TIEE

ISSUES : DATA SET

Comparing the Influence of Precipitation, Fire, and Topography on Plant Productivity in the Tallgrass Prairie

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THE ECOLOGICAL QUESTION:
How do site characteristics (topography and soil depth), fire frequency, and climate interact to influence plant productivity in the tallgrass prairie?

ECOLOGICAL CONTENT:
patterns and controls of aboveground net primary productivity (ANPP), climate, fire, forbs, grasses, limiting factors, long-term data, tallgrass prairie, topography

WHAT STUDENTS DO:
This Data Set allows students to compare the interactive effects of fire frequency, topography and inter-annual variation in precipitation on the annual productivity of two major plant groups — grasses and forbs — in the tallgrass prairie. In this exercise, students work with data on aboveground productivity in a tallgrass prairie and annual precipitation for 1984-1999. Using these data, students create figures to examine the relationships between plant productivity and precipitation, fire, topography. The plant productivity data are divided into two vegetation types (grasses and forbs; forbs are any non-woody, non-grass vascular plant), two topographical positions (uplands and lowlands), and three fire frequencies (annual, 4-yr, and 20-yr burns, respectively). As the students explore these relationships they will develop an understanding of how fire, topography, and precipitation influence tallgrass prairie productivity and how these factors vary over time. At the completion of the exercise, students discuss their interpretations and submit answers to questions developed while creating figures to explore these relationships.

SKILLS:
Students create multiple figures using spreadsheet and graphing software. To accurately interpret the results, students must critically think about plant-ecosystem relationships, determine sources of variation influencing productivity, and use this understanding to predict temporal patterns of productivity.

ASSESSABLE OUTCOMES:
Figures (bar and line graphs) created by the students and the written interpretation of the relationships shown in the graphs.

SOURCE:
Konza Prairie Biological Station Long-Term Ecological Research online archives: 1984-1999
http://www.konza.ksu.edu

OVERVIEW

The Konza Prairie Biological Station (KPBS), located in the Flint Hills of northeastern Kansas, USA (39°05' N, 96°35' W), maintains an interdisciplinary research program documenting the influences of fire, grazing, and climate on the faunal and floral ecology of the mesic prairie. KPBS was established in 1971 with land donated to The Nature Conservancy and is managed by the Division of Biology at Kansas State University. In 1981, KPBS joined the Long-Term Ecological Research (LTER) program funded by the NSF, as one of the original six field stations assembled to document temporal and spatial trends within and across biomes (www.lternet.edu).

KPBS is a 3487 hectares (ha) unplowed tallgrass prairie dominated by a few perennial warm-season grasses (big bluestem, Indian grass and little bluestem), yet supporting a species-rich community of over 500 other species consisting of herbaceous forbs, woody shrubs and trees, and both cool and warm-season grasses (Freeman 1998). KPBS experiences a temperate mid-continental climate characterized by periodic droughts and large seasonal and interannual variability in rainfall. This climate type results in cold, dry winters and warm wet summers with the majority of the annual precipitation occurring between April and September (835mm mean annual precipitation).

Historically, the Flint Hills were not cultivated because the steep hillsides and the rocky, shallow soils of the region prevented conventional tillage practices. For this reason, the region contains the largest remaining area of unplowed tallgrass prairie in North America. Another extraordinary aspect of the KPBS is its experimental design. KPBS is divided into 60 watersheds used to study three factors critical for maintaining the tallgrass prairie ecosystem: periodic fire, ungulate grazing, and a variable climate (Figure1). KPBS is one of the oldest LTER sites, and experiments with fire and grazing can be carried out over long intervals (e.g., 20 year burns) and with multiple interactions. The focus of this Data Set is to compare the interaction of fire frequency and inter-annual variation in precipitation on the annual production of grasses and forbs.

field assistant clipping annual biomass in a subplot
Copyrighted by: Alan K. Knapp

Data Collection and Analysis Methods

These data are based on analyses and measurements conducted between 1984 and 1999 at KPBS and archived online at www.konza.ksu.edu. Total aboveground productivity was estimated by quantifying the accumulation of new plant biomass at the end of the growing season along permanent transects in the experimental fire units (watersheds) of KPBS (Briggs and Knapp 1995). In general, prairie plant species in the northern Flint Hills begin growing in early April and have senesced by late September. Plants that use different photosynthetic pathways and annual differences in climate can alter this timeline, but peak biomass is typically reached by late August/early September, the date of biomass harvest each year. Total

aboveground productivity was measured using four transects with five 0.1 m^2 subplots therein. The photo above illustrates the harvest of a single subplot within the overall transect. This protocol was repeated for each soil type–watershed combination. The clipped subplots were marked so as to avoid subsequent re-sampling for at least four years. This method ensures independence in productivity data between consecutive years. Biomass was separated into multiple vegetative components that included grass and forb biomass, current year's dead (grass litter), and a minor woody plant component (if present). For this exercise, live grass and grass litter were pooled together. Following sorting, biomass was oven-dried at 60 °C for 48 hours and weighed to the nearest 0.01g (Abrams et al. 1986).

References

- Abrams, M.D., A.K. Knapp, and L.C. Hulbert 1986. A ten-year record of aboveground biomass in a Kansas tallgrass prairie: effects of fire and topographic position. *American Journal of Botany* 73: 1509-1515.

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STUDENT INSTRUCTIONS

Objectives of this Project

As you create figures using the data provided, and answer questions throughout the exercise, keep the following three objectives in mind:

1. Increase your understanding of ecological interactions and the response of plant productivity to fire, topographical position, and climate in the tallgrass prairie.

2. Learn to make and interpret figures describing ecological interactions and ecosystem functioning.

3. Based on this understanding of ecosystem functioning, predict the responses of tallgrass prairie plant productivity to a variety of climate and fire treatment conditions.

Long-term datasets provide an invaluable tool to monitor, study, and understand the changes occurring within an ecosystem over time. Using long-term experiments and datasets, ecologists can identify patterns and processes that would not be otherwise be apparent in studies conducted over a single year. In this exercise, you will work with data from an area representing the largest remaining unplowed tallgrass prairie in North America. The data come from the Konza Prairie Biological Station (KPBS), a Long Term Ecological Research (LTER) site in Kansas. KPBS contains rolling hills covered in an expanse of grasses and wildflowers. During years of average or above-average rainfall, the dominant grasses can grow 2-3 meters high and are so dense as to get lost in while walking through. Woody shrubs coexist on the upland prairie sites, and lowland regions adjacent to streams contain large gallery oak forests. Bison, white-tailed deer, and turkey are the most common and conspicuous animals present, but a diverse array of mammals, birds, reptiles, fish, and invertebrates all inhabit KPBS.

Bison on Konza Prairie
Copyrighted by: Judd Patterson

Many factors interact to influence plant growth in the tallgrass prairie. Due to the variability of the Midwestern continental climate, you will compare the yearly changes in the amount of precipitation with the rate of growth for grasses and forbs using a 16-year dataset of plant productivity. Fire is a common occurrence in these grasslands, and another important factor determining the growth and type of prairie vegetation. Therefore, you will compare plant productivity data in areas that have been burned every year or burned less frequently (at 4 year and 20 year intervals). A final factor influencing prairie productivity is soil depth and type, which varies with topography. On KPBS, the soils of upland sites are thin and rocky, while the lowland sites have deeper soil that is able to hold more moisture. At the completion of the lab, you should have a better understanding of how the influence of precipitation on productivity is, in turn, affected by interactions with fire and topography. Hopefully, you will appreciate why something that sounds simple — predicting the annual rate of prairie plant growth — can be quite difficult, especially if all the factors influencing growth are not included.

Fire Sweeping Across the Prairie
Photo by: Alan K. Knapp

Prairie Ecosystem Review

Historically, grasslands covered the middle third of the United States and were divided into three main types based on species composition and regional climate: tallgrass, mixed-grass, and shortgrass prairie. However, the fertile soils of the prairie were converted to row-crop agriculture and have also been used for grazing and urban development as European settlers domesticated the continent over the past 200 years. Of a grassland expanse that once spanned from Illinois to Kansas and Canada to Texas, only about 5% of the area once dominated by tallgrass prairie remains intact. Despite this enormous loss, few conservation and land management efforts are devoted to North American prairies. As a result, the area of native grasslands and uncultivated prairie continues to dwindle.

The prairie ecosystem is ideal for studying the response of terrestrial vegetation to natural climate variability and predicted future climate change. Because the vast majority of the plant biomass in the prairie is herbaceous, it is relatively easy to measure and record annual aboveground productivity and to recognize patterns and changes resulting from management and experimental manipulations. Trends and shifts in ecological pattern can be recognized in grasslands over periods of years compared to decades in slower-growing regions such as forests, tundra, and deserts. For this reason, datasets of only a couple decades can be a valuable tool for studying the response and recovery of vegetation to environmental perturbations (e.g., drought, fire, temperature changes).

Tallgrass Prairie Resource Limitations

Ecologists are interested in factors that 'limit' plant production in an ecosystem — factors such as light, water, and nutrients that, when added, lead to greater rate of growth. Water limitations to productivity have been clearly documented in the drier shortgrass prairie (Lauenroth and Sala 1992), but the relationship between precipitation and productivity weakens at wetter (more mesic) prairie sites (Briggs and Knapp 1995). In mesic prairies, other factors can become limiting, and the amount of aboveground biomass produced in a given location is largely determined by the minimum of three potentially co-limiting resources: water, nutrients, and light (Schimel et al. 1991). Therefore, aboveground productivity can vary widely between consecutive years or within a year (Briggs and Knapp 1995). Working in Nebraska and Kansas during the intense droughts of the 1930's, the patriarch of grassland ecology, John Weaver stated: "By 1941, seven years after drought began, these grasslands [tallgrass prairie] were almost entirely transformed into mixed prairie" (Weaver 1943). Weaver's pioneer research illustrated the defining role of rainfall and available soil water by documenting the replacement of a mesic plant community by more drought-tolerant species during dry periods. Therefore, while mesic prairies require all three resources in adequate supply, the strongest relationship between productivity and resource amount is with water availability, similar to the short and mixed-grass prairies (Knapp et al. 2001).

Generally, spatial differences in the landscape or management procedures that alter the local microclimate influence resource availability. Within a site, topographical differences may result in differing soil depth, water-holding capacity, and nutrient concentration all of which influence productivity and species composition (Briggs and Knapp 1995, 2001). Additionally, management practices such as the frequency of burning or grazing intensity can drastically alter plant resources. Annual burning volatilizes (converts to gaseous forms) nitrogen bound in dead biomass and can result in long-term nitrogen losses from the ecosystem (Blair et al. 1998). Annual burning also removes dead biomass, which increases soil temperature and the amount of light reaching the soil surface in the spring. Unburned prairies can accumulate large amounts of detritus, which results in cooler soil temperatures, greater soil moisture, and promotes the growth and success of cool-season plants (e.g., wildflowers, and other forbs and grasses) before temperatures increase to be optimal for the dominant warm-season grasses. In summary, to accurately predict plant productivity in the tallgrass prairie, you must include information characterizing the differences in topography, plant type (grasses and forbs), grazing, and fire frequency (Briggs and Knapp 1995).

Dataset 1

1. In this dataset, productivity data over a 16-year time period (1984-1999) has been averaged. In addition, the variation surrounding that average (e.g., how much it varied from year to year) is expressed as the standard error (SE). The standard error of the average gives you an idea of how much variation to expect if you repeatedly took samples (e.g., if you went back in time, sampled grass production in a site, and did this again and again). The first question we will address with this dataset is: What is the effect of fire on grassland productivity? To get started, click on the 'Chart Wizard' icon in the toolbar. The Chart type we will use is 'Column', and the Chart sub-type is 'Clustered Column'.

2. Click Next. You will need to highlight the Data range in the worksheet that you wish to plot. For this figure, we will keep it simple and compare Total Productivity between annually burned and 20-year burned prairie. Click the 'Collapse Dialog Button' at the end of the Data Range box. You will now be able to select the data from the worksheet. Highlight the entire cell range to be plotted; in this case, the mean values for Total

productivity for both burn types. Click the 'Collapse Dialog Button' again to return to the Chart Wizard. You should now see two vertical bars, one for each burn type. Click 'Next', and label the chart and axes appropriately as well as customizing the figure. Click 'Finish' when through.

3. Looking at the figure you've just created, it is apparent that annually burned prairie has higher productivity than unburned prairie, but we have no way to assess the range of variability inherent to these two burn treatments. To add this information, you will need to add y-axis error bars. To begin, right click inside one of the bars, and select 'Format Data Series...'. Click on the 'Y Error Bars' tab. For the Display, select 'Both', and for the Error Amount click the 'Custom' box. Use the Collapse Dialog Buttons as before to select the SE's associated with Total Productivity in Dataset 1. You will end up selecting the same data twice: once for the '+' box and once for the '-' box. Click 'OK'. Based on this figure, anticipate what might occur in another 16 years. Discuss with your classmates.

4. The figure of total productivity shows the difference between burned and unburned prairie, but do the different vegetation components (grasses and forbs) respond the same way to fire? To answer this question, you will create another column chart as before. However, instead of creating a separate figure for grasses and forbs, plot them in the same figure. When you reach the 'Source Data' box, select the data range for one of the vegetation types. Then Click on the 'Series' tab. You will now add a new series to the figure, in this case it will be the vegetation type not already selected. In the Values box, use the 'Collapse Dialog Button' and select the mean values for either the grass or forbs (whichever one you haven't already done). Now both vegetation types have bars over their respective fire frequency. Label and customize the figure as before. Additionally, you will need to add Y Error Bars for all four bars in the figure.

5. Using the figure you just created answer the following questions.

    a. Are grasses and forbs equally productive within this prairie (i.e., does the contribution to total productivity differ by vegetation type?)?

    b. Do grasses and forbs respond similarly to fire? If not, how do they differ? Based on your understanding of how fire changes the local microsite, propose some possible explanations for why grasses and forbs differ in response to fire.

    c. Based on these data, what further questions do you have? What information would you need to address these questions? For example, you might have questions about monthly patterns of rainfall.

Dataset 2

Instead of presenting averages over the entire period, Dataset 2 provides annual values of productivity under a variety of conditions so that you can explore the relationship between fire and productivity in greater detail. In addition, total precipitation for each year is presented in order to examine the influence of water availability on productivity. For instance, if this ecosystem is water limited, years with higher rainfall should have higher productivity and vice versa. Use the "Konza Data Set 2 Worksheet" to organize your ideas and interpretations for the figures (graph) you will be making. Answer the questions for each figure you make on this worksheet. You will turn this worksheet in to be graded at the completion of the exercise.

1. Figure 1: Because Kansas is a mid-continent site, weather patterns can differ widely from year to year. In order to assess the inter-annual variation in total precipitation, you will need to create a figure spanning the 16-year period. Using Chart Wizard again, select 'XY (Scatter)' for the Chart Type and 'Scatter with data points connected by lines' as the sub-type. For the data range, highlight both 'Year' and 'Total Precipitation'. Click 'Next' and finish the figure as before. This figure displays how variable annual precipitation can be in this location (note: 1993 has almost three times more rainfall than 1988).

2. Figure 2: Could the variation in precipitation shown in the previous figure explain some of the inter-annual variability in productivity patterns? To quantify the influence of precipitation on productivity, you will need to create a graph that illustrates a simple model called linear regression. This analysis is performed using total precipitation (the independent variable) to predict productivity (the dependent variable). As explained below, you will calculate r-squared (r^2) to assess how well precipitation predicts productivity.

   Use the Chart Wizard and select 'XY (Scatter)', but for the sub-type choose 'Scatter. Compares pairs of values'. When selecting the data to use, click on the 'Series' tab. Use the Collapse Dialog Button and highlight the 'Total Precipitation' range for the 'X Values' and highlight 'Total Productivity' for the 'Y Values'. Click 'Next' and finish the figure. Right now, this figure is only a series of points and doesn't provide a visual estimate for the goodness of fit (a method to assess how well precipitation predicts productivity). To do this, you need to add a trendline. Right-click on one of the points in the plot, and select 'Add Trendline...'. For 'Type' use linear. Click on the 'Options' tab and put a check in the 'Display R-squared value on chart'. Click OK. The r^2 value on the chart shows the relative predictive power of the model. It is a descriptive value ranging between 0 and 1. A value of 1 indicates a perfect prediction and a value of 0 suggests no relationship exists. In biological systems studied at the ecosystem scale, low r2 values are common, especially when a single variable is used as the predictor. As a general rule of thumb, if the if the best-fit line to the data is sloped up or down, then the relationships warrant further investigation. The r^2 values will change as new data points are added following future measurements at KPBS. Therefore, add the dates of data collection (1984-1999) to the title legend in order to denote which years this relationship pertains to.

   Look at the figure you just created. How well does precipitation predict productivity? Use the r^2 value to help you with this question. (Hint: what does "total" productivity mean here? Total of what?) Why might this relationship be weak?

3. Figure 3: To better understand the sources of variation, the remaining columns of Dataset 2 divide productivity into burn regimes, topographical positions, and vegetation types. When the data are separated out like this, what question(s) can we now ask? Create a figure comparing total precipitation to productivity for both burn regimes (annual and 20-year). You will create an XY scatterplot with trendlines as before. However this time when you get to Step two of the Chart Wizard (Source data step), you will need to add a series. Highlight your x and y data as before, then click on the 'Series' tab. You will click the "Add" Series button, then fill in the X and Y value blanks to the right with the appropriate data. When finished, you should have two plots on the same figure: one comparing precipitation (X Values) to annual burn (Y Values) and precipitation (X Values) to 20-year burn (Y Values). This figure shows big productivity differences in

response to fire. What influence does precipitation have on annually burned prairie? 20-year burn?

4. Figure 4: Remember that flat lines (and low r^2 values) indicate no relationship exists and further investigation is not warranted. However, relationships with trends may be broken down into smaller pieces to further understand the mechanisms responsible. For the next figure, use the data divided into topographical position in the annually burned watershed and create a new scatterplot as before. If you remember from the Introduction, upland prairies have shallow, rocky soils, while lowlands have deeper soils. Based on this information, plants at which topographical position will likely be more dependent on precipitation inputs? Is the nature (slope of the line) of the relationship between precipitation and productivity different by topography? Which position is more productive?

5. Figure 5: Finally, compare the response of grasses and forbs to precipitation within upland soils. In Dataset 1, these two plant types responded differently to fire. In this figure, you will notice they also respond differently to water. How do they differ? Why? There are several possible explanations.

You should note that by dissecting the relationship between precipitation and productivity into smaller and smaller units, the r^2 values continued to increase as sources of variation in the model were identified (burn vs. unburned, upland vs. lowland, etc.). Therefore, which component (fire frequency/ topographic position/ vegetation type) of the tallgrass prairie is most reliant on precipitation as a driver of productivity?

When you have finished making all of these figures, go back and reread your responses for each figure on the Data Set 2 Worksheet. This will help you organize what you have learned with each step of this exercise.

Dataset 3 (Additional Data)

Intermediate Burn Frequencies

1. So far, you have explored the relationship between productivity and precipitation amount using data from sites with annual and 20-year burn frequencies. This dataset provides the full 16-year record for 4-year burns in addition to the other two burn frequencies. Do the effects of the intermediate fire frequency (4-year) more closely resemble the annual burn or 20-year burn? Is the suppression of fire for four years long enough to encourage the invasion of forbs similar to that recorded in long-term unburned? These questions can be addressed using this dataset.

2. To get started, create three figures using XY(Scatter): data points connected by lines, and plot total productivity (Y-axis) for both topographic positions (uplands and lowlands) by year (X-axis). Make each figure a different fire frequency, but keep the scale of Y-axis units the same for each figure to facilitate figure-to-figure comparisons. Does the productivity response of the 4-year burn lie in between the other two? These figures nicely illustrate the large productivity differences between uplands and lowlands in the annually-burned, with that difference become less noticeable in the 20-year burns. What's changing in the unburned (20-year) to reduce this topographical difference?

3. One of the findings from Dataset 1 was that grasses and forbs respond differently to fire frequency. To further explore that idea, create another XY(Scatter): data points connected by lines, and plot grass and forb productivity for all three burn frequencies on

the same figure. In part 2 above, the biggest change over time appeared to be in the lowlands, so focus on that position for now. When finished, you should have year on the X-axis, productivity on the Y-axis, and six lines of data plotted in the figure. Compare forb productivity in the annually burned to the 20yr burn. Which fire frequency is the 4-year burn more similar to? Looking at the figure, can you guess what years the 4-year burns were conducted? Based on the differences (or lack thereof!) between productivity values of grasses and forbs, what role does fire play in this ecosystem? Which fire frequency best supports grass dominance? Speculate at which fire frequency the time between burns becomes long enough to no longer suppress forb growth (it can be different than the three shown here).

Precipitation Variability

1. One prediction of global climate change for the central U.S. is a shift in precipitation pattern from smaller, more frequent rains to larger storms with greater intervening dry periods. To assess the impact of changing precipitation patterns, scientists at the Konza Prairie are investigating the relationship between precipitation pattern and productivity. Specifically, can indices of climate variability successfully predict biological response as well as climate means (i.e., do precipitation patterns have the same predictive success for ecological understanding as precipitation averages?)?

2. In Dataset 3, a table containing predictor variables beyond total precipitation amount is available to explore the relationship between pattern and productivity. Similar to Dataset 2, create a suite of figures using these new independent variables to predict productivity at various burn frequencies, topographic positions, and vegetation types. Which situations have the strongest relationship with precipitation pattern? Are the trends consistent between paired variables (i.e., do grasses and forbs respond in the same manner to increasing length of dry interval?)? Are any relationships stronger (higher R-squared value) than those found in Dataset 2? If climate predictions come true and growing season storms are of reduced frequency but greater intensity, how would you predict tallgrass prairie productivity change (i.e. will total productivity decrease?, will grasses continue to dominate?, will annually burned prairie continue to be the most productive?)?

References

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NOTES TO FACULTY

How to Use This Data Set in a Class

This is a good Data Set to use in discussions on variability within ecosystems and on how limiting resources can influence primary productivity. Prairie ecosystems provide a great opportunity to investigate the influences of different factors, and their interactions, on productivity and biomass, because the majority of the aboveground vegetation grows and dies each season. Finally, this exercise will hopefully illustrate the unique characteristics and species inherent in this disappearing ecosystem.

How much time your students will need to make these figures in part depends on their familiarity with Excel. Although the directions include step-by-step instructions, students new to Excel will of course need more time. Students should work in groups of 3-4 during one or more lab sessions, or outside of lab for homework. Data Set 1 is small and will not take much time. The directions for Data Set 2 ask students to make 5 figures, which could take a lot of time. To save time, you could provide the first figure or two and ask students to make the rest. There is a good deal of information to keep track of here and the Worksheet is designed for that purpose.

Many undergraduates have little experience interpreting figures and therefore will need help with this. For suggestions about a two-step process (observation followed by interpretation) see the *TIEE* essay "Interpreting Figures and Tables".

Each teacher will have to decide how much feedback to give students, and how much to ask from them, as they progress through the lesson. A good way to make this decision is to consider the intended outcomes for the exercise. What do you want students to know and be able to do? This should help you decide how often, for example, you want to stop the class and ask students to discuss their progress and questions with each other. In addition to helping students better understand the material, this type of discussion gives you valuable formative feedback on student understanding. Student evaluation can be based on several products including the worksheet, the figures, or both. If students work in groups, you will have to decide if the group submits a combined piece of work or if each student submits their own. There are pluses and minuses for each. The suggestion for evaluation described below is an essay.

The Data Sets

This exercise contains three datasets for students to explore productivity patterns in tallgrass prairie. Each successive dataset builds on the previous one. Therefore, don't start with Dataset 2 without first completing Dataset 1. Dataset 1 and 2 are appropriate for undergraduate courses, and Dataset 3 integrates the relationships outlined in the previous two datasets and requires more thought. For this reason, Dataset 3 is more appropriate for graduate students or an advanced undergraduate ecology course.

Dataset 1: Contains the mean aboveground productivity plus standard error for total, grass, and forb components separated by annually and 20-year burns. These data illustrate that burned prairie is more productive than unburned largely because burning increases grass productivity. When fire is withheld, forbs increase, and grasses decrease. After the students finish their first set of graphs, assess how they have done and facilitate a discussion of their hypotheses. You could expect that if this experiment was repeated for another 16 years, the mean productivity value in annually burned prairie could range from 520 to 420 g-m^{-2} or between 420 and 344 g/m^{-2} in the 20-year burn. As a general rule, if the top of one error bar doesn't overlap with the bottom of another, then a true difference between treatments likely exists.

Dataset 2: Includes total precipitation as an explanatory variable of annual productivity. The strength of the relationship between these two variables (precipitation and productivity) is investigated by sequentially separating the data into multiple burn regimes, topographies, and vegetation types. When finished, grasses in upland, annually-burned sites are identified as being the most water-dependent.

Dataset 3 (additional data): Contains the complete record of productivity values for all burn frequencies, topographies, and vegetation types. In addition, a third fire frequency is added (4-year) to investigate the effects of intermediate disturbance in this grassland.

For the second component of this dataset, a table of additional predictor variables beyond just total precipitation amount is included to investigate the influence of changing precipitation patterns (rather than just means alone) on aboveground productivity. There are a large number of relationships that the students can compare, and largely, most will be non-significant, but important trends can be identified (e.g., increasing variability in precipitation pattern decreases productivity). This dataset provides an excellent opportunity for students to think about how a changing climate will influence productivity and how records of long-term data can serve as an alternative to experimental manipulation.

Questions for Discussion

There are many questions in the Student Instructions. Questions dealing with broader aspects may include but are not limited to:

1. Grassland ecosystems offer an unusual opportunity to assess use of fire as a management tool. Why is this?

2. Depending on managerial goals, how can fire be used to dictate the type of species present?

3. Ecology texts discuss the concept of "limiting factors" as single environmental factors that limit primary production in an ecosystem. Based on your knowledge of factors limiting production at Konza, critique this statement.

4. In ecological studies of a large spatial scale, productivity and precipitation are highly correlated. However, when the relationship between productivity and precipitation are conducted at a single location over a long period of time, this correlation decreases. Discuss 'Why' this happens based on the relationships outlined in this exercise.

Teaching Evaluation

a. Ask students to write a 300-500 word essay written for another ecology student who knows nothing about the tallgrass prairie. The essay will explain the types of questions ecologists are asking at Konza, why these are of interest, and a little about some of the findings. The objective here is to assess the degree to which students can "stand back" from the details and explain, in their own words, the main ecological concepts and questions being addressed by the Konza scientists and how the particular interactions outlined in this exercise complement the larger ecological questions being addressed within this ecosystem.

b. The worksheet students complete for Data Set 2 is an additional type of assessment. The quality of students' work can be based on:

   i.   accurately comparing the variables in the graphs

ii.   creating aesthetically-pleasing graphs

iii.   understanding *what* is being depicted figuratively

iv.   answering the questions asked for each figure correctly

Resources

Konza Prairie Biological Station
- o   http://www.konza.ksu.edu

Tallgrass plant species links:
- o   http://www.lib.ksu.edu/wildflower/

- o   http://www.noble.org/imagegallery/

Other Tallgrass prairie sites in the Great Plains
- o   NPS Tallgrass Prairie National Preserve
     http://www.nps.gov/tapr/

- o   Oklahoma Tallgrass Prairie Preserve
     http://nature.org/wherewework/northamerica/states/oklahoma/preserves/tallgrass
     .html

Tallgrass Prairie Photos
- o   http://www.naturalplanet.org

Excel Tutorials
- o   http://www.usd.edu/trio/tut/excel/

- o   http://www.fgcu.edu/support/office2000/excel/

- o   http://www.baycongroup.com/el0.htm