TIEE

Teaching Issues and Experiments in Ecology - Volume 2, August 2004

EXPERIMENTS

Inquiry-based Learning in Plant Ecology: Students Collect the Field Data, Ask the Questions, and Propose the Answers

Alan B. Griffith

Department of Biological Sciences
University of Mary Washington,
1301 College Avenue, Fredericksburg, VA 22401
540-654-1422, fax: 540-654-1081
agriffit@umw.edu

Floral diversity in the
U MW experimental plot
© Alan B. Griffith

Table of Contents:

CITATION:

Griffith, A. B. August 2004, posting date. Inquiry-based Learning in Plant Ecology: Students Collect the Field Data, Ask the Questions, and Propose the Answers. Teaching Issues and Experiments in Ecology, Vol. 2: Experiment #3 [online]. http://tiee.ecoed.net/vol/v2/experiments/proposal/abstract.html

ABSTRACT:

This laboratory activity is designed to teach upper-level students in a plant ecology course how to collect data on plant populations (distribution and abundance), formulate hypotheses to explain observed patterns, and write a research proposal to test their hypotheses. This is a semester long project requiring 13 * 2 ¾ hour lab classes. Motivation for hypothesis generation is a planted plot populated by seeded and volunteer plants. Students, working in groups of 2 or 3, make qualitative observations, collect plant distribution data, collect and analyze abiotic variable data, propose and research questions, and propose a series of experiments to answer these questions. All proposed hypotheses must be based upon the qualitative and quantitative observations made by the students. Hypotheses are generated by the student groups, reviewed by the instructor, and mutually agreed upon, after revisions, by students and instructor. Students individually prepare a written proposal and also present details of their proposals in small-research groups.

KEYWORD DESCRIPTORS:

Principal Ecological Question Addressed: The ecological questions addressed are determined by student groups, in consultation with the instructor, and generally concern hypotheses about causes of spatial and temporal patterns in plant population and community ecology in the prepared experimental garden.

Ecological Topic Keywords: The ecological keywords are determined by students' choices of hypotheses. In the past, this has included broad concepts such as interspecific competition (shoots and roots), herbivory, mutualism (and potential mechanisms of these interactions), life history differences among grasses and forbs, physiological ecology (hydraulic lift), seed dispersal and germination strategies, specific limiting factors leading to competition, and environmental correlates of species diversity.

Science Methodological Skills Developed: observation, quantitative plant sampling, soil moisture analysis, soil texture analysis, library research, hypothesis / question formulation, question / hypothesis clarification, experimental design, factorial experiment, research proposal writing, oral presentations

Pedagogical Methods Used: small group conferencing, cooperative learning, group data collection, student-directed inquiry, bounded inquiry

CLASS TIME: 13 weeks, with 2 hour and 45 minute classes per week.

OUTSIDE OF CLASS TIME: 20 hours - Students spend out of class time creating data presentations (i.e. graphs and tables), researching and reading the literature related to their hypotheses, designing and collaborating on 2 oral presentations, designing and describing appropriate experimental designs, writing an annotated bibliography, and writing a final research proposal.

STUDENT PRODUCTS:

The major assessment for students is a research proposal, presented orally and in writing, designed to answer 4 specific hypotheses / questions about the abundance and distribution of plants. Students produce components of this proposal during the semester, and present the full proposal at semester's end. The progressive "creation" of the full proposal gives students the opportunity for feedback in order to improve their work. Most of the student work for this experiment is a collaboration of 2 or 3 students in a research group. Students can analyze data together, design data presentations together, and collaborate on experimental designs. Student products are a combination of individually graded and group graded products. All written assignments are graded individually and therefore must be written by each student. For example, the appearance of graphs and/or tables can be developed as a group. But, the title / captions for these data presentations must be written individually for grading. Both oral presentations are given by the research group.

SETTING:

Field work is done in a prepared experimental garden measuring 2 m X 30 m. The experimental garden is used by 2 different laboratory sections, so the use of destructive sampling techniques is limited. Lab work will typically be required to prepare and analyze abiotic samples such as soil samples for soil moistures and soil texture. Students will also require access to computer facilities. See "Overview of Data Collection and Analysis Methods" below for more details on typical data collected and lab analyses. This experiment could be done in the Fall or the Spring, with some forethought about the experimental plots for observation by students. As designed, this is a Fall course laboratory. This means that students make their observations on a variety of plants that have grown through the summer. For a Spring course, experimental plots could be chosen to focus on perennial plants or specific populations of spring ephemerals.

COURSE CONTEXT: This class is the required laboratory for a junior /senior level plant ecology course. I teach 2 sections, with 16 students in each section. The course syllabus gives further details (Appendix1_syllabus_fall2003.doc, 36k)

INSTITUTION: University of Mary Washington is a Virginia state liberal arts university.

TRANSFERABILITY: This experiment will transfer well to any scale college or university, as equipment needs are flexible. The activities and goals could be easily changed to fit a quarter system schedule. I see this mostly as an upper division course, given its duration. It would be possible to excerpt components of this experiment for use in lower level laboratories. For example, one might use 2 - 3 laboratory periods to collect qualitative and quantitative data on field plots to motivate hypothesis generation by students about the abundance and distribution of plants in nature. This would be a worthwhile field experience where students use potentially messy data to generate clear measurable hypotheses. I do believe this format may lend itself to a year long biology or environmental science group project for high school students.

SYNOPSIS OF THE LAB ACTIVITY

WHAT HAPPENS:

Students are introduced to a prepared, experimental garden. This garden provides the focus for the development of hypotheses / questions about the distribution and abundance of plants in this garden. These hypotheses are developed by the students with minimal guidance from the instructor. Student research groups are formed during the second week of the experiment to first facilitate data collection and later to facilitate student collaboration on data analysis, hypothesis generation, and experimental design. Students first make qualitative observations of the plants and then sample plant distributions and abundances using line transects. Students also map positions of rare plants (i.e. relatively low abundance plants in this plot). Students collect several abiotic variables across the plot as potential independent variables. Some sample processing and data sharing occur in the lab. For example, soil moisture and soil texture samples are processed in the lab. Students perform background research for their hypotheses, design experiments, and describe their experiments in a proposal. Information needed by students, for example background on experimental design, is provided during lab periods throughout the semester.

LAB OBJECTIVES:

At the conclusion of this lab, students will be able to...

1. perform background research to investigate 4 specific hypotheses / questions about the abundance and distribution of plants,

2. formulate an experimental program to investigate 4 specific hypotheses / questions about the abundance and distribution of plants,

3. propose an experimental program, orally and in a formal proposal, to investigate 4 specific hypotheses / questions about the abundance and distribution of plants,

4. act collaboratively to collect and analyze data, design data presentations, research the literature, and design experiments.

It is important to note early in this guide an underlying pedagogical goal of this experiment. Students perform activities and practice processes in order to learn how science is done. In short, students are meant to learn methods for acquiring new knowledge. This is one of three possible pedagogical or scholarly goals shown in the Inquiry framework (http://tiee.ecoed.net/teach/framework.jpg). Much of the inquiry done by students in this experiment is student generated and therefore “owned” by the student.

EQUIPMENT/ LOGISTICS REQUIRED:

- Required: prepared experimental garden, plant presses, 50 meter tape, stakes or flags for line transects, string for line transects, plant identification resources, sample bags, drying oven, electronic scales, graduated cylinders for soil textural class measurement,

- Optional / useful: light meter, soil pH meter, soil fertility kits for nitrogen and phosphorus, digital camera, transportation for instructor and students if garden plot is off campus.

SUMMARY OF WHAT IS DUE:

Students are evaluated on 5 assignments delivered throughout the lab. First, each student delivers an annotated bibliography of at least 15 primary research references. Second, each student provides graphs of data they collected and that are important to the research he / she is proposing. Next, students give 2 oral presentations in research groups. Last, students assemble and integrate background research, data, and experimental designs into a research proposal.

DESCRIPTION OF THE EXPERIMENT

INTRODUCTION:

The final goal for this semester's plant ecology lab is a proposal for research. This proposal will detail the experimental designs to answer a set of 4 hypotheses / questions concerning the distribution and abundance of plants in an experimental garden plot. This proposal will include:

1. background information (a literature review),
2. the significance or importance of this research,
3. general goals of the research,
4. specific hypotheses / questions to be investigated,
5. background about the experimental plots,
6. data of the current plant abundances and distributions,
7. details of the proposed experimental designs to investigate hypotheses / questions,
8. expected results, and
9. references.

Since you will spend the majority of laboratory time on developing these research proposals, you will probably want to know why this is a worthwhile goal. Most of you will take one of several career paths after undergraduate school: a profession position related to biology, medical school, or graduate school. In any of these careers, you will likely read and evaluate research or research proposals or you will write research proposals and do research. Developing and writing a research proposal in this course will improve your evaluation and writing skills in general and specifically for research proposals. Even if you do not take any of the above career paths, there is something in this for you: improved writing skills and a writing intensive credit, improved interpersonal skills from working with a group, experience using field and laboratory techniques, and improved evaluation and interpretation of research literature. I also believe that the detailed development of hypotheses, an essential precursor to good research, is often simplified when teaching the scientific process. In short, much of this laboratory is about learning and practicing how science is done.

There are a wide range of questions that you might investigate as plant ecologists. Any question investigated in plant ecology focuses on the patterns, causes, and consequences of plant abundance and / or distribution in nature. Early plant ecologists investigated questions about the patterns or distribution of groups of species (i.e. community ecology). More recently, plant ecologists started investigating the patterns and causes of population abundances and / or distributions (i.e. population ecology). In addition, ecologists now have many technologies to help answer questions about individual plant physiology and how it changes as the environment changes (i.e. ecophysiology). In other words in this class, we might propose to investigate questions about groups of plant species, populations of individual species, or the interaction of individual plants with their environment.

The factors affecting plant abundance and distribution fall into two broad categories: abiotic and biotic causes or variables. Abiotic factors are any variable in the environment that is not living. These abiotic factors include, but are not limited to, light intensity, temperature, variation in temperature, length of growing season, fire regimes, soil moisture, rain fall, and seasonal variation in rain fall. Biotic factors are any variable in the environment that is created by another living organism. Biotic factors include, but are not limited to, competition, herbivory, mutualism, and disease. The basis for your research proposals will be hypotheses about relationships between 2 or more of these variables and individual plants, plant populations, or plant communities.

From my perspective, there are many practical reasons for understanding more about plant ecology. Many of these reasons are conservation issues. One worldwide issue is the loss of species in communities of plants and animals. What are the causes and consequences of this change of species abundance in nature? Another worldwide issue is invasive species or non-native species of plants and animals that enter a community. What are the causes and consequences of the introduction of these invasive species into established communities? A third broad concern is that human population growth and development have placed many pressures on the natural habitats of plant and animal species. One of the most commonly stated causes of species endangerment is “loss of habitat.” The wide spread degradation of natural habitats makes restoration ecology an important application of many topics in ecology (Palmer et al. 2004).

We will use a plot of land at Belmont Estates to motivate our hypotheses / questions about plant abundances and distributions. This may immediately raise the question, “What can investigations on a 60 m2 plot tell us about the loss of biodiversity or habitat restoration? These processes happen at quite large scales.” One response is, “We have to start somewhere….” More specifically we can learn much about what is happening on large scales from processes at small scales. For example, past research shows that the plant species found in different climatic regions of the world (i.e. species growing on the northern tundra or species growing in Mediterranean climates) show broad adaptations to the abiotic conditions (e.g. seasonal air temperatures and length of growing season) created by those climates. These abiotic conditions are felt by individual plants. In addition, biotic factors like competition often help determine the abundance and distribution of the plants growing within broader regions. If two plants are adapted to grow in the same climatic region, but one of the two plants out competes the other, the better competitor may be more abundant. The process of competition acts over very short distances between neighboring plants. In short, to begin understanding ecological processes happening at large scales, we can start our investigations at small scales.

MATERIALS AND METHODS:

Study Site(s):

Students used an experimental garden plot on a college property close to campus. The garden was created on the grounds of Belmont, the Gari Melchers Estate, in Falmouth, VA. The plot was a 2 m X 30 m rectangular plot. The plot was historically an unmanaged pasture and has been mown, but not seeded or fertilized for several years. Two applications of Round Up, a general purpose herbicide, were applied to the plot, covered predominantly in perennial grasses, and the soil was roto-tilled to about 1 inch depth. This light till of the soil uprooted most of the dead vegetation and exposed the soil to direct contact with new seeds.

A mixture of forb, grass, and legume seeds were seeded into this plot. The list of seeded plants, purchased from “Prairie Nursery” in Wisconsin, is shown below. The seed mixture was applied at 1/3 greater than the recommended rate of seeding (rate recommended by the vendor = 1 lb. / 4400 ft2). Each of the plant types (i.e. forbs, grasses, and legumes) was applied separately. Plant types were seeded separately because the types have very different sizes and masses. The total seed allotment for each plant type was divided into ten equal parts by weight and added equally to ten-3 m sections of the plot. Seeds were hand cast at the beginning of the summer and the plot was left unmanaged for the summer. By the fall, the plot was well covered with plants from the planting and self established local species or volunteers. The herbicide, roto-till, and seeding treatments were one time treatments completed in 2001, followed by a controlled burn of the plot in spring 2003.

List of plants seeded into plots at Belmont		
Forbs	Grasses	Legumes
Smooth aster	Big bluestem	Canada milk vetch
New England aster	Canada wild rye	Blue false indigo
Pale purple coneflower	Indiangrass	White false indigo
Purple coneflower	Switchgrass	Wild senna
Rattlesnake master		Purple prairie clover
Ox eye sunflower		Canada tick trefoil
Showy sunflower		Roundhead bushclover
Bergamot		
Smooth penstemon		
Yellow coneflower		
Black eyed susan		
Sweet black eyed susan		

Overview of Data Collection Methods and Analysis.

Prior to Lab

As currently organized, “Week 1” of this experiment, which is described below, starts in the second week of the semester (see Appendix1_syllabus_fall2003.doc, 36kb). Students learn the line transect method and practice developing hypotheses during the first week of the semester. I give a short lecture describing the characteristics of a good hypothesis and the line transect method. I also provide a handout describing the technique and goals for this lab (Methods for Line Transect Sampling). The students set up 3 meter line transects across the edge of a lawn and a woodlot. Groups of 3 - 4 students measure percent cover of all the species on the transect and describe patterns they measure in the plant species composition across the transition from lawn to woodlot. They have now used a quantitative technique to describe plant abundance and distribution. They also propose hypotheses for the causes of their measured changes in species composition.

Week 1: Introduction to Plant Community Plots.

Students visit the site of the experimental plot. They are given background information about the goals of the laboratory, and the creation of the plot and neighboring grassland (details provided above). It is important for students to first get the “lay of the land” before they do any measurements for background data on this plot of land. A combination of my description and their observations familiarizes the students with the plot, the plants on the plot, and the area of land surrounding the plot. I describe the plot and how it was created. I also describe a larger, adjacent grassland that was created similarly to the experimental plot.

I have several objectives for this first visit to Belmont:

1. describe the plot treatment so far,
2. observe a similarly treated grassland,
3. observe / name plants in the plot,
4. create a class herbarium,
5. describe plants in herbarium for future identification,
6. make qualitative observations of plants currently in the plot,
7. make qualitative observations of the plot itself.

The students finish this lab by making qualitative observations of the current abundances and distributions of the plants in the plot. The qualitative observations by students are a visual inspection of the plants in the plot and the physical environment of the plot. Observations of the plants can be guided by a series of questions such as

1. “About how many species of plants do you see in this plot?”
2. "Are different species of plants distributed evenly across the plot? Are they distributed in obvious clumps?

3. "Are there any species of plants that seem relatively rare in this plot?"
4. "Do any of the species grow in only a small section of the plot?" and
5. "Do you see any changes in the composition of plant species as you move from one end of the plot to the other?"

Observations of the physical environment include slope, adjacent land features and plants in the vicinity of the plot. For example, during the first year of this experiment, there was a garden beside the experimental plot and several species seen in the plot were also observed planted in the garden. These kinds of observations may spark ideas about how these plants came to grow in the experimental plot.

Week 2: Decide on Variables of Interest. Clarify and Quantify Observations.

Groups of 2 - 3 students use line transects, a technique introduced prior to "Week 1" of this experiment, to quantify the abundance and distribution of the plant species in the garden (see Week 2: Quantifying Observations for formatting suggestion).

Each group is then assigned to a section of the plot. Although it is not always necessary to identify plant species for this exercise, the class develops a reference herbarium for this experimental plot. As students find new species on their line transects, they bring specimens for identification and preservation. When possible, plants are identified to species. Otherwise, each species is given a generic name (e. g., grass 1, grass 2) that is consistently used by all student groups. This reference herbarium allows groups of students to compare and compile species specific data among different transects. After students have completed their transects, we return to the campus laboratory, and students share the data they have collected. Students must also state what abiotic variables they wish to collect in and around the experimental plot. This defines the equipment needs for the next week. Students start working in their research groups during the "Week 2" lab. Although the data collected here and next week are shared by the whole class, I believe it is useful to have students start working in their research groups now to get to know each other and develop their group relationships.

Week 3: Clarify and Quantify Observations. Measure Abiotic Variables.

Students identify and map rare plants in the plot. Rare is defined by plants distributed such that they do not or are not likely to fall on a line transect. These rare plant data supplement the quantitative data collected the previous week. They may motivate students' questions about causes of rarity or low abundance in plants. Students split into small groups to take abiotic variable measurements or to collect samples for abiotic variables. For example, one group of students will typically measure quantum flux at different levels in the herbaceous canopy. Students also typically wish to know something about soil moistures across the plot. Therefore, a group of students takes soil core samples for subsequent treatment and analysis. All students participate in the treatment and analysis of samples in the laboratory. For example, soil samples for soil moisture content must be weighed before and after drying in an oven.

Week 4: Statement of Hypotheses / Questions. Literature Reviews Begin.

Students complete treatment and analysis of samples. They also share data from these analyses. Students decide among themselves how they will organize and move data between them. Students, in their research proposal groups, must state at least four (4) different hypotheses / questions. Student groups develop their own hypotheses / questions through a bounded inquiry. I work interactively with the research groups as they generate specific questions. During this process, I ask questions to clarify the dependent and independent variables that the students are working with. I also ask questions like, ”Are your independent variables biotic or abiotic variables?” “Are your dependent and independent variables measurable?” “How will you measure your variables?” “How are your 4 hypotheses / questions related to one another?” This last question is important because I want each research group to propose an integrated set of research questions. After agreeing on hypotheses, each group sends me an email copy of their hypotheses for my records. Sometime during this session, I give a 15 - 20 minute primer on the use of the college library’s online databases of the primary literature (see Week 4: Library Research Strategies).

Week 5: The Proposal - Content and Form.

During this session, I preview my expectations for the full research proposal (see Week 5: Guidelines for Research Proposals) due at the end of the semester. This preview includes a description of the different sections of the proposal, some requirements on content, and examples (see Week 5: Example Research Proposal - Appendix3_proposal_example.doc (156k)). The research proposal must clearly state the 4 hypotheses / questions that were developed by the research group. Experiments must be proposed to answer each of these 4 hypotheses / questions. Students continue their literature reviews.

Week 6: Data Analysis and Presentation.

I give a 15 - 20 minute primer on the use of spreadsheet software to generate graphs. This primer includes how to create a graph from scratch, as well as, some specific information on the format requirements for graphs (i.e. “instructions to authors” information). Editorial formats of graphs and bibliographies follow the conventions of Ecology and Ecological Applications and the examples in the research proposal guidelines (see above). Students also receive a description of annotated bibliographies (see Week 6: Guidelines for Annotated Bibliographies), which includes other examples of the correct bibliographic style.

Week 7: Experimental Design.

I give a 20 - 30 minute primer on experimental design. This primer includes a review of dependent and independent variables, experimental units, the significance of randomization, types of variation, and several specific designs. I discuss completely randomized designs, blocked designs, factorial designs, and a strategy to eliminate repeated measures in experimental designs.

Students also get a preview of the oral presentation requirements during this lab class. The presentation requirements and information on developing a quality oral presentation are covered in more detail in the “Tools for Assessment of Student Learning Outcomes” section below.

Week 8: Annotated Bibliography Due.

Students hand in their first assignment, an annotated bibliography. This assignment is meant to provide most of the information students will need to write the background section of their proposal.

Week 9: Oral Presentation #1.

Each oral presentation is given as a research group. But, individuals are given individual assessment for their part in the presentation. The focus of this presentation is literature review, background data, and a specific statement of hypotheses / questions. Students are assessed (see Week 9: Oral Presentation Midpoint Assessment Form) on the quality of their presentation organization and style. I use this exercise partly as a formative assessment to give students feedback on the content they have gathered so far. The presentation length is 15 minutes.

Week 10: Data Presentations Due.

Students hand in any graphs and/or tables they will include in their final research proposal. These data are preliminary data collected from the field site or relevant data collected from other sources. An example of other relevant data would be local, monthly, mean air temperatures or average length of growing season. All students must present a graph of the plant distributions in the experimental plot, as this data was the original motivation for hypotheses / questions. Any other data collected from the plot or external sources (e.g. local mean high temperatures) that are relevant must be handed in at this time. Before this, students have been given instruction on the criteria for and examples of good graphs and tables. My assessment focuses on editorial requirements (e.g. fonts, font sizes), clarity of data presentation, and completeness of the title / caption.

Week 11: Peer / Supervisor Review.

A complete rough draft of the final research proposal is due at this meeting. Students exchange a copy of their drafts with 2 students not in their research group. I have not made this an anonymous review process, although this could easily be done. Each student chooses their 2 student reviewers. I provide guidelines or criteria (see Week 11: Guidelines for Peer Reviews of Research Proposals) for this review by peers. I also review papers at the request of authors. Many questions about experimental design come up at this time and I can use this as formative feedback on experimental designs.

Week 12: Oral Presentation #2.

Each oral presentation is given as a research group. But, individuals are given individual assessments (see Week 12: Oral Presentation Final Assessment Form) for their part in the presentation. A literature review and statement of questions are given, but briefly, because they were covered in the first presentation. This second presentation focuses on expected outcomes, experimental designs, and potential benefits. Students are assessed on the quality and organization of the presentation. Students are assessed on the quality of their literature review, statement of questions, and appropriateness of experimental design, but not during this oral presentation. The quality of their literature is assessed in their annotated bibliography. The quality of their questions is formally assessed in the research proposal, but I've provided enough feedback before this to work out most problems. Lastly, I use this oral presentation as a formative assessment to give students feedback on experimental designs. They are then given time to incorporate these design changes into their written research proposals. I do this for two reasons. First, creating experimental designs to answer specific ecological questions is little known or completely unknown to most of our students. Therefore, they need the time and feedback to work out the details. Second, students have given me feedback on evaluations that a week between the second oral presentation and the written research proposal is very important for them to make necessary changes to their experimental design, based upon my comments during oral presentations.

Week 13: Final Paper Due.

Students hand in their final research proposals and do the course evaluation. Student experimental proposals are assessed based upon a grading rubric (see Week 13: Research Proposal Final Assessment Form).

Additional Documents.

- Week Prior to "Start": Detailed Methods for Line Transect Sampling
- Week 2: Quantifying Observations
- Week 5: Guidelines for Research Proposals
- Week 6: Guidelines for Annotated Bibliographies
- Week 9: Oral Presentation Midpoint Assessment Form
- Week 11: Guidelines for Peer Reviews of Research Proposals
- Week 12: Oral Presentation Final Assessment Form
- Week 13: Research Proposal Final Assessment Form

- Ecology Lab Course Syllabus (Appendix1_syllabus_fall2003.doc, 36kb)
- Week 4: Library Research Strategies (Appendix2_literature_searches.ppt, 40kb)
- Week 5: Example Research Proposal (Appendix3_proposal_example.doc, 156kb)

Questions for Further Thought and Discussion:

1. Discuss the relationship between a factorial experimental design and the concept of interactions we've talked about in lecture.

2. The experimental garden at Belmont was populated by plants seeded into the plot and volunteers that may have been in a seed bank. How would you describe the different processes that determine the presence or absence of these different plants to this plot. What experimental designs might you use to distinguish among the processes that determine the presence or absence of seeded or seed bank plants?

3. Describe the broad goals of your experimental program and the specific hypotheses / questions to be answered by your experiments. State how these goals and questions are different from one another by relating them to your background concepts and your experimental design.

4. Pick your favorite abiotic dependent variable and your favorite biotic dependent variable. Also, choose some independent variable like (don't limit yourself to my list) growth rate, carbon fixation, or seed production. Describe your expected results from a simple 2x2 factorial experiment. I would like you to describe 2 possible outcomes: results to show no interaction between the two variables and results to show an interaction between the two variables.

5. As a plant ecologist let's say you are interested in conserving populations of a Federally endangered plant. How would you suggest going about doing the research that would help restore the populations of this rare plant? Would you approach it from a population ecology perspective (i.e. investigate the factors that impact the population dynamics of this single plant)? Would you approach it from a community ecology perspective (i.e. investigate the community and community dynamics in which the populations of the plant live)? Describe at least 2 advantages and disadvantages of each approach to restoring populations.

6. The hypotheses / questions you have proposed have probably dealt with the distribution and/or abundance of plants in space. Take one of your hypotheses and restate it so that it looks at the distribution and/or abundance of plants in time. Describe how you would have to change your experimental design to test this new hypothesis / question.

*** Note: Answers to many of these questions and numerous other comments by the contributing author can be found in the "NOTES TO FACULTY" section below.

References:

Ecology References:

Barbour, M., J. Burk, W. Pitts, F. Gilliam, and M. Schwartz. 1999. *Terrestrial Plant Ecology* (3rd ed.). Addison Wesley Longman, Inc., Menlo Park, CA, USA.

Crawley, M.J. 1997. *Plant Ecology* (2nd ed.). Blackwell Scientific Publications.

Gurevitch, J., S. Scheiner, and G. Fox. 2002. *The Ecology of Plants*. Sinauer Associates, Inc., Sunderland, MA, USA.

Palmer, M., E. Bernhardt, E. Chornesky, S. Collins, A. Dobson, C. Duke, B. Gold, R. Jacobson, S. Kingsland, R. Kranz, M. Mappin, M. Martinez, F. Micheli, J. Morse, M. Pace, M. Pascual, S. Palumbi, O. Reichman, A. Simons, A.Townsend, and M. Turner. 2004. Ecology for a small planet. *Science* 304: 1251 - 1252.

Westoby, M., D. Falster, A. Moles, P. Vesk, and I. Wright. 2002. Plant ecological strategies: some leading dimensions of variation between species. *Annual Review of Ecology and Systematics* 33: 125-159.

Whigham, D. 2004. Ecology of woodland herbs in temperate deciduous forests. *Annual Review of Ecology, Evolution, and Systematics* 35: In press, (expected 12/04).

Pedagogical References:

Grant, B. W. and I. Vatnick. 1998. Environmental correlates with leaf stomata density: a multi-week bounded inquiry for an undergraduate introductory biology laboratory. *Journal of College Science Teaching* 28: 109-112.

TIEE Teaching Resources: Glossary - Bounded inquiry description (tiee.ecoed.net/teach/teach_glossary.html#bounded)

TIEE Teaching Resources: Table describing "Inquiry Framework: Levels of Student Ownership" (tiee.ecoed.net/teach/framework.jpg)

Weimer, M. 2002. *Learner-centered Teaching: Five Key Changes to Practice*. Jossey-Bass, San Francisco, CA, USA.

Web page on Learner Centered Teaching and syllabus development (www.cte.iastate.edu/tips/syllabi.html)

Plant Identification Resources:

Brown, L. 1992. *Grasses: An Identification Guide (The Peterson Nature Library)*. Houghton Mifflin Company, Boston, MA, USA.

Gleason, H. and A. Cronquist. 1991. *Manual of vascular plants of northeastern United States and adjacent Canada*. New York Botanical Gardens, New York, NY, USA

Newcomb, L. and G. Morrison. 1989. *Newcomb's Wildflower Guide*. Little, Brown and Company, Boston, MA, USA.

Peterson, R. and M. McKenny. 1998. *A field guide to wildflowers : northeastern and north-central North America (Peterson Field Guides)*. Houghton Mifflin Company, Boston, MA, USA.

Sampling Resources:

General discussion of methods for sampling plants such as quadrat, transect, point, and gradient methods (digital.library.okstate.edu/oas/oas_pdf/v71/p43_45.pdf)

Griffith, A., and I. Forseth. 2003. Establishment and reproduction of *Aeschynomene virginica* (L.) (Fabaceae) a rare, annual, wetland species in relation to vegetation removal and water level. *Plant Ecology* 167: 117 - 125. {Example of using allometric relationships to estimate plant biomass}

Descriptions of sampling strategies, plant sampling methods, and measuring cover, frequency, and basal area (www.geobotany.uaf.edu/teaching/biol474/lesson14slides.pdf)

Discussion of quadrat sampling and plot-less methods (www.serg.sdsu.edu/SERG/techniques/mfps.html)

Experimental design:

These references focus on the simplest experimental designs: complete random, blocking, and factorial designs

biometrics.hri.ac.uk/experimentaldesigns/website/hri.htm

www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag3024?OpenDocument

www.tfrec.wsu.edu/ANOVA/

Tools for Assessment of Student Learning Outcomes:

Students are assessed on two oral presentations and three written assignments. The integrating assignment for the semester is a written research proposal of a standard form. This proposal does not include a budget. Different portions of the research proposal are collected as the semester progresses. This modular development of students' proposals is designed to give students feedback on segments of the proposal before the complete proposal is due at the end of the semester. This strategy allows students to improve the content and format of their proposals through formative assessments from their instructor and peers. This section is organized first by assignment and second by assessment goal.

Assessment by Assignment

The first assessment due is an annotated bibliography. The goal of this assessment is for students to organize their background research in order to focus on their hypotheses / questions. Students receive a description of an annotated bibliography (see Week 6: Guidelines for Annotated Bibliographies). Annotated bibliographies must be in alphabetical order by the first author's last name. The bibliographic style must match that of Ecology and examples are given in the annotated bibliography handout and the proposal guidelines (see Week 5: Guidelines for Research Proposals). Students are graded on style and organization of their bibliographies. The content of the annotation is graded based upon how well it is focused on the questions and results of the bibliographic reference. In addition, the annotation is graded based upon how it is related to the student's hypotheses / questions.

The second assessment is the first of two group oral presentations. The grading sheet used for oral presentations should be shown to students the week before their presentations (see Week 9: Oral Presentation Midpoint Assessment Form). This explicitly shows them the criteria for the assessment of their performance. On the grading sheet, positive feedback and constructive criticism are particularly important as they should give the speaker a clear statement of how to improve the content and organization of their presentation, as well as goals for improving their public speaking skills.

The third assessment is data presentations the authors will place in the final proposal. Students primarily have graphs and few tables. This is because most of the data we collect is best presented in graphs and I also stress that data should be presented graphically whenever possible. The evaluation of these graphs is straight forward. I have seen many if not most of these graphs previously and had a chance to comment on the format and titles / captions. My main criteria for a quality title / caption is "Does this title / caption allow the data presentation to be understood when it stands alone?" In terms of form and formatting, I provide examples of graphs that are consistent with Ecology editorial standards and I also provide copies of Ecology.

The fourth assessment is the second group oral presentation. The second presentation focuses on the segments of the experiment proposal not covered during the first presentation. These are also the segments of the proposal that the students have been working on since the first presentation. The grading sheet used for oral presentations should be shown to students the week before their presentations (see Week 12: Oral Presentation Final Assessment Form). They should also have copies of their assessment from the first presentation.

The final assessment is the students' written proposal. Most sections or elements of this proposal have been seen several times before it is handed in for assessment. That said, it remains a complex writing task for most of the students. Proposals are assessed objectively for both form, about 25% of the total grade, and content, about 75% of the total grade (see Week 13: Research Proposal Final Assessment Form).

Assessment by Goal

Goal: Students present information orally

Assessment: Oral presentation scoring rubric; instructor and peer review

Overview: Effective public speaking skills are an integral part of many, if not most, of the professional and/or post-graduate positions our students will hold. Students are given criteria for their presentation assessment (see above), so they know the elements of public speaking on which they will be graded. There are many strategies for evaluating public speaking and criteria can change over time. Students are also provided several resources to guide them through preparing presentations. Our campus has a well appointed Speaking Center (www.mwc.edu/spkc/center/) where students can go to practice and get detailed feedback on any aspect of their presentations, from initial organization to final presentation. Students also are given access to documents produced by the UMW Speaking Center staff that provide guidance for this process:

* A Brief Guide to Constructing a Speech,
* Guidelines for Planning a Group Presentation,
* Preparation Outline Checklist,
* Preparing the Main Points for a Presentation.

Goal: Students formulate research questions / hypotheses

Assessment: Instructor / student interactions, oral presentation assessment, and written proposal assessment

Overview: Some student feedback suggests that, of all the components of science methodological skills, they have had the least practice formulating clear and precise research hypotheses / questions. Students formulate their questions, in collaboration with peers in groups of 2 or 3. Research groups also consult closely with the instructor. My input in the process is meant to focus students' attention on the dependent and independent variables in which they are interested and the measurability of these variables. I also guide students to ask questions that are, in some way related to each other. This relationship provides each research group with a larger perspective for their research proposal. Once these questions have been formulated and agreed upon by each group and the instructor, each group sends an email that records the agreed upon questions. Research questions are formally assessed within the context of the group oral presentations and the written proposal. Assessment of questions in the written proposal goes to how well students describe the relationship among their questions and whether or not their experiments answer those questions (see Week 13: Research Proposal Final Assessment Form).

Goal: Students apply appropriate designs to specific research questions / hypotheses.

Assessment: Oral presentation assessment and written proposal assessment.

Overview: These are the guidelines for the students' experimental designs: 1. Some of the proposed experiments must be controlled experiments in the field, 2. At least one of your experiments must be an experiment that will answer all or part of a particular hypothesis, and be a laboratory or greenhouse experiment, and 3. Observational experiments can be proposed, although they are not required. Students are encouraged to use experimental designs they have found in papers on related research and they are encouraged to use factorial designs. During the 7th week of the exercise, I provide criteria for design of good experiments. I provide feedback to the research groups during their 2nd oral presentation and formally assess designs while grading the final proposals (see Week 13: Research Proposal Final Assessment Form). Questions about experimental design consistently arise during the peer reviews.

Goal: Students self organize for data collection tasks and data sharing among themselves.

Assessment: Peer comments and assessment.

Overview: Students are given free rein to organize the class for data collection and data sharing, once they are clear on the requirements. I have not done any formal assessment of this process. Two things seem to happen during data collection and sharing. Either a group of leaders forces the class the pause and think about efficient ways to collect and share or a group realizes how inefficient they have been and tries to remediate.

Goal: Students critically assess peers' research proposals.

Assessment: Peer assessment.

Overview: It is critical that students learn self assessment and peer assessment skills. Each student seeks 2 peers, not in their research group, to review a rough draft of their proposal. This is done during lab time. Each student is given criteria for their review of the proposals orally and in writing (see Week 11: Guidelines for Peer

Reviews of Research Proposals). This is an exercise primarily for students to develop evaluative skills. Secondarily, students read their peers' work for comparison to their own writing.

Goal: Students organize and write a research proposal.

Assessment: Scoring rubric on proposal sections and final proposal. Peer review of written proposal.

Overview: While students have received considerable feedback and assessment on components of the written proposal, the writing and integration of the final proposal is a complex task. Early in the semester, I describe the components of the proposal in detail (see Week 5: Guidelines for Research Proposals) and provide an example of a good proposal (see Week 5: Example Research Proposal). I will also make good student proposals available for examination as I gather them into my files. The proposals are assessed according to the proposal grading rubric (see Week 13: Research Proposal Final Assessment Form), as stated before.

Tools for Formative Evaluation of this Experiment:

To date, I have received formative evaluation of this experiment in the context of my student course evaluations. This instrument (i.e. the course evaluation) is not designed to give consistent formative evaluation.

An extensive discussion on Evaluation appears in the Teaching section of the TIEE website: http://tiee.ecoed.net/teach/teach.html.

NOTES TO FACULTY

Comments by Contributing Author – Alan B Griffith

Challenges to Anticipate and Solve:

1. Equipment availability: Students want to collect all kinds of data from this experimental plot. Much of it involves abiotic variables. The challenge is to come up with equipment to allow this data collection and to get students to collect data for which you have equipment. My strategy for this is both short and long term. In the short term, I require students to think about why they wish to collect any given data. This often leads them to realize they do not need that data. If they still feel they need this data and we do not have the equipment, I simply tell them that. If this data is important for the research they are proposing, I suggest they include this data collection as an experiment in their proposal. In the long run, I will purchase useful equipment that is not yet available in my department.

   A variety of equipment is easy to make, acquire, or purchase inexpensively. Equipment for quadrat, point, and line transect sampling of vegetation is easy to obtain or build. For example, 1 m2 quadrats can be built with 4 lengths of PVC pipe and 4-90o PVC corners. Larger quadrats for sampling larger scales (e.g. trees and shrubs) can be constructed with 4 stakes and string. Soil test kits for estimation of soil nitrogen, phosphorus, potassium, and pH are readily available from many sources (e.g. Hach, LaMotte, and local garden suppliers) and not expensive. Simple methods to visualize and estimate stomata density are found in Grant and Vatnick 2004 (TIEE Vol 1 - tiee.ecoed.net/v1/experiments/ stomata/stomata.html). Although large scale destructive sampling is not appropriate in our experimental plot, students could selectively sample plants to develop allometric estimates of plant biomass (see Griffith and Forseth 2003)

   Students interested in ecophysiology may be out of luck due to the cost of equipment. Light meters and sensors for photosynthetically active radiation (PAR) are available from about $500 to $1000. Be sure to purchase a sensor that measure in units that can be related to photosynthesis (e.g. μmol · m-2 · s-1). Portable photosynthesis, gas exchange, and water relations measurement equipment like the LiCor 6400 costs about $10,000. Leaf area meters may cost from $2500 to $5000, but leaf area can be estimated using leaf sketches on graph paper.

2. Formulating questions: Many students struggle with formulating specific questions for their proposals. Students must propose questions with specific measurable dependent and independent variables. The challenge of the instructor is to provide support in this difficult and many times first time task, but not to tell students what questions to ask. I ask students what their dependent and independent variables are and if they are measurable. I also stress that there should be some relationship among their questions to create an integrated

research proposal. It is this relationship among research questions that creates a broader context for the proposed research. In developing their research agenda, students may work from the specific questions to the broader conceptual questions or they may work from the broad concepts to the specific questions. I do not yet know which direction is preferable pedagogically.

To date for my course, the ecological questions addressed by my student groups have generally concerned spatial and temporal patterns in plant population and community ecology. The broad concepts covered include mutualism and potential mechanisms of that mutualism, life history differences among grasses and forbs, seed germination strategies, competition and specific limiting factors leading to competition, environmental correlates of species diversity, and root competition.

Here are 4 sets of questions showing a range of ecological concepts addressed. The broad concepts covered include mutualism and potential mechanisms of that mutualism, life history differences among grasses and forbs, seed germination strategies, competition and specific limiting factors leading to competition, environmental correlates of species diversity, and root competition. Although all of these hypotheses deal with spatial ecology, students should be able to address hypotheses / questions about changes in time, if they have an historical dataset of plant abundance and distribution from the experimental plot.

a Does *Amaranthus* sp. have a mutualistic relationship with *Digitaria* sp.? Does *Digitaria* sp. grow taller when growing close to *Amaranthus* sp.? Does *Amaranthus* sp. decrease wind speeds around its stems? Does *Digitaria* sp. grow more densely when growing close to *Amaranthus* sp.?

b) Do grasses germinate earlier in the summer than plants with broad leaves and short stature (i.e. forbs)? Do forbs germinate better under low light conditions than thin leaved, tall plants (grasses)? Do forbs increase stem length more quickly in low light conditions than in high light conditions? For grasses that germinate in open canopies, does high light intensity increase phytochrome activity in the seeds?

c) Does Oxalis sp. (wood sorrel) grow in lower abundance when growing in the presence of other plant species than when growing in the presence of other Oxalis sp. plants? Does Oxalis sp. grow in lower abundance when growing in low light levels? Does Oxalis sp. have lower stomatal apertures to increase CO_2 uptake in low light levels? Does Oxalis sp. grow in lower abundance when growing in low soil nitrogen levels?

d) Does species richness increase with increased incident light levels? Does species richness increase with increased soil moisture levels? Does total biomass of plants increase when fibrous root plants and tap root plants grow together, as compared to when fibrous root plants grow with fibrous root plants or tap root plants grow with tap root plants? Do fibrous root plants uptake soil nitrogen from more shallow soil depths than tap root plants?

3. Experimental plot: While my experimental plot was off campus, this may or may not be a challenge for some departments. Some schools do not provide transportation resources. In this case, any appropriately sized plot of vegetated land on campus will do for motivation. For example, the faculty of Cedar Crest College, Allentown, PA maintain a research plot on campus which is a small piece of land that has not been mown for many years. The faculty have kept a time series of data from ongoing sampling of the plot. Alternatively, most grassy lawns are not monocultures and so contain considerable diversity. This surprising amount of diversity leads to interesting questions. For example, given the strict and routine management of lawns, how do we explain the distribution and abundance of plant species on these lawns?

4. Working in groups: At the University of Mary Washington there is an explicit honor code that reads, in short, as follows, “I hereby declare, upon my word of honor, that I have neither given nor received unauthorized help on this work.” Students raise many questions about what work can be done as a group and what must be produced individually. The instructor needs to be clear from the onset about these group vs. individual issues. I will give two examples of the differences between group and individual work. First, data from the experimental garden (e.g. plant abundance, plant distribution, maps of rare plants, soil moistures, and soil textures) has been collected by different groups in the class. This is simply an efficient way of collecting data useful to the whole class. For example, if there are 6 groups in the class, the experimental garden can be split into six smaller sections for each group to sample plant abundance. This data must, in turn, be shared among all six groups. Once the data is shared each individual should have a copy of all data collected by each group for their use. Each individual should create appropriate data presentations and write titles and captions for the presentations. It may be difficult or impossible to verify that each student has created his/her own graphs and tables. I would say though that you can expect significant differences among the titles and captions of graphs and tables when you assess their data presentations. Second, annotated bibliographies are assessed individually, but they emerge from the work of the group. I believe it is sensible and efficient for the members of a group to share their literature search efforts. This shared effort has several purposes. Students will have different levels of experience with literature searches. Thus, the group can work together and learn from each other. At UMW, the whole class works in our “Science Literacy Center,” a dedicated computer room in the science building. Each student can do literature searches at his/her own computer and work side-by-side with peers. The group can also share ideas about the appropriateness of papers as they find them. I have also allowed students to share the task of typing and formatting references. The task of writing reference annotations after reading papers is an individual task.

    In addition, group work invariably leads to personality conflicts in one or two groups. To a certain extent, I believe students should be encouraged to work out these conflicts among themselves. These people will likely work in teams during their careers and will run into the same kinds of conflicts in the future.

Another group issue that may arise is whether or not all members of the group contribute equally. This is a difficult matter to track and I have not yet developed consistent measures to evaluate this equity issue. First, keep your eyes and ears open. As you work with and ask questions of research groups, note who answers questions and who does not. Challenge quiet students to respond to your questions as you interact with groups. You may have to explicitly ask more verbal students to remain silent. Ask individuals in a group about any tension you sense among members of the group. Second, carefully compare individual assignments among the individuals of each research group. Assignments like the annotated bibliography are sufficiently complex that there should be little similarity among individuals in a group. Third, ask students about their group's dynamics and division of labor. Have they shared resources while gathering references for their research? Has each member contributed equitably to the organization and creation of oral presentations? The discussion on Formative Evaluation in the Teaching Section of this website provides some guidance on how to ask students to evaluate their performance and their peers' performance in the group.

5. in-class and out-of-class time commitment: The experiment schedule as presented in the class syllabus (see syllabus_fall2003.doc, 36kb) does not use laboratory class time as efficiently as is possible. The experiment is currently designed to have a significant amount of in-class time devoted to work such as library research, oral presentation development, and peer reviews of proposals. This decreases the amount of time that one might expect from students out of class. As I refine the details of this experiment, some of this in-class time will be reorganized. When I move some of this in-class work to out-of-class work, I anticipate inserting short term exercises during laboratory class time to supplement lecture concepts, computer modeling exercises, and / or discussions of research articles.

Comments On the Lab Description:

Introducing the Lab to Your Students.

Before going to the field site for this experiment, the students receive the introductory handout for this experiment. They have already received the course syllabus, which lists the assignments for the laboratory portion of the course. The handout includes the goals for this experiment, some background on the context of this experiment, and the objectives of the first laboratory. I verbally describe the assignments that will be due for their laboratory work. I also verbally describe the handout and briefly describe the process we will follow to produce the final assignment: a written research proposal. This places their assignments in the context of the work for this experiment. The remainder of the first laboratory is conducted at the Gari Melchers Estate, the site of the experimental plot. The head gardener and grounds manager of the estate gives a brief history of the grounds of the estate. She also gives a brief description and history of a prairie grassland plot she has developed over several years. This is significant because the same prairie species were seeded into the class' experimental plot. I describe to the students how the experimental plot before them was treated and reiterate the role of this plot in the objectives for the course. Students then turn to their first task of making observations about the current abundance and distribution of plants in experimental plot.

Comments On the Activities in the Lab.

I have always told students to be prepared for all weather conditions. This must be covered during the week prior to the first laboratory of this experiment and it should be part of the syllabus. Remind them to bring sturdy shoes, rain gear, pencils, water, and sun screen. Thunder and lightning and/or a drenching rain will scuttle the field work for the day. If you can't work a particular day, look ahead to see if you can have students organize themselves for the upcoming work. You might also rearrange some of the laboratory mini-lectures to fill in this open time.

Have good instructions available with the equipment for the experiment. Students may want you to tell them what to do at every step. Turn this around and tell them to follow the directions carefully so they can figure the equipment out for themselves. That said, know your equipment well enough to know which equipment is too complex to use without instruction.

I borrow some of the laboratory equipment (e.g. graduated cylinders, mass scales) for this experiment. This has worked well at my institution, but it may be an issue for some people. If you do borrow equipment on a weekly basis, give yourself time to gather materials before the laboratory starts. If you will not be able to borrow equipment as needed you will need to budget for these items.

I have not taught any students with disabilities in this course yet. Always work closely with your "Office of Disability Services" to develop appropriate accommodations for students with disabilities.

The text of this experiment has been written with a bias toward differences in plant abundance and distributions in space and not in time. There is no reason why this experiment does not lend itself to hypotheses about time. Students would need some historical records about the abundance and distribution of plants in the experimental plot to support hypotheses about temporal changes. Even 1 or 2 years of data beyond the current year's data would provide interesting fuel for students' hypotheses. I do not yet have these historical records (i.e. I have not done this experiment multiple years).

When I first designed and organized this experiment, I thought it would be interesting to take a good set of hypotheses with their experimental designs and apply these designs to the experimental plots for the class. As I implemented the experiment, I realized that laying an experimental design over the experiment plot would greatly change the nature of this exercise. In terms of future classes, this would tend to constraint the range of possible variables that students would consider. I do not want to limit the range of hypotheses that students might consider in the future and therefore will not try to "implement" experiments on the experimental plot. The possibility of students implementing their designs is outside the scope of this laboratory. I am comfortable with my focus on hypothesis generation, experimental design, and proposal writing because these parts of the scientific process are not, generally, as well covered as other parts of the process. Students get ample opportunity to learn technique, generate data in experiments, and draw conclusions from these data. They spend less time on the initial observations and hypotheses. I have received several comments from my students to this effect. However, my institution, like most other undergraduate colleges and universities, has an active undergraduate independent research program. The proposals written in this experiment would be excellent starting points for potential research projects.

Comments On Questions for Further Thought:

Comments on Question 1: Discuss relationship between factorial designs and interactions…

I introduce the concept of variable interactions, both conceptually and graphically, in the lectures for this course. Students should describe interactions and give examples of synergisms and antagonisms. The attached spreadsheet (interaction.xls, 26kb) shows examples of graphs where there is a) no interaction, b) an antagonism, or c) a synergism. They should describe a simple factorial experiment that provides information about two variables acting simultaneously. For example, a simple factorial experiment might include soil moisture (watered to field capacity twice weekly and watered to field capacity once weekly) and herbivory (herbivores excluded or herbivores not excluded from experimental units) as independent variables and number of seeds produced as dependent variable. The experimental design assigns all the possible combinations of soil moistures and herbivory to experimental units (2x2 = 4 possibilities). Given this background, students should discuss how this experiment can measure potential interactions among independent variables. Both antagonism and synergism are interactions. This 2x2 factorial experiment is the simplest factorial combination possible. As seen in the graphs, no interaction means that when you add the effect of water (seed count change between points A and B) and the effect of herbivory (seed count change between points A and C) this adds to the effect of both variables together (seed count change between points A and D). This is the same as the effects of the two variables on seed count being "additive." When the effect of two variables together is less than the additive effect, it is an antagonist effect. When the effect of two variables together is greater than the additive effect, it is a synergistic effect.

Comments on Question 2: Presence or absence of seeded and volunteer plants….

Seed addition experiments are used to distinguish between dispersal limitation and competition as processes determining the presence or absence of species in a space. An experimental design that varies the density of seeds placed in plot can show whether or not the amount of dispersing seeds limits the establishment of plant species. A design that varies the density of standing plants in experimental plots can show whether or not density (i.e. competition) impacts the establishment of plants.

Comments on Question 3: Describe broad goals and specific hypotheses….

Students have had a difficult time distinguishing between and articulating the difference between the broad concepts and the specific hypotheses addressed by their experimental programs. It is therefore useful to have the students think about the “big picture” versus the “details” of their experiments early in this process. The goal of this question is to have students think about and clearly state the conceptual problems covered by their experiments and the specific dependent and independent variables that are meant to measure these conceptual problems.

Comments on Question 4: Pick your favorite abiotic dependent variable ….

This question asks students to apply their knowledge of factorial experiments and interactions. I will use the example of water level, herbivory and carbon fixation. Water availability is an abiotic variable, herbivory is a biotic variable, and carbon fixation is a dependent variable. A 2X2 factorial experiment would create treatments where each independent variable had 2 levels. So, this experiment would create low water and high water availability treatments. The experiment would also include low and high level herbivory treatments. All of the possible combinations of these variables are treat 1: low water and low herbivory, treat 2: high water and low herbivory, treat 3: low water and high herbivory, treat 4: high water and high herbivory. The easiest way to approach this is to create a graph and describe the outcome. A graph with no interaction between water level and herbivory will show 2 parallel lines. Let’s say the X-axis shows water level and the Y-axis shows carbon fixation. The lower line on the graph would be for high herbivory and the upper line on the graph would be for low herbivory. Each line has a positive slope because as you increase water availability to a plant carbon fixation will increase (i.e. the plant is not water stressed). The line showing low herbivory is higher than the line showing high herbivory because herbivory removes photosynthetic area. I think the most sensible description of an interaction between these variables is one where the low water and high herbivory treatment decrease carbon fixation more than expected. Therefore, the mean difference between low water: low herbivory point and the low water: high herbivory point is greater than the mean difference between the high water: low herbivory point and the high water and high herbivory point.

Comments on Question 5: As a plant ecologist let’s say you are interested in conserving populations ….

This is an open ended question that could have practical and / or philosophical answers. One might discuss the importance of focus. If we are interested in conserving a particular plant, then the research should focus on the ecology and population dynamics of that particular plant and not a much broader set of plants. There could be population demographic reasons (e.g. demographic stochasticity) that have made the plant endangered that have little to do with the surrounding plant community. That said, it is clear that an individual plant does not live in isolation from the other plants in the community. It makes sense then that we need to know something about the endangered plant and the other plants in the community that are interacting negatively and possibly positively with the endangered plant. Some students may argue that if we have limited funds to conserve this plant our focus should be on the plant of interest and not a larger community that might require more resources. If the initial research on the individual plant requires us to research the broader community, then do that in the future. Some students may enjoin that it really is not worth our resources to conserve an individual plant just because it is endangered. It is really habitats and environments that we should be conserving and therefore we must always investigate the characteristics of whole communities.

Comments on Question 6: The hypotheses / questions you have proposed have probably dealt with the distribution and/or abundance of plants in space….

Students in this class, to date, have focused exclusively on questions across space and not across time. This could be a result of my biases. This question is designed to have students explore the ideas of their variables changing within a growing season or from year to year. I touch on experimental designs that measure variables over time and introduce repeated measures designs and non-repeated measures designs like split-plot designs. Students might describe using one of these designs or might discuss an experiment that must run across several years.

Comments On the Assessment of Student Learning Outcomes:

The Table describing "Inquiry Framework: Levels of Student Ownership" makes explicit a range of objectives for inquiry-based teaching: teach existing knowledge, teach the process of knowledge construction, or create new knowledge. My objective in this experiment is to teach the process of knowledge construction. Therefore, my focus for assessment of student learning outcomes is how well students show they have learned these processes and tools that scientists use daily such as literature searches, annotated bibliographies, critical analysis of papers, and writing proposals. Because of this focus, my student assessments such as the proposal grading rubric (see Week 13: Research Proposal Final Assessment Form) looks more closely at how a student has constructed the proposal than at the concepts that the student has included in the proposal.

Comments On the Evaluation of the Lab Activity:

Evaluation is discussed above. In addition, extensive notes on how to conduct formative evaluation are in the Teaching Resources sector of TIEE under the keyword "Formative Evaluation" and in an Essay on Evaluation of Course Reforms

Comments On Translating the Activity to Other Institutional Scales:

The fact that I used a created experimental garden should not be an impediment to the translation of this activity to any particular place. I believe almost any plot of similar size could be used to motivate the generation of hypotheses / questions for an experimental proposal. In fact, over time it would be interesting to use different plots as each plot's history and current environment should create different potential questions.

I believe the general format of this exercise would lend itself to a long term project in a high school biology or environmental science class. This process allows students to explore some of the details of observation and question formulation that precedes experimental design and experimentation. From my experience, the average freshman undergraduate has had little experience formulating clear and focused questions with measurable dependent and independent variables. Much more direction would be required for data collection, data sharing, and data analysis. One difference between upper level undergraduates and high school students is their level of exposure to ecological concepts. A preview of potentially important factors for the distribution and abundance of plants would help fill some of this gap. It would also be appropriate to limit the potential ecological concepts that students would consider for experiments. This would allow the instructor to preview few concepts in more detail before beginning observations.

I have down played the potential for this format as a lower level laboratory experience because, in my experience, most instructors would not want to relinquish this much laboratory time. At my institution, our freshman-level biology laboratory is still a content oriented course with much potential for inquiry-based learning. It is currently constrained to follow along with the content schedule of the lectures. Without these constraints, excerpts from this format could be used in lower-level biology laboratories. One example was given in the short description of "Transferability." Students might also be given several sets of hypotheses from which to choose. After some background on experimental design, they could design appropriate experiments to test their chosen hypotheses. There is a tradeoff though for using excerpts from this extended experiment: loss of ownership by the students. The more information given to students and not generated by students means they are less invested in the project.

This experiment could be transferred to a quarter system schedule by moving some of the current activities out of class time and combining 2 or 3 laboratories. In short, the schedule could easily be compressed. For example, week 9 on the schedule shows that annotated bibliographies are due and I would give time for oral presentation preparations and questions. This preparation and question time could be moved out of class time and the first oral presentation moved forward a week. Peer and supervisor reviews could also be done outside of class time. The line transect method is currently taught outside of the context of this experiment. It is covered the week prior to the introduction of this experiment. This transect methods instruction could be done at / on the plots for the experiment and the initial plant abundance / distribution data could be collected during this instruction. The students get some initial practice formulating hypotheses during this transect methods instruction lab, but I believe this practice could be lost with little difficulty.

ACKNOWLEDGMENTS:

The fundamental elements of this experimental proposal were formulated while acting as teaching assistant for Dr. Irv Forseth, University of Maryland. Over the course of several years teaching his plant ecology lab, he and his teaching assistants designed and created a laboratory course that relied more and more on extended greenhouse experiments of plant competition and soil heterogeneity. Two friends and colleagues, Dr. Andrew McElrone and Dr. Michael Peek organized and formulated these laboratories at the University of Maryland. Although we had few details, we also knew that Dr. Brenda Casper, University of Pennsylvania, conducted a plant ecology lab consisting solely of an extended experiment of the students' design. This submission has benefited from comments by TIEE Editors and an anonymous reviewer.
