairie is a quiet place. In quite places men are forced to listen, and the stillness prepares the senses to receive. In the quiet privacy of the prairie one has the time to examine things in depth. Our focus is sharpened and our thoughts are made clear.

> "In quiet places reason abounds.....in quiet people there is a vision and a purpose.....many things are revealed to the humble that are hidden from the great."[3]

J. E. Weaver was a quiet man, and he was a man of humility. He went into the prairie with his senses ready to receive. That he regarded the prairie as a repository of information is shown in these words from his book, *North American Prairie*:[4]

> "Every grass-covered hillside is an open book for those who care to read. Upon its pages are written the conditions of the present, the events of the past, and a forecast of those of the future. Some see without understanding; but let us look closely and understandingly, and act wisely, and in time bring our methods of land use and conservation activities into close harmony with the dictates of Nature."

Nature was Weaver's great, but hidden teacher. He asked her his questions, and she answered him. He learned about organization, and natural law, and he realized clearly that everything in our lives must fit into that organization and law. Weaver was one of Nature's most apt pupils, and as a

---

2/ Margalef, Ramon. 1968. *Perspectives in Ecology Theory.* The University of Chicago Press, Chicago.

3/ Adlai Stevenson, quoted in Illinois State University Museum Brochure, 1978

4/ Weaver, J. E. 1954. *North American Prairie.* Johnsen Publ. Company, Lincoln, Nebraska. p. 325.

teacher himself, was effective in the transfer of what he learned to his students.

I was among the last few of his students. I worked with him, published with him, taught under his supervision, and I always watched him very closely. He would not have been bothered had he known how closely he was watched. He would have expected it, for he realized that the greatest responsibility for a teacher is to set a suitable model for students to follow.

It is my hope that in revealing some of his personal qualities and his approaches to teaching and research that useful insights may be gained by those who are already here today. It is thus, that I speak of a man and his prairie.

Professor Weaver is remembered by the scientific community for his research, and it was substantial. His students remember him for his teaching. There is no question that Weaver liked his research, but I believe he enjoyed his teaching as much. He liked teaching because it was the natural follow-up to discovery of new information. He enjoyed telling others about it. Teaching also kept him in contact with young people, and he enjoyed them. He felt teaching was a partnership, and that teacher and student both gained from the transaction. Weaver enjoyed the successes of his students and gloried in pointing these out to others.

His students came from far and wide, and as they left his tutelage to enter their own practice, they became leaders wherever they went and helped to shape the field of ecology with their contributions.

Weaver wrote about the prairie with love and emotion. In reading his opening chapter of *North American Prairie,* one finds his descriptive prose quite poetic. He was moved by the vastness, the solitude, the sun, the wind, the cloud shadows, and the order, structure, and unity expressed in the vegetation. He marveled at the dynamic nature of the prairie, its longevity, and its resiliency. The use and misuse of the grassland resource was approached with both love and concern. His approach to the study of prairie was with single minded purpose. His writings, and his words were always delivered with the conviction and zeal of a missionary.

Excitement was in his eye when he was teaching, or even outside the classroom when he was telling about something of botanical interest. I remember well the last time I saw him. I had been on a vacation trip, and was passing through Lincoln. I stopped by his office to speak with him. I had my oldest son with me. Professor Weaver was still doing research, and though he was no longer able to dig up roots of prairie plants, he did not let this stop him. He hired a young man to do the manual work and he went along to show him where and how. As we visited, he went to the cabinet in his office, and spread out before us the object of his latest research. He explained to us what it was about and of its significance as I had heard him do so many times. When we left to go on our way, and once outside the building, my son said to me..."Dad, did you see the excitement he had in his eyes?"

Dr. Weaver's purpose was expressed many times and in different ways, but always with steadfastness. He was methodical in his planning, preparation for classes, his research, schedules, etc. He always made up a list of things he hoped to accomplish the next day. There were always left on his desk in front of everything so that he would deal with them the very first thing next morning. He checked them off as they were finished. The result, of course, was steady progress and substantial productivity.

Professor Weaver always preferred an eight o'clock class. The reason for this was not simply to get it over with so that he would have the rest of the day for other matters. He chose to have an eight o'clock because he would be energetic and fresh..... and so would the students. He would arrive early.....usually a full hour ahead of time so that he could get things in order. It was more of a mental readiness or "pumping up" that he gave himself. It was something like that which a high jumper goes through before he makes an attempt to clear the bar. When Weaver had reached the proper level of excitement he would come into the classroom exactly on time and give a very spirited lecture and performance. He was great on gestures, and used his body, arms, legs and hands to emphasize certain things. In speaking of a decline in rainfall or of organic matter from east to west across the grasslands, he would place himself at the east side of the classroom, and walk westward as he made his point. In talking about the rise of warm air he would bend down and lift the air upwards as he explained it. With his hands and fingers, he would show the working of roots through the soil. After all of this, in his hour long lecture, he was ready to unwind. He would get his hat and coat and go for a thirty minute walk. He would return fully charged for the days activities.

Professor Weaver never used a desk lamp, but simply used the overhead lights in his office. To offset the overhead glare, he used a green sun visor, and this became his "badge" among the graduate students. After writing for about two hours in the morning he would knock off at 11:30

A.M. for lunch downtown. It was only a few blocks to walk, and again he liked the walk. He went early and intended to beat the crowd. He generally went alone, because he seemed to have things on his mind that would be confused by small talk with someone else. After lunch he unrolled a rubber mat, placed it on a long table he used for his writing, dropped his "galluses" and took a nap. When the shade of his office door was pulled it signalled that he was not to be disturbed.

He was up and ready to go again at 1:00 P.M., and he worked at research and writing until 5:00 P.M. I don't think I ever saw him leave the office early. When he left for home at the end of the day, he carried with him the unfinished manuscripts he was working on. He exlained to his students, as he patted his manuscrpts, that his writing would be safely divided so that if Bessey Hall burned down during the night, he would have a second copy at home. We were amused in our youthful optimism, but he was very serious about this, and as usual was prepared for any eventuality.

Another lesson I learned and which I think is a good one is this. He told me that he retired early, and as he stretched out and relaxed that his subconscious began to work. At these times he admitted to having some very good thoughts and ideas. He learned that he could remember nothing of them the next day so he regularly kept a notebook on his nightstand and when these good ideas began coming, he would roll over, take his pencil, and write them down and thus preserve them into the next day. He told me the story of the man who had gotten such a good idea that he fell to his knees and thanked the Lord for allowing this to happen. When he stood up again, he found that he had forgotten what it was for which he was giving the Lord his thanks. The lesson, he said was to always write it down immediately before it can be forgotten and to do this before anything else. "Do it now" was one of his guiding principles.

Professor Weaver would always take notes in the field, recording observations, feelings, describing, etc. These notations were always fresh, crisp, and vivid in his writings. He knew that times passing caused the impressions to fade.

Many people had the impression that Professor Weaver lacked humanity. This was likely due to his business manner and to the single mindedness of purpose. All but those who were close to him felt he was surrounded by a hard shell that couldn't be easily penetrated. Those who knew him best also knew the inner man. He was both warm hearted and kind. He was generous as well. Some would say that with this on the inside and a shell on the outside that he was really like a porcupine which liked to be cuddled.

Professor Weaver was demanding, and sometimes he carried it a little too far. If one disagreed or stood for what he felt was right it was not held against him. I had a confrontation with Dr. Weaver one time, and I stood my ground. Within twenty-four hours he came around to patch up our difference and admit to being wrong. I have always felt that it takes a pretty big person to be able to do this.

One of Weaver's greatest moments of humanity was expressed when he noticed one of his graduate students was still around during the early part of the Christmas break period. Every other student had gone somewhere for the holidays. He cornered the student and asked why he hadn't gone home for Christmas? With some amount of embarrassment the student admitted that he was without funds. Dr. Weaver wrote his personal check to the student, and gave it to him with the word that a person should be at home with his family at Christmas time.

J. E. was proud of his children and his grandchildren. He told me of taking his grandchildren to the zoo in Chicago, where his daughter lived. The grandchildren "elected" grandpa to throw an orange to the ostrich. The kids wanted to see the bulge of the orange in the creatures neck if it tried to swallow the orange. Weaver pulled off this stunt for his grandchildren even though he was filled with trepidation. What if the bird choked? What if I were apprehended.....he might even be jailed, he thought. When there was nobody watching, he slyly fished the orange from his coat pocket and delivered it to the pen and at the same moment became the most innocent spectator on the grounds.

Weaver was a surprising man in that he was active and durable over a long and productive career, but he was not overly strong in a physical sense. He was only about 5' 9" or so, somewhat slight, and his office shelves always contained several medicines he was taking.

Weaver spent a lifetime of study on the prairie, fifty years in all, and left a legacy of some 102 scientific articles, and 17 books. These publications covered virtually every conceivable aspect of the prairie ecosystem. Many of his investigations pioneered, and included such things as the study of root systems, growth rate and development of roots, competition between plants, rate of aboveground and below-ground phytomass production, rate of decomposition of plant products, and their role in soil formation, the relation of root distribution to soil type, uptake of minerals, and many others. There were many studies of the initiating and continuing causes of succession, such as grazing and drought. There were numerous autecology studies as well.

Over 100 students received master's and doctor's degrees with this inspiring teacher. His reputation was both national and international. The remarkable thing was that just about everything he did was accomplished without extravagant government grants, contracts and subsidies which abound today. Much of his research was done on a pitifully small piece of prairie lying about three miles north of the University, and which was rented for the price of $10.00 per year. This site became the most studied piece of prairie anywhere in the world. Much of his research was paid for with his own funds. Many of his instruments were designed and built cheaply, or simply consisted of straps, strings, stakes and spade.

Many honors were gathered through the years, but Weaver gave none of his time to the politics of honors. He simply took them in stride with modesty and gratitude. He would have to be regarded as a prolific writer by any standard. His rather lengthy articles and monographs are a contrast to the "quickies" which are being produced today. There was a star beside his name in the listing in *American Men of Science.* It remained there for a period of 27 years, and it placed him in a select group of the 100 outstanding botanists in this country. Professor Weaver was a Research Associate with the Carnegie Institute of Washington, President of the Nebraska Academy of Sciences, President of the Ecological Society of America, and near the end of his career, he was named an honorary President of the International Botanical Congress.

J. E. Weaver was an important part of North American Ecology, and of the ecology of its grasslands in particular. He showed his students the history of ecology. He showed his students that the field of ecology had a future, and he made those students feel that they were a part of that future. His words which have stayed with me and served me best are, "look carefully and look often," and by so doing, one is best able to draw from Nature, the hidden teacher for all of us, her very best lessons.

Bibliography

Cather, Willa. 1954 (new printing). My Antonia. Houghton, Mifflin Co., New York and Boston.

Haas, Herman J., and John W. Voigt. 1977. The next step in the evolution of the human species. Philosophy Forum 15:23-47.

Margalef, Ramon. 1968. Perspectives in Ecological Theory. The University of Chicago Press, Chicago.

Stevenson, Adlai. quoted in Illinois State Museum Brochue. 1978.

Weaver, J. E. 1954. North American Prairie. Johnsen Publ. Company, Lincoln, Nebraska.

A while longer [illegible] to walk, and again he liked the walk. He went early and intended to beat the crowd. He generally went alone, because [illegible]

[illegible] P.M. I don't think I ever saw him leave the office early. When he left for home at the end of the day, he carried with him the unfinished manuscripts he was working on. [illegible] parts [illegible] would be safely divided so that if Bessey Hall burned down [illegible] but he was very serious [illegible] was prepared for any eventuality.

[illegible] a good one is this. He told me that he retired early, and as he stretched out and relaxed that his subconscious [illegible] ted to having some very good thoughts and ideas. He learned that he could remember nothing of [illegible] on [illegible] began coming, he would roll over, take his pencil, and write them down and thus preserve them into the next day. He told me the story of the man who had gotten such a good idea that he fell to his knees and thanked the Lord for allowing this to happen. When he stood up again, he found that he had forgotten what it was for which he was giving the Lord his thanks. The lesson, he said was to always write it down immediately before it can be forgotten and to do this before anything else. "Do it now" was one of his guiding principles.

Professor Weaver would always take notes in the field, recording observations, feelings, describing, etc. These notations were always fresh, crisp, and vivid in his writings. He knew that times passing caused the impressions to fade.

Many people had the impression that Professor Weaver lacked humanity. This was likely due to his business manner and to the single mindedness of purpose. All but those who were close to him felt he was surrounded by a hard shell that couldn't be easily penetrated. Those who knew him best also knew the inner man. He was both warm hearted and kind. He was generous as well. Some would say that with this on the inside and a shell on the outside that he was really like a porcupine which liked to be cuddled.

[illegible]

One of Weaver's greatest moments of humanity was expressed when he noticed one of his graduate students was still around during the early part of the Christmas break period. Every other student had gone somewhere for the holidays. He cornered the student and asked why he hadn't gone home for Christmas? With some amount of embarrassment the student admitted that he was without funds. Dr. Weaver wrote his personal check to the student and gave it to him with the word that a person should be at home with his family at Christmas time.

J. E. was proud of his children and his grandchildren. He told me of taking his grandchildren to the zoo in Chicago where his daughter lived. The grandchildren [illegible] to throw an orange to the ostrich. The kids wanted to see the bulge of the orange in the creature's neck if it tried to swallow the orange. Weaver pulled off this stunt for his grandchildren even though he was filled with trepidation. What if the bird choked? What if I were apprehended.....he might even be jailed, he thought. When there was nobody watching, he slyly fished the orange from his coat pocket and delivered it to the pen and at the same moment became the most innocent spectator on the grounds.

Weaver was a surprising man in that he was active and durable over a long and productive career, but he was not overly strong in a physical sense. He was only about 5' 9" or so, somewhat slight, and his office shelves always contained several medicines he was taking.

Weaver spent a lifetime of study on the prairie, fifty years in all, and left a legacy of some 102 scientific articles, and 17 books. These publications covered virtually every conceivable aspect of the prairie ecosystem. Many of his investigations pioneered, and included such things as the study of root systems, growth rate and development of roots, competition between plants, rate of aboveground and below-ground phytomass production, rate of decomposition of plant products, and their role in soil formation, the relation of root distribution to soil type, uptake of minerals, and many others. There were many studies of the initiating and continuing causes of succession, such as grazing and drought. There were numerous autecology studies as well.