A PROPOSAL TO PERFORM

LONG-TERM ECOLOGICAL RESEARCH IN TALLGRASS PRAIRIE: RESPONSES TO FIRE AND GRAZING

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LONG-TERM ECOLOGICAL RESEARCH IN TALLGRASS PRAIRIE: RESPONSES TO FIRE AND GRAZING

~~I. ABSTRACT~~

Tallgrass prairie once covered about 7% of the conterminous United States. The deep, fertile prairie soils that are characteristic of this ecosystem represent an important natural resource to the nation; thus most of this landscape type has been plowed and converted to agricultural production. The steep slopes and shallow upland soils in the Flint Hills of Kansas prevented plowing and this region became famous instead for the quality of the native vegetation for livestock production.

Ecological research in United States will be extended by the development of a research natural area in this ecosystem and a network of sites will be well served by the inclusion of a tallgrass prairie example. Our past efforts have been devoted to these ideas; our present and future efforts are motivated by them.

Following the leadership of L. C. Hulbert, The Nature Conservancy (TNC), with money provided by Katharine Ordway, set aside the Konza Prairie Research Natural Area (KPRNA) during the period 1971 to 1979. Under ownership and lease agreements between TNC and Kansas State University, the 3500 ha site is managed for research by the Division of Biology.

The management of KPRNA involves burning replicate watersheds at intervals of 1, 2, 4, and 10 years plus some watersheds left unburned. This pattern is repeated in areas that will be left ungrazed and areas where native grazers, bison, elk and pronghorn are to be reintroduced. LTER takes advantage of this design by making measurements of ecosystem parameters at permanent plots that were placed in these treatments at the beginning of the program. Some prairie responses are known to be soil dependent, so long-term measurements are made on two soil types (deep prairie loam and shallow upland ridges) as well.

New knowledge about the effects of fire <u>and</u> the effects of the absence of fire on phenomena in tallgrass prairie are among the major contributions of the first four years of LTER. For example:

Nitrogen from the atmosphere represented a substantial imported subsidy. Investigations of the influence of fire on water and nitrogen interception and the alteration of throughfall quality and quantity by standing dead and litter (removed by fire), suggested insights about mechanisms of regulation of net primary productivity and nitrogen cycling in tallgrass prairie.

Other new information included: (1) an evaluation of the effects of fire frequency on the diversity and species richness of grasshopper assemblages, (2) a description of how small mammal population responses and the population stability of breeding birds in the four years following fire are keyed to the length of the period since the last fire and (3) evaluation of the effects of fire on prairie plant species composition, physiological vigor and reproductive performance. These are significant short-term results, temporal patterns are only beginning to emerge.

II. A SUMMARY OF THE 1979 LTER PROPOSAL

In the initial proposal we: (1) demonstrated that Kansas State University, as the steward of the Konza Prairie Research Natural Area and the land grant institution of the State of Kansas already had the commitment, willingness and wisdom to to be involved in the emerging LTER program; (2) described how LTER measurements would be made to take best advantage of the characteristics of the site and the management plan; and (3) proposed an experimental evaluation of long term effects of fire and grazing by documenting long-term trends in relation to climatic records.

A. The guiding hypothesis put forward at that time was:

> "The ecological processes mediated by species populations and their involvements in energy flows and matter cycles in bluestem prairie are under the major control of naturally occurring extrinsic perturbations."

We believed that, in the context of a network of sites working with comparative hypotheses, the tallgrass prairie would be intermediate in this regard between deciduous forest, with more intrinsic homeostatic mechanisms, and short grass prairie or steppe which is even more controlled by extrinsic factors.

The external driving factors of the tallgrass prairie ecosystem are fire and water. Since prairie vegetation is adapted to, and maintained as dominant by fire, perhaps fire should be considered an intrinsic variable. We felt that edaphic variations represented an independent control variable of geologic origin that would influence long term patterns.

B. Rationale for LTER at KPRNA

Thus, the questions that motivated us to acquire the Konza Prairie, that directed our decisions about the management of the site for research (see page 4 et seq.), that stimulated the development of the long term measurements we proposed are related to the effects of fire, grazing, soils and climate on ecosystem function.

Our opinion was (and is) that the first value of long-term ecological research is to define pattern, then later to evaluate the process; to describe and document events rather than to interpret them immediately. Long-term research can demonstrate correlations among the time courses of separate measureable phenomena; interpretation, on the other hand, infers causality and ultimately requires the indentification of cause and effect relationships with experimental designs that isolate hypothetical causes.

The heuristic value of LTER is enormous. Long term data sets document the status of the system (at equilibrium, recovering from disturbance, or near the extremes of annual variations) in which short term experiments are performed so that interpretation is more realistic. Short term experimental investigation was intended to be, and continues to be an important complement to the LTER enterprise at Konza Prairie.

III. GENERAL GOALS FOR THE KONZA PRAIRIE RESEARCH NATURAL AREA

The following is a brief statement of goals prepared by the Konza Prairie Executive Committee to guide the development of the research and educational program at Konza Prairie. The objectives of our long-term ecological research are consistent with these goals.

A. Encourage the continued development of basic and applied research in tallgrass prairie.

1. Maintain the long-term fire and grazing research management treatments.

2. Document long-term patterns (i.e., annual variations and long-term trends) in floristic, faunistic, edaphic, meteorologic, and hydrologic phenomena to evaluate the responses of tallgrass prairie to fire and grazing treatments.

3. Foster research by providing this long-term documentation to investigators to aid the interpretation of short-term investigation.

4. Foster research by providing for comparison with other grassland sites and with other ecosystems, including agroecosystems.

5. Encourage and aid applications of ecological research. To provide information for such tasks as: defining baseline conditions, setting emission or effluent standards, evaluating the benefits to society of natural systems, evaluating the technological impact (especially long-term trends) on the integrity of natural systems and to provide information to aid attempts to abate damaging effects.

6. To provide on-site housing, laboratory space and equipment for scientists conducting short-term investigations.

7. Provide support staff to facilitate short-term investigations.

B. Disseminate the results of research

1. Stimulate publication in refereed journals.

2. Stimulate production of informative materials for the popular media.

3. Organize seminars, short courses and conferences.

4. Organize visits for the public.

5. Provide access for eduational uses.

C. Improve financial support for Konza Prairie programs.

IV. THE KPRNA MANAGEMENT PLAN AND ITS RATIONALE

The management plan is intended to provide the range of conditions in tallgrass prairie resulting from natural phenomena in order to facilitate ecological research.

The most direct expressions of the management plan is the map in Figure 1 and the aerial photograph in the envelope attached to the proposal. The transparent overlays to the photo (also in the envelop) will aid your interpretation of this narrative description of the plan and, below, of its use for the LTER measurements.

A. Background

The major management activity is the use of fire, an integral feature of the tallgrass prairie. In most years there is sufficient rainfall to support the growth of forest species. The grasses typically produce 300 to 600 g m^{-2} of aboveground biomass, but with favorable weather in deep soil up to 1200 g m^{-2} is common. Standing dead grasses and litter accumulate in the absence of fire and grazing so that, through time up to about 4 years, the fuel load increases and the prairie becomes more flammable. As grasses become senescent at the end of the growing season they translocate much of the season's photosynthate to below ground storage, leaving flammable material above ground that is essentially of no further direct value to the individual plants. There is no living tissue above ground so individual grass plants are invulnerable to fire. Woody forest species, on the other hand, possess living growth tissues above ground making them vulnerable to fire.

Fires may have been ignited by natural causes, such as lightning (this has been observed at Konza Prairie), or by aboriginal men (Pyne, 1982). In either case fire precluded the invasion of forest species and maintained grasses as the dominant vegetation (Daubenmire 1968, Bragg and Hulbert 1976, Old 1969, Risser et al. 1981, Boerner 1982).

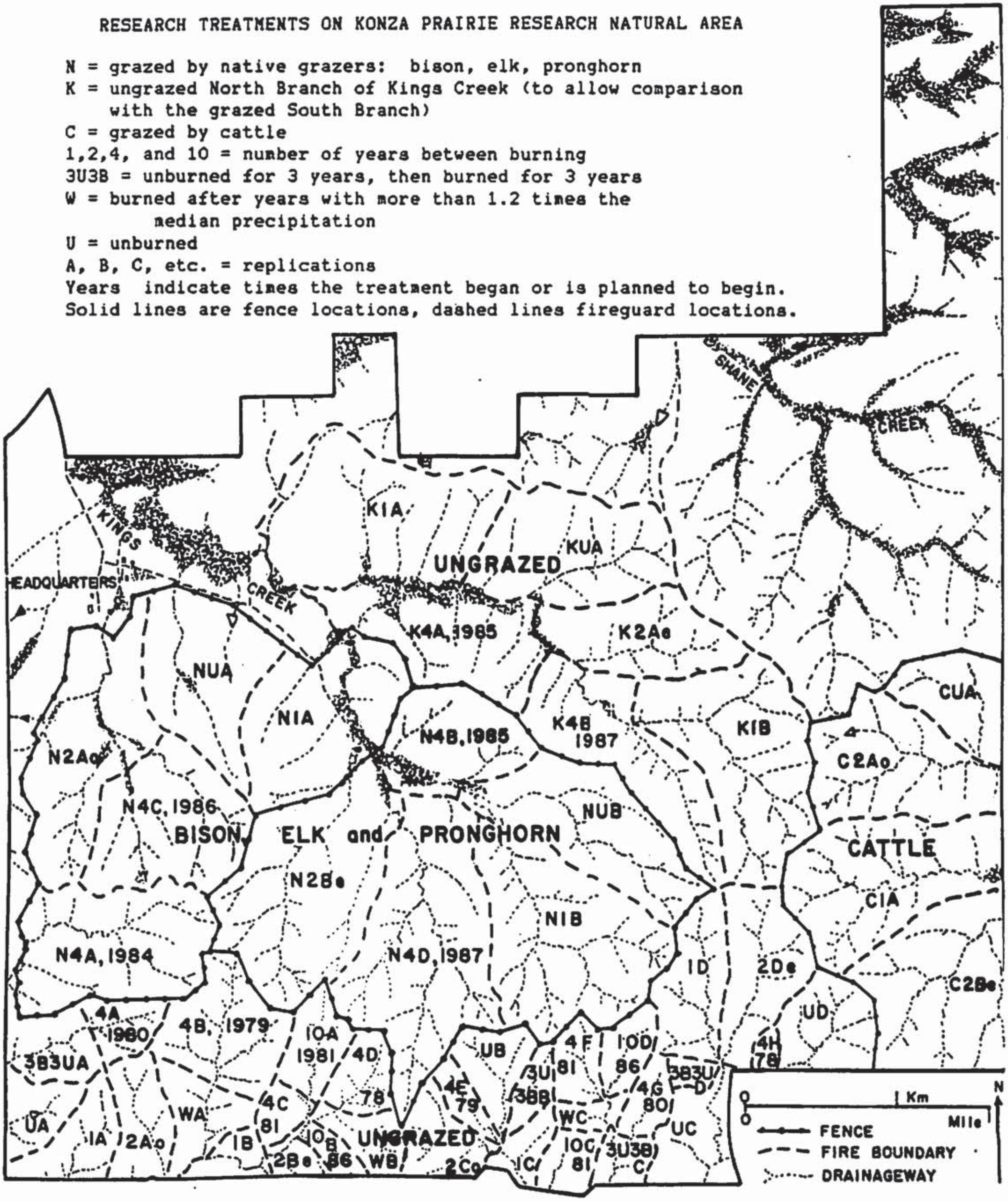
One result of this understanding is the recognition that tallgrass prairie cannot be preserved without management; fire or, possibly, mowing. For research purposes, to evaluate the details of fire effects in tallgrass prairie, fires are ignited by us at pre-determined times and controlled at pre-determined boundaries; usually along watershed divides so that we achieve a range of conditions in tallgrass prairie. Fires are ignited in the spring, generally in the first half of April unless designated otherwise.

Note: The management of the site is provided for by funds from Kansas State University.

Figure 1.

RESEARCH TREATMENTS ON KONZA PRAIRIE RESEARCH NATURAL AREA

N = grazed by native grazers: bison, elk, pronghorn
K = ungrazed North Branch of Kings Creek (to allow comparison with the grazed South Branch)
C = grazed by cattle
1,2,4, and 10 = number of years between burning
3U3B = unburned for 3 years, then burned for 3 years
W = burned after years with more than 1.2 times the median precipitation
U = unburned
A, B, C, etc. = replications
Years indicate times the treatment began or is planned to begin.
Solid lines are fence locations, dashed lines fireguard locations.



B. The treatment areas. Fire treatments are superimposed on three grazing regimes:

1. Ungrazed. The area at the south end of the site, ca. rows 28-30, columns A-W on the photo and the "K" treatments in the North Branch of Kings Creek are to be left ungrazed. Surface water from the southern treatment watersheds drains southward into Swede Creek, a tributary of McDowell Creek, then to the Kansas River. There are areas where fires are ignited at one, two, four and ten year intervals and some watersheds are left unburned. These are labelled 1A, 1B, 1C, $2A_o$, 4B, 1975, UB, etc. The numbers indicate intervals in years and letters indicate replicates.

Other ungrazed treatments include:

a- areas burned for three consecutive years followed by three years without fire (a management strategem to preclude growth of woody vegetation with minimal burning), labelled 3U3BA, or 3B3UA, etc.,

b- areas burned in years when the annual precipitation exceeds 1.2 times the median precipitation for the site (a treatment with a stochasitic element to it yet that is related to years when additional water leads to higher fuel loads, thus increasing the likelihood that fire would ignite and carry), labelled WA, WB, etc.,

c- Strips, twenty-five meters wide, are mowed along Intestate 70 in March, July and November, the cut material is removed from part and left on the other.

d- small plots elsewhere on the site are burned in November, March or in the summer, some timed to burn with the wind, some against it.

2. Grazing treatment with native ungulates. The central region of KPRNA is the Kings Creek drainage. There are two main tributaries, the North and South Branches, whose confluence is located by coordinates I-16 on the photo. Watersheds in each of these branches are fire treatments areas. (Refer to Overlay A.) The intervals between fires on these treatments are 1, 2 and 4 years. Some watersheds are unburned. Bison, elk and pronghorn are to be reintroduced to the South Branch. These grazed and burned treatments are labelled N1A, N1B, $N2_e$, N4 1987, NU etc. (Similar intervals between fires will be imposed upon watersheds in the North Branch but these will be left as ungrazed controls in the Kings Creek drainage so that hydrologic and nutrient export evaluation is possible with appropriate sampling just above the confluence of the North and South Branches.

3. Grazing treatment with domestic ungulates. Four watersheds along the eastern border of the site, draining east into Deep Creek, are to be burned at one and two year intervals or left unburned. These watersheds are to be grazed by cattle at the same population density or grazing pressure as the native ungulates on the Kings Creek watershed. These watersheds are located on the photo approximately by rows 18-28 in columns X-ZZ and are labelled with the prefix "C".

V. RATIONALE BEHIND THE MANAGEMENT PLAN

The following notes convey some of our thinking as we made the compromises forced upon us by constraints of space, landscape configurations, analytical complexity and financial support for management. Where randomized blocks, split plots and nested designs were often called for to evaluate rigorously many of the effects of interest, implementation of the most appropriate design was impossible. Even so, analytical considerations influenced many decisions about replication and treatment interactions. The impossibilities may preclude some rigorous evaluation (cf. Hurlbert 1984) but they will not preclude learning a great deal about tallgrass prairie.

The original mangement plan has been modified several times. Once when the large Dewey Ranch was added to the area, allowing for more complete watershed treatment units (see Fig. 12). Others involved excluding the native grazers from the North Branch of Kings Creek, leaving it as an ungrazed control and reducing the number of fire treatments in the South Branch (thus also making them larger), the area to be grazed by native ungulates. This strategem provided for the installation of the stream gaging instruments. Other changes are minor boundary shifts or treatments, not changes in strategy. All of them so far have been made before implementation. Of course, once a treatment for a long-term experiment has been implemented changes are resisted.

1. The intervals between fires were chosen to bracket the range of intervals that we believed to have occurred on the pre-settlement prairie; annual fires for long periods was not likely, nor was a decade without fire (Bragg and Hulbert 1976). The natural interval is between these extremes. An unburned reference treatment provides for comparative short term experimental work or observations to obtain further information about the effects of the absence of fire.

2. Implementing a plan that included all of the yearly intervals between one and ten years (with replicate treatments) was niether logistically possible; nor was there sufficient space if watersheds were to be used as natural boundaries for any of the treatments. Thus, the one, two and four year intervals represent a geometric progression.

3. Not all of the two or four year interval treatments are burned in the same year. Half of the two year intervals are burned in each of alternate years. These are designated by subscript "o" (odd years) or "e" (even years) on the aerial photo. In the ungrazed area, two replicates of the four year interval treatment are burned in each year. These are designated on the aerial photo by the year in which the treatment was initiated , i.e., 4B, 1975 (add multiples of four to determine the dates of subsequent fires). In the grazed area, however, there was insufficient room for replicates unless all four, (or two, or three) watersheds were burned in the same year. Considering that the treatment is the interval between fires, not the year in which the fire occurred, led to the present scheme.

There are fewer treatment replicates as a result of these compromises, but investigations of phenomena responding to fire one, two, three or four years preceeding can be conducted in any one year, and the effects of characteristics of the year in which the fire occurred can be included in analyses.

4. Past fires undoubtedly occurred in seasons other than spring. Provision for this variable in the management plan would be both complex and expensive. To include an array of treatments that provides for that analysis we felt: (1) that we should know more about the seasonal frequency of natural fires and (2) that we should be cautious about committing all of the land resource for that purpose.

Spring was chosen as the season for burning because: (1) spring burning is a common management practice in the Flint Hills since soils are exposed to erosion for a shorter time (Owensby 1981) and (2) information from Konza Prairie research might have more application to range management if we followed that timing. Of course, there are small plots burned at other seasons and there is space for watersheds to be burned in fall or winter if that seems warranted and is financially feasible in the future.

5. There are serious problems with the evaluation of the effects of native grazing using this design alone. The most obvious problem is caused by the facts that the grazing treatment is not replicated and the grazers have free access to all the fire interval treatments. Additional manipulations will be required to evaluate fully the interactions of fire and grazing. For example: enclosures and exclosures are being considered. This planning proceeds as we gather pre-treatment data. As the implementation is described note that the reintroduction is in several phases. The initial reintroduction is to be made only to the western part of the area (overlay D) so that: (1) planning can continue as we learn about the animals, their effects and their behavior, (2) the developing herd will be familiar ("fence-wise") with KPRNA. There are also plans to be made relative to the genetic composition of the herd.

VI. LTER USE OF THE MANAGEMENT PLAN

The measurements we proposed to develop and initiate were selected to represent the five core areas required in the program annoucement (NSF 79-64):

(1) pattern and control of primary production

(2) spatial and temporal distribution of populations selected to represent trophic structure

(3) pattern and control of organic matter accumulation in surface layers and in sediments

(4) patterns of inorganic inputs and movements of nutrients through soils, groundwater and surface waters

(5) patterns and frequency of disturbances to the research site.

Measurements were proposed to be made on permanent sites, randomly chosen in watersheds experiencing two intervals between fire (one year and four years) and unburned, two soil types in each of those watersheds (deep loam located near the bottom of major slopes and shallow rocky located on the ridge tops). Measurements were repeated in watersheds that are to remain ungrazed (1D, 4B, and UB) and watersheds to which the native grazers (bison, elk and pronghorn) are to be reintroduced (NU, N1B and N4 1987).

The primary concern of LTER is to evaluate the time course of measurable phenomena. So, while the locations of the measurment sites were randomly chosen in treatment and soil type areas in the first year, the plots were carefully documented and have not been changed subsequently. Where there have been suggestions for changes because of unexpected results, we have added new sites while continuing measurements at the original ones. This will be discussed further in the later sections of the proposal.

Transparent overlays in the attached envelop identify the locations of current measurement sites.

A. Vegetation sites: (Overlay B)

1. species composition, canopy coverage
2. above ground biomass
3. seeds and flowering stem density
4. gallery forest litterfall

B. Consumer population estimates: (Overlays B and C)

1. grasshoppers and other arthropods (B)
2. small mammal traplines (C)
3. bird transects (C)
4. prairie chicken survey

C. Nutrient cycling estimates: (Overlay A)

1. soil moisture, soil water nutrients (porous cup lysimeters)
2. USGS hydrologic monitoring station
3. prairie throughfall
4. prairie litterfall
5. weather station and National Atmospheric Deposition Program
6. bulk precipitation collectors
7. precipitation gages and stream gaging stations

Phenological observations accompany the vegetation analysis and there are phenological records kept on birds as well. Plantings from the Northeast phenology network (New York State Agricultural Experiment Station) have been made near the headquarters area (Overlay A.) to extend the utility of these measurements.

Most of the originally proposed measurements have been implemented (see next section) but there have been additions and modifications.

VII. PROGRESS IN LIGHT OF THE ORIGINAL LTER PROPOSAL

There is relatively little known about tallgrass prairie (Risser et al. 1981), thus new information is valuable and leads to new experiments or new measurements being made.

KPRNA has been a site for ecological research since 1972. The number of people working here was relatively small and many were faced with the details of establishing the security and integrity of, and support for the operation of, the site. Recently, and partly with LTER support, numbers of published papers, numbers of undergraduate and graduate students, post doctoral research associates and visiting scientists has increased, and extramural support for research has increased dramatically.

The publication record is presented in Appendix A. Obviously, long term results are not to be expected after four years into the experiments; nevertheless, publishable results have been obtained during the implementation of the work. Note that most of the research papers deal with descriptions and causality of the effects of fire by comparing burned with unburned treatments.

Some notable results that have been reported are:

A. Effects of fire on nitrogen cycling.

Measurements of nitrogen in rainfall, throughfall and soil water during the past two years indicated that vegetation and microbes on standing dead on unburned watersheds remove more inorganic nitrogen from precipitation, converting it to organic nitrogen in throughfall than is removed by vegetation and microbes on burned watersheds. Despite this reduced input of inorganic nitrogen to the soil, the nitrate concentration is higher in the soil water of unburned watersheds. We interpret this to mean that the absence of fire is, in a sense, a disturbance. The grasses, less productive without fire, may be less efficient in the removal of nitrate from soil water. Nitrate concentration in soil water is lower than that in rain water. Unburned prairie, therefore, accumulates nitrogen, but may lose it during storm flows or nitrogen may be more subject to denitrification on the wetter, unburned watersheds. Burned prairie sequesters nitrogen as organic biomass. (Seastedt 1985) KPRNA/ LTER scientists and colleagues from Colorado State University working at KPRNA are investigating both pathways of loss.

B. Physiological response of big bluestem to fire

Big bluestem, (Andropogon gerardii), a dominant tall grass species on Konza Prairie was more vigorous in the growing season following a spring fire than in the absence of fire. Vigor was reflected in higher photosynthetic rates, greater stomatal conductance to water vapor diffusion, higher leaf nitrogen content and higher nitrogen use efficiency by plants on burned sites than on unburned sites. Thus, in a sense, the absence of fire was a disturbance (Knapp 1984).

C. Examples of emerging pattern in LTER data.

Pattern is emerging from some data sets (with three years of LTER data) that is related to variation in the interval between experimental fires. Testable hypotheses are being formulated as a result of these observations. There are many examples. Four follow:

1. Intermediate frequency of disturbance.

Local species diversity of grasshoppers was greater on sites burned every fourth year than on sites burned more or less frequently (Figure 2). Intermediate frequency of fire is hypothesized to promote high grasshopper diversity indirectly through its effects on the insects' host plant diversity. (Evans 1984).

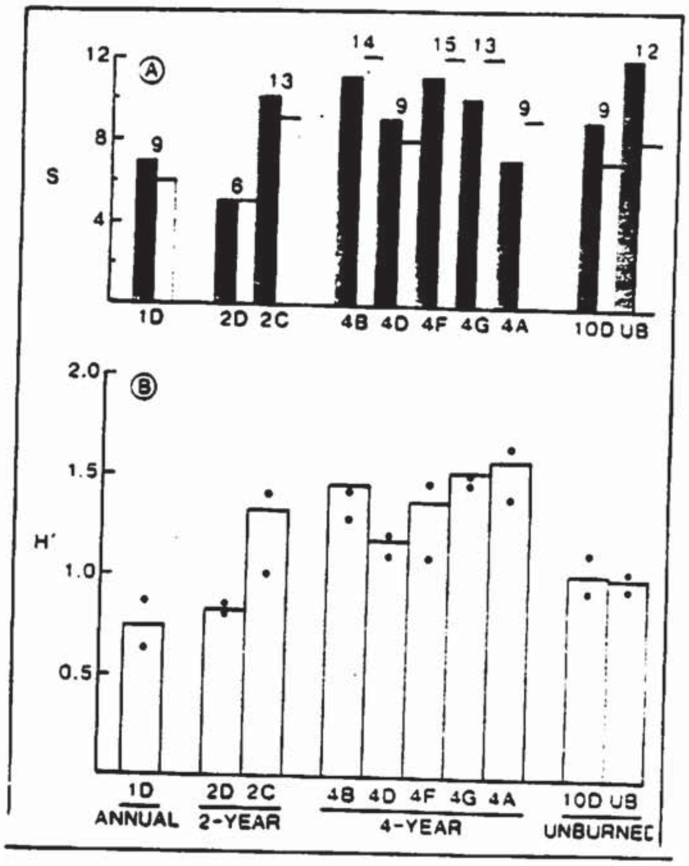


Fig. 2

Upper panel: Species richness (S) of grasshoppers for individual watersheds: solid and open bars represent S for replicate sites A and B respectively. The number above each pair bars equals S for the two replicate sites combined. Watershed 1D (annual burn), 2C (two year interval) and 4B (four year interval) were burned in the year for which these statistics were calculated, 1983.

Lower Panel: Species diversity (H') of grasshoppers for individual watersheds: solid circles and bars represent H' values for replicate sites A and B indivdually and combined, respectively; standard deviations (not shown here) were less than 0.01% in all cases. (E. W. Evans)

2. Regularity of disturbance

The year to year stability of breeding bird populations is higher in annually burned and unburned sites than on the four year burn sites. This stability index decreases in a fashion related to the time since the last fire on sites that are burned at four year intervals (Figure 3). Prairie birds, almost without exception, spend the non-breeding season away from the prairie. Evolved dependency on constant habitat expectation is hypothesized (Zimmerman unpubl.).

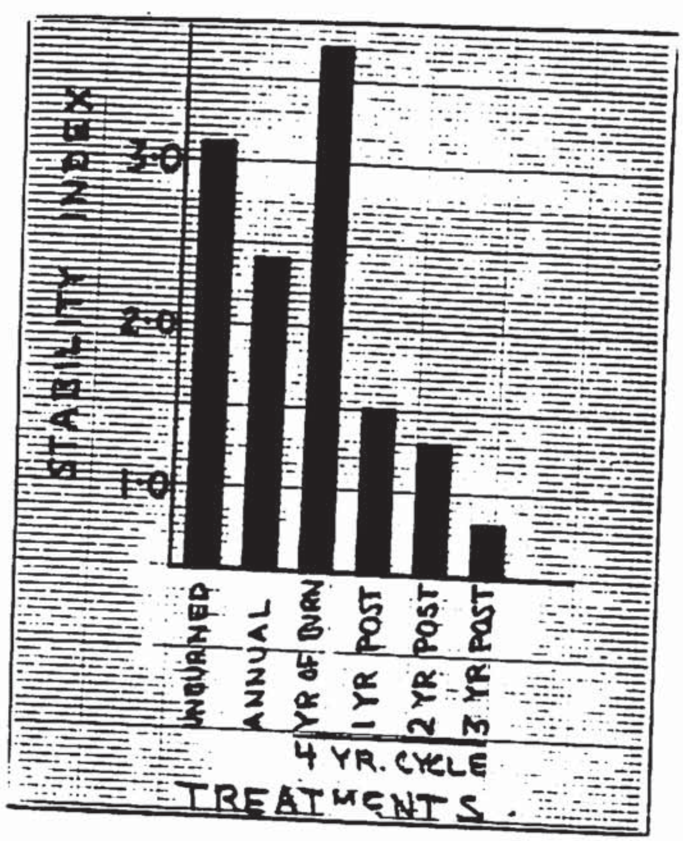


Fig. 3.

Stability index equals the inverse of the range in bird numbers per kilometer of transect over four breeding seasons divided by the mean number of birds per kilometer over the four seasons. (J. L. Zimmerman)

3. Time since the last disturbance

Total small mammal numbers respond positively to spring fire. Some individual species, however, respond negatively. Deer mice (Peromyscus maniculatus) reach their greatest densities during the first year after a spring fire and decline thereafter. Western harvest mice (Reithrodontomys megalotis), on the other hand, decline to their lowest levels following fire (bars A and 1 on the summer panels in Figure 4). It is hypothesized that these different responses are related to effects of fire on food sources (litter removal by fire makes seeds on soil surface more available to rodents) and/or nest building materials (litter accumulation in the absence of fire) (Kaufman et al. 1985).

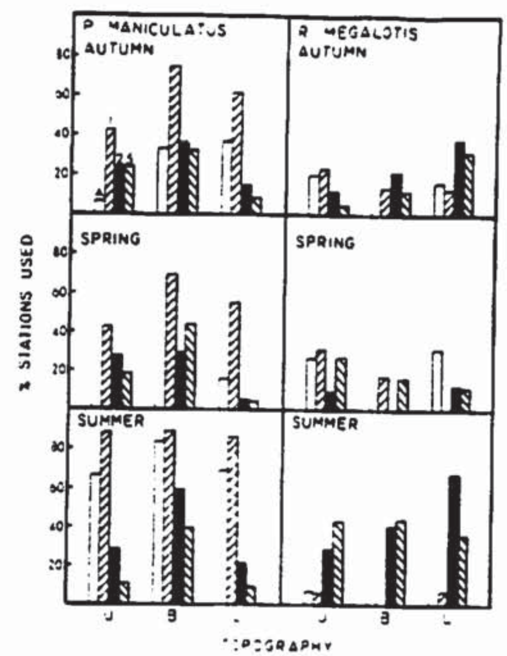


Fig. 4.

Effect of season, time since fire and soil - topography on habitat use by Peromyscus maniculatus and Reithrodontomys megalotis. Fire categories include annual burns (A) and periodic burns in the first year after fire (1), second - fourth year after fire (2) and fifth year, or more, after fire (5). Soil - topography categories are: shallow upland soils (U), rocky breaks (B) and deep lowland soils (L). (D. W. Kaufman)

4. Interaction of fire and climate.

The number of flower stalks of big bluestem (Figure 5) and other common C4 grasses is greatly affected by both fire and climate. The number of flower stalks is high in the year following fire. The number of flower stalks is higher in a wet year (1981) than in a drought year (1983) Further, the number of stalks in a wet year (1981) that follows a drought year (1980) is higher than the number of stalks in a wet year (1982) that follows a wet year (Hulbert and Knapp, unpublished).

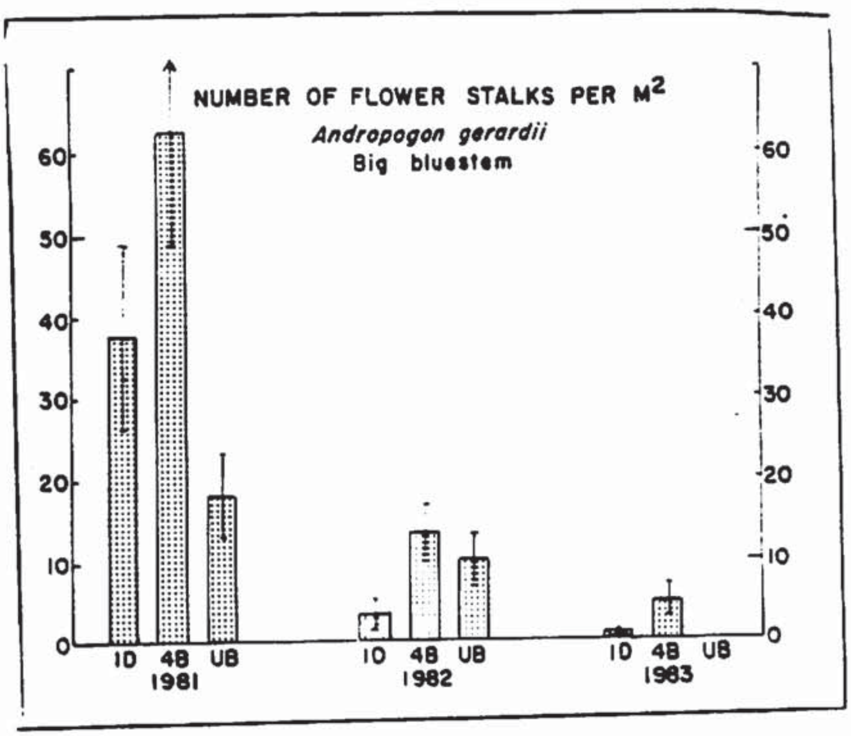


Fig. 5.

Big bluestem flower stalk density in three years on annually burned (1D), burned at four year intervals (4B) and unburned (UB) areas on deep soil. The four year interval treatment was burned in 1983. The vertical lines on each bar represent standard errors.

D. Evaluation of fire history.

Oak dominated gallery forests have expanded since the original Land Office Survey of Konza Prairie in 1858. Some bur and chinquapin oak trees were repeatedly scarred by recurring fires in the Konza Prairie gallery forest. Fire history evaluation yields an estimate of mean interval between fires sufficient to scar trees in various stands ranging from 11 to 20 years (Abrams in press). This is a longer interval than is thought maintain prairie and may be related to the imposition of grazing that reduced the fuel loads required to carry fire through the forested area.

We hypothesize that more frequent fires were characteristic of pre-settlement prairie and on gallery forest sites where the interval between experimental fires is 1, 2, or 4 years the gallery forest will regress.

There are other examples of progress in the literature listed in Appendix A. These few are offered as examples of new knowledge, some of which would not have been uncovered without the intention of tracking the time course of long term phenomena.

E. Communication of other results

In addition to the publications listed in Appendix A, Konza Prairie scientists gave 26 oral or poster presentations at national and regional meetings in the past year and 9 attended the LTER "all-scientists meetings" at Lake Itasca and all of them presented posters there. Five KPRNA scientists have responded this year to invitations to present ten seminars at other institutions and three have made contributions to symposia. The group is communicating what it has learned quite actively.

F. New faculty and research associates

Since the original proposal was submitted in 1979 the Division of Biology has added two faculty positions (Kaufman and Seastedt) with emphasis on the Konza Prairie program and a third new faculty member (Reichman) is initiating work there this spring. The LTER award itself provides support for six post-doctoral associates and a seventh post-doctoral fellowship was awarded independently (Gurtz) for work on Konza Prairie. We view the addition of these scientists to the group as a most positive event in the first five years of the program.

New faculty in the Ecology and Systematics section of the Division of Biology:

Donald W. Kaufman, Associate Professor of Biology
Timothy R. Seastedt, Assistant Professor of Biology
O. James Reichman, Assistant Professor of Biology

Research associates:

Marc D. Abrams	John M. Briggs	Edward W. Evans	Alan K. Knapp
Elmer J. Finck	Frank S. Gilliam	Martin E. Gurtz	

G. Implementation of the management plan

The major progress was the initiation of fence construction to enclose the native grazers. The major task in the next year is to complete it. All other phases of initiating the experimental fire treatments are on schedule.

H. Development of methods

The first two years of the grant period were devoted to methods development, selection of sample sites and testing the methods. The criteria were: (1) the measure should discriminate between burned and unburned treatments, (2) should be sensitive to annual variation, (3) should be relatively inexpensive and simple to perform, (4) remain useable for the long term and (5) the measurements should be nondestructive since long term measurments are required.

These methods have now been successfully developed for the collection of data shown in the list of data sets shown in Appendix B. The sites where the data are collected can be discerned with the use of the transparent overlays.

All of the methods have been recorded, checked and described with written narratives. Maps locating the sample sites have been constructed and included in an LTER methods manual. Examples of several of the methods from this manual are included in Appendix C.

I. Data management

Since the data being accumulated are intended for future use, future needs are being anticipated. The data management system at the KPRNA was developed with help from data managers with more experience at other sites. M. E. Gurtz was instrumental in the implementation of the early protocols and J. R. Briggs continues to expand its utility.

Appendix D. describes the data management system. We have developed satisfactory data entry, error checking and archiving procedures. By the time you read this, new hardware (IBM/PC/AT, 2) will be in place that operates graphics, analytical and data handling software (RS/1). This will facilitate scientists' manipulation of the data, looking for pattern, merging data sets and performing preliminary analyses. Requirements for large analyses will still be met with SAS (or other software) on the mainframe computer of the KSU Computing Center. All that remains to have direct hard wire connection with the mainframe is to string the wire through the connecting pipeline that was recently completed. Uploading and downloading archived data sets will then be faster and more likely to be error free.

The documentation for most of the data sets is complete. This is almost a continuous task as data sets are expanded, methods refined or as new data sets are started. The documentation references the methods manual closely.

The combination of the two provides confidence that the data are useable, understandable and could be continued with minimal difficulty.

VIII. SHORT-TERM RESEARCH

The integration of long-term data sets with short-term experimental investigation is one of the compelling advantages of site related LTER. The long-term records provide for recognition of pattern and for correlation of patterns between different elements of the system. The long-term record gives us the information to establish the state of ecological processes (e.g., at equilibrium, changing, highly variable from year to year, accumulating materials, degrading, etc.) but establishing causes and effects cannot be concluded from correlation or regression analyses.

Short-term experiments, on the other hand, can be more intensely and rigorously designed, manipulations can be more tightly controlled and therefore cause and effect can be evaluated. Thus the long-term record is more interpretable because of the short-term experiments and the short-term experiments are better interpreted in the context of the long-term records.

Short-term investigations are performed by faculty, post docs, graduate students (as thesis research) and visiting investigators. Table 1 is a presentation of the short-term investigations that are active now.

Investigators (s)	Title of project	Support	Related LTER data
Gurtz. M. E.	Predictability of hydrologic regimes: influence of stream populations.	NSF	Hydrology Stream chemistry
Hulbert, L.C., E. W. Evans D. W. Kaufman T. R. Seastedt	Effects of aboveground and belowground arthropod and small mammal herbivory on tallgrass prairie	NSF	Vegetation Arthropod popula.
Tate, C. M.	Nitrogen dynamics of prairie streams	KSU	Hydrology Stream chemistry
Petersen, G. E.	Primary production of algae in prairie streams	NSF	Hydrology Stream chemistry
Parton W.J. Schimmel, D. Owensby, C. E.	Influence of fire on nitrogen cycles in tallgrass prairie	NSF	Soil chemistry Throughfall Bulk precip. NADP

Marzolf, G. R.	Dissolved organic links between riparian vegetation and stream ecosystems	USGS	Hydrology Stream chemistry Bulk precip.
Kaufman, D. W.	Experimental analysis of population and community ecology of small mammals in tallgrass prairie	NSF	Small mammal pop. Aboveground plant biomass
Marzolf, G. R.	Evaluation of pesticide levels in stream fishes	KDHE	Hydrology
Hayes, D.	Translocation of photosynthate and belowground productivity of big bluestem	KSU	Aboveground plant biomass
Peterson, S.	Habitat use by small mammals in response to fire and topography	KSU	Small mammal pop.
Clark, B.	Habitat selection by small mammals in tallgrass prairie	KSU	Small mammal pop.
Zimmerman, J. L.	Breeding season dist. and habitat selection by Henslow's sparrow	KFG	Bird populations
Reichman, O.J.	Gophers and plant species composition	NSF	Plant spp. comp. Aboveground plant biomass
Hooker, K.	Influences of dissolved organic carbon on microbial assemblages in prairie streams	KSU	Hydrology Stream chemistry
Loring, D.	Predation on chironomid larvae by darters	KSU	Hydrology
Kavanaugh, J.	Phenology of chironomid assemblages in streams	KBS	Hydrology
Knapp, A.K.	Responses of big bluestem to water stress		Meteorology Soil moisture
Abrams, M. D.	Plant species composition responses to fire		Plant spp. comp.

There are other short-term investigations being planned with support pending. Others were not listed because the data gathering phases are over even though publications are not yet submitted. The publication list documents past investigations. The point is that most of the work that is being conducted at the site makes use of and contributes to interpretations of the LTER data sets.

IX. ALTERATIONS IN THE ORIGINAL DESIGN FOR LTER

Alterations in the long-term measurments themselves have been minimal, i.e., most of the data sets that were proposed have been initiated, three years of data are archived, the fourth year's data is approaching that stage and the fifth growing season is about to begin.

The changes documented here are methodological, refinements and/or additions.

A. Changes in methods

1. Above ground biomass was proposed to be measured with a technique based on the principle that plant biomass absorbs beta particles and that the attenuation of beta radiation from a known source to a detector a known distance away would be proportional to biomass. If this method had been successful this measure would have been rapid (thus allowing large numbers of samples and a better estimate) and non-destructive (thus allowing the measurements to be made on the same sites through the season and in successive years. The method proved to be satisfactory for the burned areas, but not for areas where there was substantial dead vegetational mass. Unfortunatly, the variance from the measurements was too high on the unburned areas for the analyses desired (Knapp, Abrams and Hulbert in press) and the method has been abandoned in favor of clipping plots.

Clipped vegetation is sorted to live grasses and forbs and standing dead. This is more tedious and time consuming than beta attenuation, but we will have more information about the plots that are clipped. The number of samples was not sacrificed, only the work required to get the information has increased.

2. Mammal trapping was modified to live trapping on a transect design rather than snap trapping on a grid as originally proposed. These transects are permanent and will remain in place. The original design proposed to estimate populations of only three species, wood rats, cotton rats and prairie voles. The present methods are not limited to these species, rather all species captured are recorded. Thus again, more information is being gathered than was proposed.

3. Plant species composition measurements are more extensive and more quantitative than originally proposed. (cf. Methods manual in Appendix B for current methods).

B. Expansion

1. Belowground measurements. The original proposal was heavily and correctly criticised for its insufficient attention to the soil ecosystem. A considerable amount of effort has been directed to increase the amount of research on below ground processes. A faculty member (Seastedt) has been added whose major focus is on belowground processes. So far, however, the LTER measurments are limited to a soil nutrient analysis on several of the LTER watersheds and to weekly analysis of soil water chemistry sampled at 20 cm and 80 cm during the periods of the year when sufficient soil moisture is present. There are at least 5 replicate lysimeters 20 cm deep in each field and 4 replicates at 80 cm.

The additional belowground work is being done on a short term experimental basis and is parallel to the LTER effort.

The soil environment, while perhaps the most important unknown in the prairie ecosystem, is still the most intractable. Methods for long term tracking that are simple, inexpensive and non-destructive so that long-term data gathering can proceed have not yet been devised to our satisfaction.

An investigation of plant productivity and nitrogen content in relation to fire was initiated in 1980 by Hayes and Hulbert (Hayes 1985). This research has been expanded to include the effects of drought and nitrogen availability on nitrogen uptake, retranslocation of nitrogen and root productivity. Hayes has separated drought effects into water stress and nitrogen stress components and has compared these stresses on big bluestem under greenhouse conditions.

The soil fauna of Konza Prairie has received considerable attention in the last two or so years. James (1982 and 1983) has investigated earthworms and their response to fire and moisture and Seastedt (1984a and b) has investigated soil arthropod assemblages. Additional publications on nematodes (Todd, KSU Dept. of Pl. Path.) are under preparation and on arthropods (Seastedt et al. submitted) in relation to fire and mowing of the prairie.

Hulbert, Seastedt, Evans and Kaufman (BSR 8305436) have collected the first comprehensive data set on above- and belowground plant productivity and nitrogen content in relation to various intensities of above- and belowground herbivory by invertebrates and small mammals. The following hypotheses are being tested.

a. Net primary productivity (NPP) and nitrogen cycling are enhanced by nominal herbivory.

b. Carbon to nitrogen ratios of roots is influenced by aboveground herbivory.

c. Above- and belowground insects compete for plant resources. Removal of belowground insects stimulates increases in populations of aboveground insects and vice-versa.

d. Detritivores, such as earthworms, increase net primary productivity by increasing nitrogen and and phosphorous availability. Root:shoot ratios, however, remain unchanged or are increased in the presence of native earthworm species.

Preliminary results indicate that NPP is not sensitive to low to moderate levels of herbivory, but that the composition and densities of consumer groups are influenced by the activities of other groups and by plant chemistry (C:N). Just as moderate levels of herbivory stimulates plant productivity (e.g. McNaughton 1979), moderate levels of aboveground herbivory also stimulates productivity of belowground herbivores, i.e., moderate grazing increases both primary and secondary productivity (Seastedt in press).

Preliminary observations have led to the planning of additional investigations. Proposals have been submitted to conduct the following:

rejected —	Todd and Seastedt	Evaluation of herbivory by nematodes	USDA
Funded —	James and Seastedt	A comparison of native and introduced (European) earthworms on productivity of tallgrass prairie	NSF (BSR 8506452)

Much of the soil nitrogen work recently conducted at KPRNA has been done by visiting scientists from Colorado State University (W. J. Parton and D. S. Schimmel) collaborating with C. E. Owensby (KSU, Dept. of Agronomy) and L. Kapustka (Miami University, Ohio). They have investigated soil nitrogen immobilization and mineralization processes in relation to fire. Hypotheses currently being addressed are:

e. Fire increases nutrient availability by changing soil temperature and immobilzation potential.

f. N_2 fixation is depressed and $N_0$2 and NO_3 losses are enhanced in the absence of fire.

g. Grazing reduces N loss by directly returning N to the soils and by reducing fire intensity.

h. Fire intensity influences subsequent forage quality by controlling post-fire residue levels.

i. Uneven grazing generates patches of varying fire intensity and, hence, forage quality.

The results of these investigations will be useful as we prepare for the investigation of stream water and dissolved export of materials from the treatment watersheds and as we design investigations following the reintroduction of bison, elk and pronghorn to the site.

Another project submitted to NSF by A. P. Schwab (KSU Dept. of Agronomy) proposes to study the phosphorous cycle of the tallgrass prairie. The study assumes that the productivity of the tallgrass prairie is seldom if ever phosphorous limited, yet phosphorous is found at low level. Schwab et al. therefore assume that the system has evolved mechanisms to obtain phosphorous depsite its low availability. The group (that includes B. A. Hetrick, a mycologist in the Dept. of Plant Pathology and Seastedt) will:

j. Measure fluxes of inorganic and organic soil phosphorous in burned and unburned prairie.

k. Compare phosphorous uptake mechanisms of prairie forbs and grasses.

l. Quantify the effects of mycorrhizae and soil invertebrates on the phosphorous availability to plants.

2. Stream measurements. LTER data proposed originally were limited to hydrologic measurements provided by the U.S. Geological Survey's contribution plus several data sets to be determined as ongoing investigations, e.g., decomposition (Killingbeck et al. 1982), leaf degradation (Smith 1982), organic matter loading (Gurtz, et al. 1983), photosynthetic production (Petersen unpubl.).

The Survey's contribution results from the inclusion of the Kings Creek watershed in their network of benchmark watersheds (cf. overlay A). The gage is a "bubble gage" in the open unmodified channel. Figure 6. illustrates the first 5 years of the USGS record.

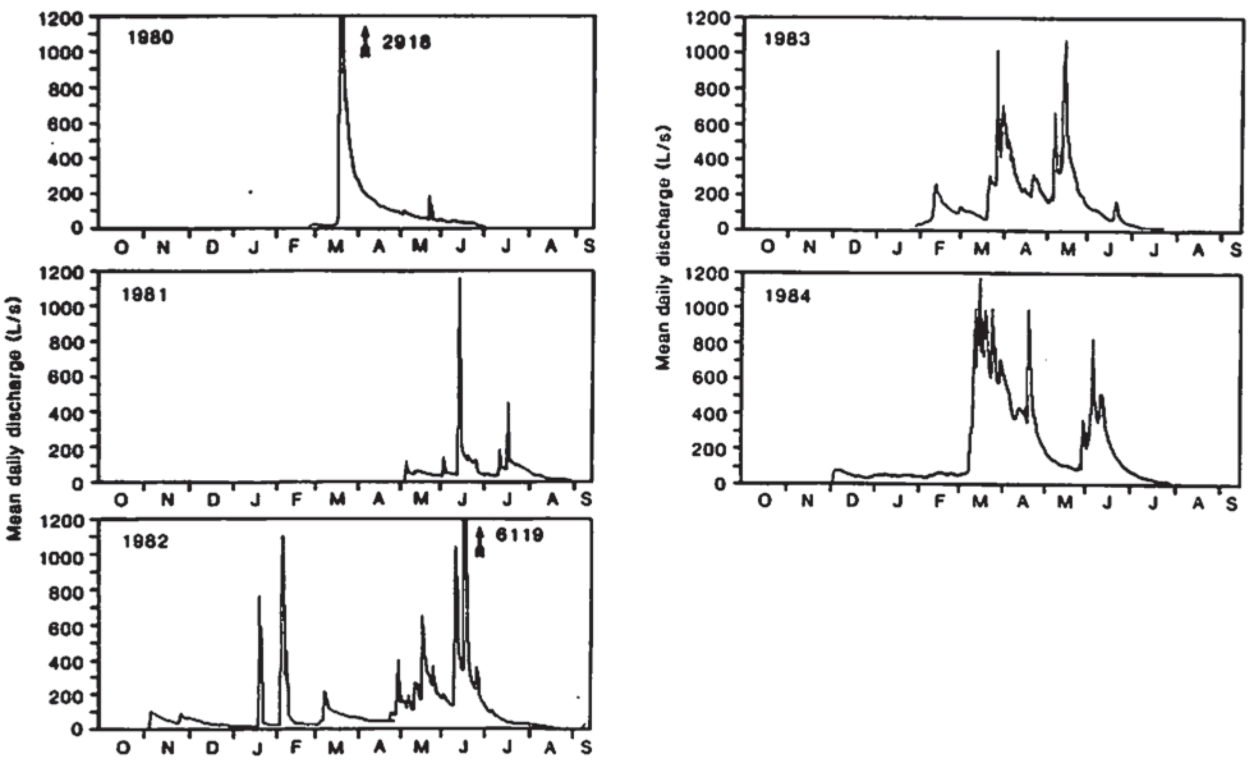
This has been useful information for the interpretation of three M.S. and five Ph.D. thesis investigations (Petersen 1978, Smith 1982, McArthur 1984, Tate 1985, Hooker 198-, Petersen 198-, Loring 198- and Kavanaugh 198-) and an investigation of organic matter loading (Gurtz et al. 1982).

It has served also as the basis for a current study of hydrologic regimes (Gurtz 1984-1986, NSF Fellowship in Environmental Biology). Hydrologic disturbances occur at both ends of the hydrologic spectrum, flooding and drought. Hypothetically, the long term patterns of intensity and recurrence interval of these events influence the life histories and the community structure of stream invertebrates. This work is designed to test that hypothesis. The hydrologic pattern is also being used to compare the hydrologic predictability of streams in the LTER network and elsewhere.

The USGS gage is located downstream from the confluence of streams draining the Kings Creek LTER treatment units and thus its record integrates them rather than being useful to evaluate them. Furthermore, the USGS stream water chemistry data was sporadic and usually characterized base flow conditions. We know from two years of sampling through the course of storm flows from watersheds 1D and 2D that storm flow chemistry is strikingly different from base flow chemistry. Conductivity decreases through the hydrograph (a SO_4 and CO_3 dilution effect) while NO_3-N and dissolved organic carbon concentrations increase several fold. The fact that we do not have discharge data to accompany these measurements is frustrating but we do conclude that storm flow exports of nitrogen and organic carbon are the most interesting and significant.

Kings Creek hydrograph

Fig 6.



The U. S. Environmental Protection Agency became interested in the water quality data because it represents a unique baseline for the agricultural midwest. A proposal was prepared to provide measurements at the scale of the fire treatments and to add these to the LTER measurements. That proposal is still pending. Meanwhile, four triangular-throated flumes have been constructed on watersheds NUB, N1, N4 1987 and $N2_e$ (Overlay A) so that we could begin to collect pre-treatment data. Data loggers and sensors are on order. The period of record from these begins in the spring of 1985.

Investigation of ecological phenomena in this prairie stream is, we believe, soundly based though just beginning. The measurements to be added to the Konza Prairie LTER measurements (cf. the next section of the proposal) will provide the most important data for the widest array of investigations, both aquatic and terrestrial, and they are expandable when resources are available. The additions are substantial.

X. CONTINUATION AND REFINEMENT: DEVELOPMENT OF HYPOTHESES AND QUESTIONS

A. Background, watersheds:

The terrestrial landscape unit most often used to study ecosystem level phenomena is the watershed, this is axiomatic. Likens et al. (1970) and Swank and Douglas (1974), for example, manipulated watersheds with clear cutting, pesticide application and reforestation to evaulate effects on nutrient to evaluate effects on nutrient and water releases. Nutrient budgets have been used to gain initial insights (Likens et al. 1967). Materials imported to watersheds with precipitation and dryfall have been measured and compared with water-borne exports and with accumulations in various elements of the biogeochemical system. The resulting comparisons then have been used as integrative observations to infer ecological processes in the watershed. Subsequent investigation often reveals regulatory mechanisms and controlling processes mediated by the biota (e.g. Gosz et al. 1976).

Background, disturbance:

Ecological disturbances are events that disrupt community structure through loss of biomass and/or individuals and/or through alteration of resource availability. They are characterized by their intensity, their frequency and their spatial distribution. The responses of biotic elements of a system to a given disturbance depends on the structure of the system (its physical configuration and biomass distribution), the vulnerability of individuals and the life histories and competitive characteristics of the biota after the disturbance is past. Disturbances have been considered in terms of stability (Connell and Slatyer 1977), species richness and diversity (Connell 1978; Evans 1984), competition (Dayton 1971), patch dynamics (Paine and Levin 1981) and succession (White 1979). This is an active area of inquiry, especially among students of communities and populations.

Many other connotations of disturbance, e.g., damaging, make the word difficult to define or, more accurately, less useful as a descriptor of how events in nature operate to produce the non-equilibrium mosaic that we perceive as community or ecosystem. We are considering, for example, that the absence of fire in prairie is a "disturbance", surely this is an unconventional use of the word, yet the absence of fire has effects that fit the common view of ecological disturbance. Such phrases as "spatial and temporal heterogeneity", "pattern and process", "patch dynamics", "time-space interactions", "gap formation" etc., testify that ecologists are grappling with problems of this sort. This makes it clear that disturbances or perturbations over a wide range of intensities and frequencies are surely involved in the development of ecosystems.

B. Applications to Konza Prairie

The original guiding hypothesis (p. 2) was a general expression of our outlook as we began the development of a research program at a new site for ecological research. The phrasing of the hypothesis was intended to emphasize two aspects of ecological inquiry: (1) the development of models of prairie energy flows and material cycles (an ecosystem approach) and (2) the examination of the complexity of how populations of organisms are distributed, how they grow and decline, how they compete, how they have evolved (a community or population approach). We consider those approaches to be heirarchically organized; their integration is bound to lend more robust character to ecosystem models.

The application of many different talents and skills will be required to uncover the controlling phenomena at the several levels in the ecosystem hierarchy. Concentrating research at sites is appropriate. KPRNA is well suited to such a focus/goal, and the people that have gathered to work toward it are enthusiastic and talented. Our original hypothesis was a useful guide for the LTER measurements initiated in 1980, it stands at the center of many more specific hypotheses being tested and it provides a basis for potential comparative work.

Given that: (1) fire and grazing are significant evolutionary forces in grassland, i.e. they are selective forces for adaptive features of organisms in tallgrass prairie and that (2) the biota are involved in mediating ecosystem responses to disturbance or experimental manipulation, a major value of long-term, site specific research emerges. That is, new knowledge accumulates in a matrix of related empirical information. Thus, the data base is more realistic for modeling, for synthesis and for testing theoretical ecosystem constructs.

Relatedness often is inferred from trophic patterns. We know, for example, that investigations of the responses of vegetation to fire and grazing will aid interpretation of investigations of consumer responses to fire (Evans 1984) and competitor responses to grazing (Seastedt, in review). In fact, a direct trophic scheme demands that consumer responses be defined in terms of producer responses. Consider, however, that some plant phenomena are driven by consumer activity. The complex reality also includes indirect responses among plants (Tilman 1985) and significant feedback mechanisms between consumers and vegetation (Wiegert

1965, McNaughton 1983 and LaMotte 1983). We conclude that evaluation of ecosystem responses involves watershed level measurements and community level interpretation.

Our original hypothesis is, however, no longer sufficient to express some current approaches to the development of LTER in tallgrass prairie. Our perspective of the research utility of the site has expanded with experience, as new scientists have joined us, as patterns in the data have unfolded, as visiting scientists have begun to work here and as our advisory group has become involved in our planning processes.

C. Implementation for LTER at Konza Prairie

The preceding has guided our thinking as we look toward further development of LTER at Konza Prairie.

No changes in the management plan are needed to implement what we propose here, only additional measurments to make more analyses more robust. The basis for this follows.

The watershed basis for the management plan at Konza Prairie places the scale of the experimental manipulations (viz. disturbances) at the appropriate level for ecosystem investigation. Thus, we have the opportunity to compare the responses of treatment units (and the biotic components living and evolving in them) to the fire disturbances that typifies or is intrinsic to the prairie ecosystem. Grazing, as an experimental manipulation, is less restricted to the various fire treatment watersheds, but with appropriate information about the behavior of the grazers we believe that we can learn useful things about tallgrass prairie specifically, and ecosystem function in general.

We now propose to:

1. continue for the period 1986-1990 the same measurements on the same seven watersheds (1C, 1D, 4B, UB, NUB, N1B and N4 1987) that have been the focus of our attention these past four years. The uninterrupted decade of 40 or so data sets will be useful for the examination of the tallgrass prairie ecosystem,

2. expand the LTER effort to include:

(a) routine LTER data collection from two additional watersheds burned at two year intervals ($2D_e$ and $N2_e$) in order to provide more useful time sequence data to test theoretical constructs involving intermediate frequencies of disturbance;

(b) routine LTER data collection from replicate watersheds burned at four year intervals (4A, 4D, 4F, N4A 1984, N4C 1986, N4B 1985) to provide a spatial heterogenity component through time and to provide for a closer analysis of the interaction between fire and the behavior of the grazers, particularly bison;

(c) modeling efforts to evaluate the emerging patterns and lead to synthesis and new short term investigations;

(d) planning, after Phase I of the reintroduction of the native ungulates, of more detailed investigation of the interactions between herbivores and vegetation in response to intervals between fires; and

(e) routine hydrologic and stream chemistry data from four watersheds (NUB, N1D, N4D, 1987, $N2_e$) that:

i- provide for integrating measures of watershed level phenomena

ii- are nested in the Kings Creek (USGS benchmark) watershed;

iii- are treated differently with respect to the interval between fires but are equally accessible to grazers; and,

iv- include detailed topographic charts of reference stream segments.

XI. UNIFYING QUESTIONS, HYPOTHESES AND MODELS

The following provides examples of some of our thoughts. It is not meant to be definitive, rather to be persuasive that the management design and our choices of long term measurements are and will be useful to a wide range of inquiries, now and later.

A. Terrestrial communities

Many community ecologists are stressing the importance of recurring, "natural disturbances" in determining patterns (or lack thereof) in the communities they study. We are examining how fire acts to influence consumer assemblages on Konza Prairie. At least two aspects of community structure are presently concerned with disturbance theories and both are postulated to vary with the frequency of disturbance, a feature that the KPRNA management plan especially enables us to consider:

1. Community stability: Disturbances are thought to affect individual species in different ways and/or to different degrees, thereby disrupting equilibrium or stable conditions, or preventing conditions from ever coming to equilibrium.

Regarding prairie fire in particular, a working hypothesis can be advanced: "Stability in species composition and density of consumers is dependent on the frequency of fire. Annual and unburned treatments result in the highest stability which then decreases with length of the interval between fires." (illustrated in Fig. 3.)

Stability in species composition: illustrated by birds, mammals and grasshopppers (Figs. 2, 3 and 4).

Stability in density: illustrated by birds (Figs. 3.)

2. Community diversity. A number of recent papers have stressed that periodic disturbance to natural communities may maintain high species richness and diversity both regionally and locally.

a. Regional diversity: Fire as a disturbance may maintain high consumer diversity in tallgrass prairie by preserving (or continually regenerating) habitat diversity across the landscape. (illustrated by Fig. 4)

b. Local diversity: Periodic disturbance to natural communities maintains high diversity by preventing competitive exclusion, and furthermore, that highest diversities may be maintained by periodic disturbances occurring at intermediate frequency.

While emphasis has been placed on the direct effects of disturbance on interactions of competing organisms, the general theme can be extended logically to include secondary or indirect effects of disturbance on other organisms that exploit these competitors, e.g., consumers of terrestrial plants. (illustrated by prairie grasshoppers, Fig. 2)

B. Terrestrial ecosystems

We recognize that the tallgrass prairie ecosystem is hierarchically organized and composed of components operating and responding at different fequencies (Allen and Starr 1982). Some of this frequency is experimentally controlled at KPRNA. Some questions that are being asked at all levels of the hierarchy are:

1. What are the patterns of temporal variation in ecosystem processes, in community organization and in population dynamics?

2. Are these characteristics of ecosystems, communities and populations "patchy"?

3. How do "natural disturbances" (macro-resetting events?!) alter the tempoporal patterns from those seen in other systems without disturbance?

4. Do "natural disturbances" reduce or increase spatial heterogeneity compared with similar communities or systems without disturbance.

Perturbations by fire and grazing by large ungulates are interpretable by their effects on the energy, nutrient and water balances of the system. These effects, therefore, center on the removal of standing dead and litter.

In the absence of this an interrelated group of negative feedback loops reduces productivity (Fig. 7) whereas, fire or moderate grazing by large

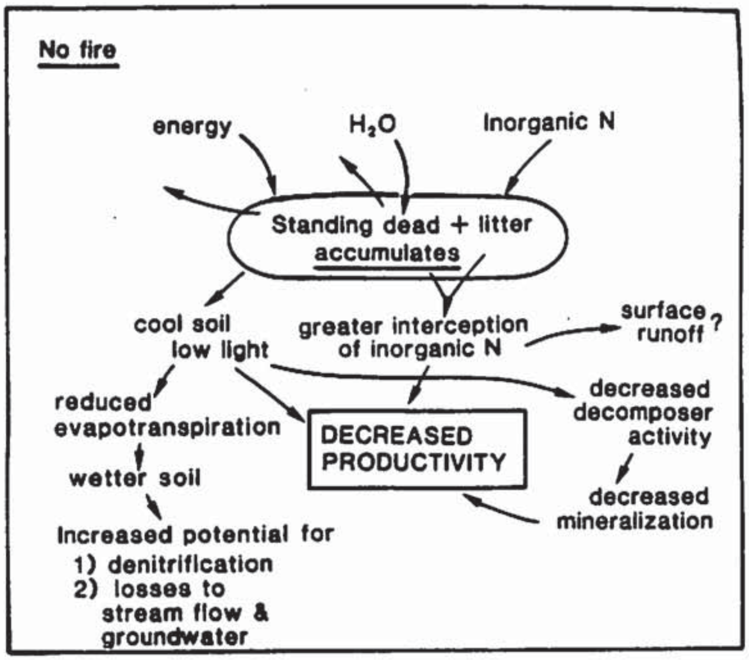


Fig. 7

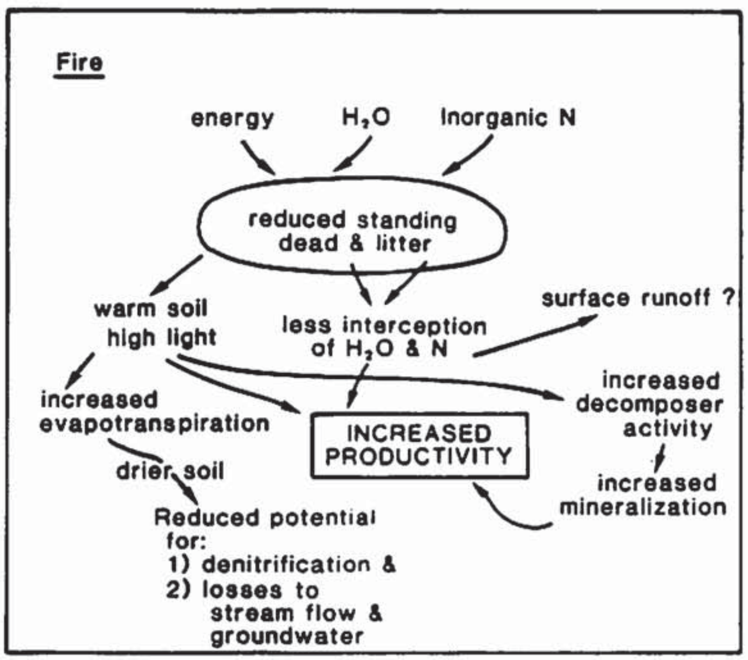


Fig. 8

mammals creates positive feedback loops to increase productivity (Fig. 8).

In the absence of repeated burning and/or grazing, however, decomposition does not "keep up" with aboveground NPP. This provides the negative feedback that prevents the system from maintaining continued high levels of NPP.

Thus, productivity should always be maximized in a year following fire, except in years when reduced availability of water limits late spring growth.

Soil detritivores, such a certain nematodes and earthworms increase in density following fire and their activities may form another positive feedback loop. Their activities are related, however, to soil temperature and rhizosphere phenomena such that their presence in high densities is insufficient to maintain the system.

C. Aquatic ecosystems

The Kings Creek basin lies entirely inside the boundaries of KPRNA. It is a USGS benchmark watershed (Beisecker and Lefieste, 1975). Its two major branches represent the grazing treatment by native ungulates and the non-grazed ("K") control in the management plan. The effects of the grazing treatment will be difficult to evaluate rigorously, but with sufficient pre-treatment data and observation we are confident that interesting information can be gained.

The stream exemplifies the characteristics of tallgrass prairie streams described by Jewell (1927); including channels with ephemeral, intermittent and perennial flow. Most of the precipitation in this mid-continent climate occurs in late spring and early summer in the form of thunderstorms. The resulting storm flows rise and fall rapidly, i.e., hydrographs with sharp peaks. By the end of the growing season many channels are dry. The Fig. on p. 23 illustrates this with the first few years of the USGS hydrologic record. Thus flood and dessication are added to our consideration of "natural disturbance". (M. E. Gurtz is midway in the first of a two year investigation of the responses of stream invertebrates to differing hydrologic regimes in this watershed.)

The disturbances of fire and grazing that are being investigated in the treatment watersheds may have measurable effects in the streams, e.g., we hypothesize that runoff from burned watersheds will be greater than from unburned watersheds where the lesser runoff is also delayed.

Hypotheses concerning nutrient cycling are testable as well. Tate (1985) correlated mid-summer depression of nitrate concentration in stream water with the growth/dormancy pattern of the grasses. This leads to the hypothesis that spring fire, which accelerates the initiation of grass growth, will reduce nitrogen losses from burned watersheds by depressing stream nitrate levels earlier in the year than without fire. Alternatively, changes in runoff patterns and reduced interception of nitrate laden precipitation may increase nitrogen losses on burned watersheds. Timing of fire, precipitation and the precedent soil moisture conditions are confounding elements of the picture.

Riparian vegetation in the watershed has two distinct growth forms (Fig. 10 & 11); the headwaters are embedded in grassland and the lower reaches flow through a forest where oaks, hackberry, elm, ash and sycamore trees are characteristic. The stream courses are the only places where such forest develops in tallgrass prairie, thus the special term "gallery forest". We hypothesize that increasing the frequency of fire in watersheds containing gallery forest will cause the forest to recede (Fig. 13), thus the quantity of organic material entering the streams from riparian vegetation will decrease. Gurtz et al. (1982) documented the differences in organic loading from these riparian zones and McArthur (1984, 1985) demonstrated that dissolved organic matter quality from different riparian sources controlled microbial assemblages and their metabolism in the stream.

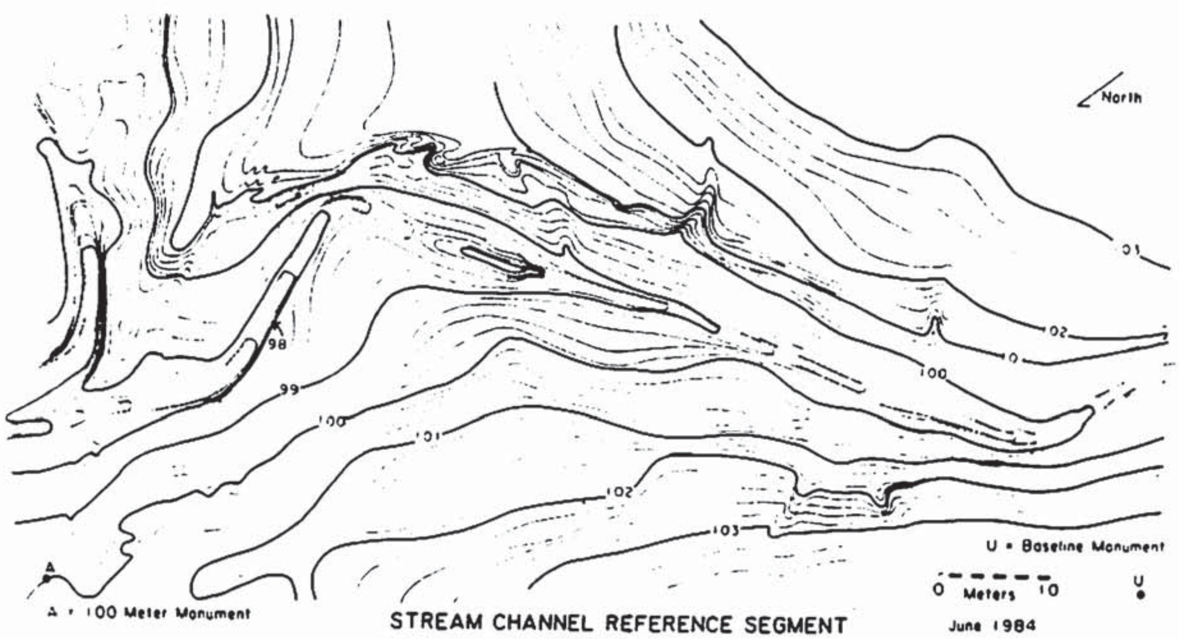
G. R. Marzolf is initiating investigations of dissolved organic materials from riparian vegetation in collaboration with E. M. Thurman (U.S.G.S., Denver) and G. E. Petersen has completed the data collection phase of a thesis investigation of instream photosynthesis in prairie and gallery forest reaches of the watershed. These investigations center on the interactions of instream processes, photosynthesis, decomposition and hydrologic regime. Watershed processes such as growth and production of riparian vegetation are influenced by fire, thus we hypothesize that riparian vegetation will mediate an influence of fire on water quality. Our initial foci are nitrogen and organic carbon quantities and qualities.

The original proposal did not propose measurements at the treatment watershed level. We were uncertain of the costs and did not want to overbalance an essentially terrestrial investigation with aquatic measurements. The long term data to describe pattern in the stream was relegated to the U.S.G.S. benchmark gaging operation.

The USGS data are useful, but they are inadequate to evaluate the effects of fire. Hydrologic measurement is indispensable (the <u>sine qua non</u> of watershed investigations) so we have begun to install gaging structures, data loggers and flow proportional automatic stream samplers at the points where streams leave the treatment watersheds (overlay A) We propose to add stream discharge, nitrogen concentration, temperature and conductivity to the LTER data sets.

If fire and grazing alter hydrologic regimes it follows that there will be geomorphic effects: erosion, sediment transport and deposition. The grazers themselves are expected to use the stream as a water source, a potential artifact of being "fenced away" from larger water sources such as larger rivers. To anticipate such questions we have established reference stream channel segments in several of the watersheds (overlay D). The positions of the segments were chosen to equalize watershed size and to be in the same geologic formations in each watershed. Fortunately, the shale and limestone strata dip only slightly so positioning the reference segments in the same formations also fixed the sizes as nearly -

equal. Fig. 9 is an example of the topographic charts that were prepared. These are accompanied by photographic records from monument points. M. D. Abrams is initiating a detailed investigation of woody vegetation invasion that will include these reference segments (these watersheds have not been grazed or burned since 1976). Changes in woody species distribution and dominance, in stream channel configuration, wood loading to the channel, recovery of grasses etc., after the implementation of the fire manipulations in 1987 and the later reintroduction of the grazers can then be documented.



STREAM CHANNEL REFERENCE SEGMENT
WATERSHED N4$_{West}$
KONZA PRAIRIE RESEARCH NATURAL AREA
SOUTH BRANCH OF KINGS CREEK
Contour Interval = 0.20 Meters

One of seven reference stream channel segments established in 1984 to provide for documentation of geomorphic effects of fire and grazing mediated by potential alterations in the hydrologic regimes of experimental watersheds.

Figure 9.

XII. SITE DESCRIPTION

Konza Prairie is representative of Flint Hills Upland, a broad band of tallgrass prairie that extends from Oklahoma nearly to Nebraska, averaging about 70 km wide. It is a dissected upland with hard chert- and flint-bearing limestone layers that result in these steep-sided hills (Figs. 10 and 11.

The vegetation is characteristic of native tallgrass or bluestem prairie, Andropogon-Panicum-Sorghastrum, #74 of Kuchler (1964) and # 2530 of the prairie division of the humid temperate domain of Bailey (1978). Since settlement about 130 years ago KPRNA had been grazed by cattle during the growing season (about May 1 to Oct. 1). It was burned often in the springs to encourage early grass production, to discourage the growth of woody vegetation and to encourage more even grazing. The majority of Konza Prairie was in good to excellent range condition when acquired, i.e., the native species were dominant and vigorous. More than 430 species of vascular plants are now documented by specimens in the KSU herbarium. Since acquisition the tallgrass species have become more dominant on those treatments burned annually but not grazed (Fig. 13). In wet years the flowering stems on lowland soils reach nearly three meters in height over extensive areas.

A. Site integrity

The Nature Conservancy, a private, non-profit membership governed organization purchased the site and has set it aside for ecological research. The Nature Conservancy has an exemplary record in ensuring site integrity. KPRNA is an ecological preserve for the "indefinite future" meant to be "in perpetuity". The site has been identified as an Experimental Ecological Reserve (EER) (Reichle and Lauff 1975) and as a Man-and-the-Biosphere Reserve by UNESCO.

The lease and ownership agreements with Kansas State University involve the payment of taxes and insurance and the mangement of the site for research purposes by the Division of Biology. The management of the site has been integral with the LTER effort and was described earlier. KSU staff live on the site permanently to help protect against vandalism. This has not yet been a problem. The site is surrounded by farmers and ranchers who have been on their land, in many cases, all of their lives. They have visited KPRNA, know our objectives and cooperate with us. We know that we have gained their support.

The support from Kansas State University for the development of the program at Konza Prairie has been good and it is growing. The management costs are borne by a line item in the University budget. The increase that we sought for this year was identified as the number two priority item from the University to the Kansas Board of Regents. This period of austerity and political turmoil on budget matters in Kansas led to a deletion of the item by the Governor. The Kansas legislature recently (15 March) reinstated it. Existing support from the University is solid and, while the increase is uncertain, it also seems that there is support for our efforts elsewhere in the state.

Fig. 10. An aerial view of Konza Prairie illustrating the heterogeneity among and within watersheds. Note the patchy vegetation on the flat at the right center of the photo, related to grazing intensity in the past.

Fig. 11. A downslope view of the lower portion of the Kings Creek basin showing the gallery forest along the lower reaches of the stream course. Note also the pattern of interbedded Permian shale and limestone that nearly follow contours and impart a banded pattern to the vegetation on the slopes. This may be a response to variations in water available at the surface as well as being due to parent material of the soils.

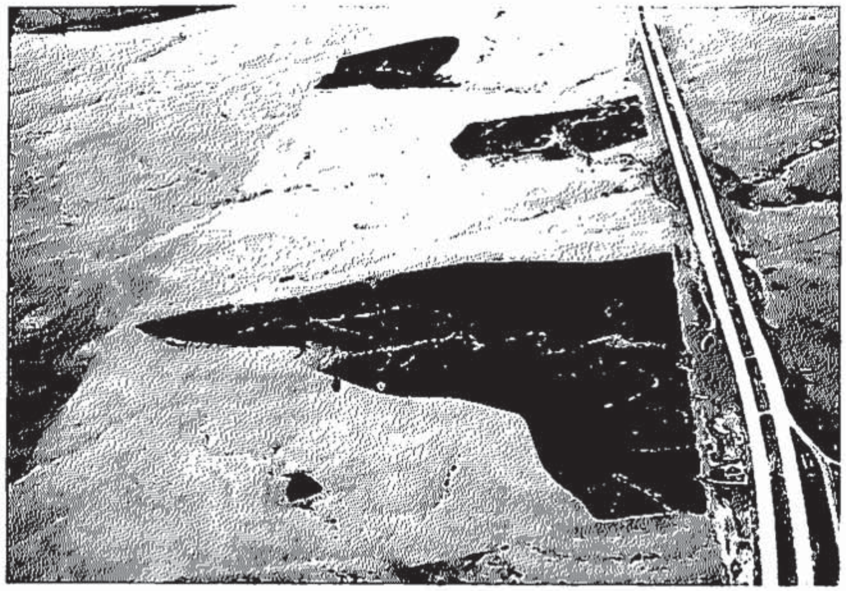


Fig. 12. Ungrazed treatment watershed in April 1974, prior to the purchase of the Dewey Ranch (upper left). Note the difference in the grazed and ungrazed vegetation on either side of the fenceline that runs from lower left to upper center. Burned watersheds are 1A (foreground), 1B (middle distance) and 4D (background). Interstate 70 is at the right. The purchase of the Dewey Ranch, 3 years after this photo, allowed revision of the boundaries to include entire watersheds.

Fig. 13. An illustration of the interaction of fire and grazing on vegetation. The area to the left was frequently burned, thereby supressing the growth of woody plants, thus the grasses dominate. In contrast, the area to the right of the fenceline has been unburned for many years and the growth of woody vegetation was not suppressed. (Bragg and Hulbert 1976).

B. Development of facilities

The site is only 12 miles from the campus (Figure 14). For most purposes local scientists' work from the campus is possible on a routine basis, year around. For security purposes, the site manager and some researchers live on the site. A few visiting scientists have been accommodated on the site for short periods. Those who have stayed for extended periods have lived in Manhattan and we have been able to supply some space on the campus. Because of this proximity, the need for on-site facilities has been minimal and the development of the research program has been more rapid than if the site had been remote. As use by visiting scientists increases, as we anticipate, space at Konza Prairie will be further developed.

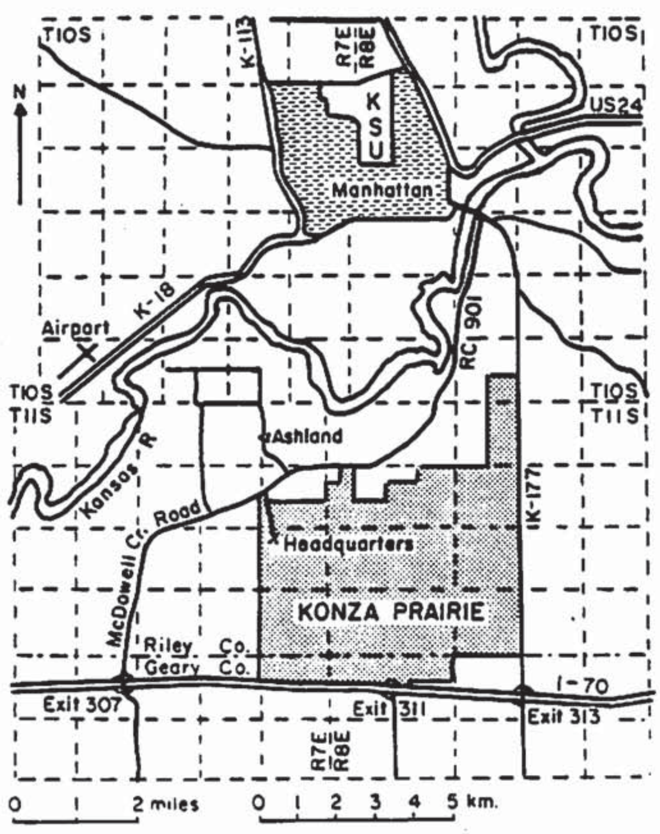


Fig. 14.

1. On site accomplishments

A. Maintenance of access roads is a continuing high priority item. The main road through the Kings Creek watershed and along the divide receives more traffic each year. Efforts to improve and to maintain this road have been substantial. Access to most research sites is by foot from this road and it is useable for all but the wettest periods and when drifted snow closes it.

B. In addition to the main ranch house there are three frame houses on the site that have been made liveable. One is occupied by the site manager, (Gelroth) and the other two are occupied by researchers (Gurtz in one and Seastedt and Tate in the other). There is still work to be done on these buildings but occupancy on the site is important.

C. The 8' electric fence for enclosing the native grazers is under construction. The first phase of the reintroduction is to take place on an area at the western half of the eventual grazer area (see overlay D). All of the materials for the fence have been purchased and a power company line truck was purchased to aid the construction. The fence is being constructed by KPRNA staff.

D. Four triangular-throated flumes were finished last fall so that hydrologic data could be added to the LTER program (see overlay A). A proposal to construct additional stream gaging points and operate them for purposes of evaluating baseline water quality is still pending with the EPA. The data loggers and the sensors for stream discharge are to be shipped on 1 April 1985.

E. A pre-fabricated building from the campus was moved to the site by the University.

F. The existing stone ranch house and barn were acquired with the site and are useable to some extent on a seasonal basis. They are structurally solid and they represent potentially excellent space for visiting scientists, laboratories, meetings, short courses and conferences and visitors. In order that the space can be used for short stays by visiting scientists and so that some work can be done at the site by local scientists and students, one large upper room was air conditioned, a phone was installed and a toilet and shower room were improved. A vehicle maintenance shop and a small workshop was developed in an outbuilding at the headquarters area. This small facility is well organized and run efficiently by the site manager (Gelroth) and his staff.

G. KPRNA owns and operates several pieces of fire control equipment; two three-quarter ton 4WD pick-up trucks and two farm tractor and trailer units each with "slip-on" water reservoirs with pumping power and hoses. This equipment has been developed over the past five years and KPRNA personnel are instructed in its use. There is radio contact between fire control vehicles, with the headquarters area at the site and with labs on the campus. The radio is operated on a

U. S. Forest Service restricted frequency with no other users in the area. The fidelity of reception is exceptionally good and the range of the unit is approximately 30 miles. We have devised a system of phone communication among KPRNA staff so that in the event of accidental fires a crew can be assembled at the site rapidly. It worked on the one occasion when it was used in 1984.

2. On site development yet to be accomplished

A. All weather storage for fire control vehicles. During feeezing weather (Nov. - Mar.) the water reservoirs in the fire control units must be drained because the pumps and valves don't withstand freezing. To achieve readiness to fight accidental fires we intend to insulate and minimally heat a building for the storage of the fire equipment during freezing weather. Development of space for vehicle maintenance and research construction may be done at the same time.

B. As the research program develops (see goals, page 3) the needs of visiting scientists require attention. Visitors to this point have been patient and tolerant of somewhat difficult conditions. Furthermore, we believe that in order to make best use of the site for research purposes, that we will have to exert some effort toward making the accomodations appealing.

To accomplish this we are in the serious planning stages and will soon be seeking support for the following:

C. Renovation of space in the stone house and/or elsewhere for visiting scientists

D. Provision of laboratory space for visiting scientists and for local scientists for some purposes, e.g., insectary, artificial stream, data logger maintenance and data entry, space for plant, etc.

E. Bath house and cooking commons for visiting scientists.

F. Development of a conference center and educational facilities.

G. Equipment storage and further improvement of roads and trails.

3. On campus accomplishments

Since 1983 the KPRNA faculty and staff have been granted and have redesigned most of an additional floor of Bushnell Hall on the campus. Much of the renovation (lighting, painting, tiling floors) has been completed and more will be done this year.

A. Several rooms have been especially treated: two wet labs for the installation of auto analyzers, glass washing and sample preparation, and a new reverse osmosis distilled water system for the entire building is now being installed.

B. One room was equipped for data management; i.e. computer hardware in one place, disc storage, hard copies of the LTER data and documentation information.

C. A conference room.

D. Other of these rooms provide office space, sorting space, weighing, drying ashing, etc. for the LTER personnel and student hourly workers.

E. The KSU computing center routinely backs up archived tapes on a three tape rotating protocol. One tape on call, one tape in storage in a vault at 1300 feet below ground in a salt mine in Rice Co., Kansas (i.e., secure) and the third one is a copy of the secure tape but kept on the campus. These tapes are rotated on a routine basis every six months. LTER data that has been verified and archived is automatically treated in this way, in addition to our own back up procedures. (Appendix D).

XIII. USE OF THE SITE BY OTHER INVESTIGATORS AND AGENCIES

A. KSU faculty and post-docs. The availability of Konza Prairie for research purposes has provided a new opportunity for ecological researchers in Kansas. The number of short-term investigations, including thesis research, is growing rapidly. Most of these are presented earlier (p. 21-22).

B. Undergraduate research participation. During the period 1974-1980, Konza Prairie was the focus for a successful Undergraduate Research Participation program sponsored by the Division of Biology with NSF support and supervised by J. L. Zimmerman. This program involved 65 students from across the United States during the period when it was active.

C. Graduate students. Completed graduate student dissertations are listed in Appendix A. Current use by graduate students is included on pages 16 and 17.

D. Scientists from other KSU departments

Several scientists from departments in the College of Agriculture have made use of the site for aspects of their work.

Auen, L. Effects of clipping in winter on loamy upland prairie.

L. Corah 1982-1983. Evaluation of a growth stimulant (rumensin) for cattle.

Hetrick, B.A. Vesicular-arbuscular mycorrhizal fungi associated with tallgrass prairie and cultivated winter wheat.

E. Kanemasu 1983- Measurement of aboveground biomass with reflectance spectrometry. NASA.

Owensby, C. E. 1983- Effects of fire and grazing on nitrogen cycles in tallgrass prairie. See Parton et al. below.

Sweet, R. 1981- Biosystematics of spiders

Todd, T.C. 1983- Nematodes of tallgrass prairie.

B. State, federal and international organizations with links to Konza Prairie

U. S. Environmental Protection Agency	Kansas Department of Health and Environment
U. S. Geological Survey	Kansas Fish and Game Commission
National Aeronautics and Space Administration	Kansas Historical Society
U. S. Dept. of Agriculture	British Broadcasting Corp.
The Nature Conservancy	UNESCO's Man and the Biosphere

C. Visiting scientists

Kavanaugh, J. and L. Ferrington. 1985 - Biological Survey of Kansas, Diversity, species richness and phenology of chironomid midges in Kings Creek.

Ferrington, L. 1985. Biological Survey of Kansas. Distribution of midges in the Kings Creek basin.

James, S.C. 1984 - Maharishi International University. Effects of fire and competition on native and introduced earthworm populations.

Kapustka, L. 1983- Miami University of Ohio. Nitrogen fixation in tallgrass prairie.

Kryson, J. L. 1979-1982. Northern Grain Insects Laboratory, ARS. Brookings, SD. Studies of *Diabrotrea barbari* (Coleoptera: Chrysomelidae) on cucurbits.

Mayo, J. 1983. Kansas State College, Emporia. Ecophysiology and nitrogen metabolism of tallgrasses.

Pigage, J. C. and H. Pigage. 1982. Elmhurst College. Ectoparasites of the eastern woodrat, *Neotoma floridanus*.

Parton, W. J., D. Schimmel. 1983 - Colorado State University. Effects of fire and grazing on nitrogen cycles in tallgrass prairie.

XIV. COLLABORATION OF KPRNA SCIENTISTS WITH OTHER LTER SITES.

Gurtz, M. E.	Hydrologic predictability and its influence in stream ecosystems. Using data from Konza Prairie. Coweeta, H. J. Andrews and Large Rivers
Gurtz, M. E. Marzolf, G.R	Organic matter processing. J. Webster (Coweeta) is organizing this comparison across LTER sites.
Marzolf, G. R.	Quality of dissolved organic carbon in stream and soil interstitial waters. With E. M. Thurman, U.S. Geological Survey, Denver. Konza Prairie and Niwot Ridge.
Marzolf, G.R. Gurtz, M. E	Sediment transport workshop sponsored by N. Bhowmik (Illinois Water Survey and Illinois Natural History Survey) This will involve representatives from sites with stream components to examine the possibilities and feasibilities for comparative work in geomorphology.
Seastedt, T. R.	Comparative investigations into phenomena involving litter and soil arthropods is being organized by. J. Lattin (Andrews)
Seastedt, T. R.	Sulfur cycles in LTER soils. J. Fitzgerald (Coweeta) performed the comparative analyses from soils from several LTER sites.

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XVI. PERSONNEL, INTERSITE ACTIVITY AND ADVISORY COMMITTEE

A. Current personnel

During the tenure of the LTER program the "Konza Prairie group" at Kansas State University has grown some and the leadership of the project has become more and more a group enterprise. L. C. Hulbert, G. R. Marzolf and J. L. Zimmerman have provided the continuity. New co-P.I. and faculty additions include E. W. Evans, D. W. Kaufman and T. R. Seastedt. O. J. Reichman, another new faculty member, is initiating work at the site and will become more formally involved this summer and fall.

Lloyd Hulbert is the Director of the Konza Prairie Research Natural Area. He takes responsibility for seeing to the management of the site and directing the activities of the site manager, Joe Gelroth. He takes responsibility for bringing decisions about the LTER vegetation data sets before the group and provides the leadership in seeing to the publication of vegetation oriented investigation. He convenes the KPRNA executive group for discussions of KPRNA program development.

Dick Marzolf is the PI of the LTER project. He takes responsibility for the administration of the LTER grant and the data management system, though major decisions about personnel, budgeting and science direction are very much a group effort. Marzolf takes responsibility to convene this group of scientists for administrative purposes related to the grant. He represents the project on the LTER coordinating committee. He takes responsibility for bringing decisions about the stream chemistry and hydrology data sets before the group, and provides the leadership in seeing to the publication of pertinant results of aquatic investigations.

Marzolf is planning a sabbatical leave in the AY 1985-86. He will spend the year with the U.S. Geological Survey in Denver. The objectives of the sabbatical include: (1) the development of the LTER hydrological analyses in collaboration with Survey hydrologists and (2) examination of dissolved organic matter quality in soil interstitial water and stream water from Konza Prairie in collaboration with Mike Thurman who is performing similar analyses at several sites including Niwot Ridge. Jerry Leenheer and Ron Malcomb in the Survey laboratory are evaluating the structure of humic acids, with the water source for that being the Okefenokee Swamp.

John Zimmerman is directly involved in the collection of long term records of breeding bird populations and avian phenology. He takes responsibility for continuous attention to the accuracy and writing of the KPRNA/LTER methods manual, an essential documentation task. He takes responsibility for bringing decisions about the avian data sets before the group and sees to the publication of results in that area.

Don Kaufman is the Associate Director of the KPRNA. He organizes and schedules the weekly KPRNA research discussions. He takes responsibility for bringing decisions about the small mammal LTER data sets before the group and provides the leadership for publishing in this area. He is taking additional responsibilty leading the group in the development of plans for investigation of the native grazers when the reintroduction takes place. He will assume the role of PI in Marzolf's absence in 1985-86.

Tim Seastedt takes responsibility for the belowground investigations, bringing decisions about nutrient cycling and ecosystem process data sets before the group. He will be instrumental in tightening the organization of the chemical analytical facilities so the increased numbers of samples from the watershed level work can be smoothly processed. He has assumed leadership in the development of modeling initiatives and for pushing ecosystem level approaches and questions. If we find the right person, we intend to add a post-doctoral research associate to the group in the area of ecosystem modeling. Such a person would work closely with Seastedt.

Ted Evans has been on leave from the project this academic year, working at the University of East Anglia in the laboratory of A.F.G. Dixon. He returns in June 1985. At that time he will be appointed Asst. Res. Scientist, with standing in the University to seek his own research support, independently. He takes direct responsibility for the insect population and community data sets. He takes responsibility for bringing matters associated with those data sets before the group and has assumed leadership with Kaufman in initiating discussions about community level phenomena in tallgrass prairie.

This group provides collective leadership for ecological research on tallgrass prairie at KPRNA.

The extended group includes the following research associates with co-equal standing as scientists, but with lesser responsibilities for support or synthesis.

M. D. Abrams has major responsibility for the collection of data for the analysis of tallgrass prairie vegetation, biomass, phenology, litterfall and species composition. He has taken the leadership in developing research on the fire history and development of gallery forest.

E. J. Finck has major responsibility for collection of data for the vertebrate population data sets. He has taken the leadership in the development of organization and coordination of the group for maintenance tasks, for coordinating fire fighting strategies.

J. M. Briggs is the data manager. His responsibility is to see to the entry of data and to validation, error analysis and archiving. He also attends to the care and servicing of the weather station. He has special skills in statistical analysis and will be developing file handling and analytical graphic software specifically for the LTER data.

Current personnel (con't.)

M. E. Gurtz is an independent post-doctoral research associate. His research is integrated with the LTER stream research. He developed the first phases of the data management system that Briggs is continuing. He is very much part of the research discussions.

C. A. McAfee is a recently hired field technician. He is currently involved in the installation of the instrument shelters, data loggers and automatic stream samplers. He will be responsible for the routine servicing of these installations and coordinating the sampling schedule for these and other samples requiring chemical analysis with the chemist technician.

We hire student help on a seasonal basis to help with field work, sample sorting, data entry, glassware washing etc. We expect a substantial amount of the this level of work to continue and have given graduate students the positions in the summer as well as undergraduates.

B. Proposed personnel

We have provided for an additional two positions in the renewal budget.

The first is a post-doctoral position for ecosystem modeling that might address the BSR program's suggestion that this is an area where additional effort would be useful and productive. This may not be possible, depending on the pool of applicants. The option to add such a person to the faculty does not exist. That being so, we will advertise so as to attract applicants from other ecological subdisciplines as well; areas that we believe would add useful points of view, talents and skills to the group. Other possibilities include: soil microbiologist, plant physiological ecologist, plant community ecologist, nutrient chemist or etc.

The second position will be a technician to operate and further coordinate the chemical analytical laboratory. The addition of more soil interstitial water sites, the stream chemistry from at least four watersheds (more as the analytical operation becomes efficient) and the continuing calls for plant analyses and the needs for graduate student thesis aid.

C. Intersite activity

Collaborative effort by KPRNA scientists is growing and numerous opportunities for significant contributions are being developed. In addition to participation in the collaborative investigations listed on pages 40 and 41, KPRNA scientists participated heavily in meetings at Las Cruces, NM and Lake Itasca, MN that were devoted to development of collaboration among site scientists. Next month (May 1985) D. W. Kaufman will represent KPRNA at a site leadership meeting in Ft. Collins, CO that is being planned and specifically devoted to intersite investigation.

We cannot forsee all specific intersite projects for the next five years, nevertheless, we are excited by prospects for these intitiatives and we encourage intersite work. We expect our participation to increase considerably in the next few years.

D. Advisory committee

Paul G. Risser (Illinois Natural History Survey) and Richard B. Root (Cornell University) have served for the past five years and will continue. James R. Gosz has taken a program officer's position at the Foundation and will step down, as will Larry L. Tieszen. These last two will be replaced by Richard G. Wiegert (University of Georgia) and Samuel J. McNaughton (Syracuse University).