Learning Ecology by Doing Ecology

Long-Term Field Experiments in Succession

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We believe that ecology field laboratories are not being taught as they should be. In these laboratories, students should be using the scientific method and working in carefully designed long-term field experiments. Instead, many undergraduate ecology laboratories involve mensurative field observations, such as observational guided nature walks, listing species abundances from contrasting areas, or short-term manipulative experiments in the greenhouse. At best, these approaches are natural snapshot experiments (Diamond 1986) in which ecosystems that differ from one another in only one or two characteristics (for example, number of species in polluted versus unpolluted areas) are compared. These experiences are invaluable in the teaching of environmental sciences (Carter 1993) and are well integrated into many environmental science curricula. However, they do not provide a thorough training in the scientific method or reflect the way in which much of the best ecological research is conducted.

The typical approach outlined above is in contrast to a large proportion of empirical ecological and environmental research that is based upon field experiments and the scientific method. Further, there is an increasing reliance on long-term field experiments in the development and testing of modern ecological theory. Thus a dichotomy between teaching and research exists despite the long-held belief among educators that students learn best through inquiry and the scientific method as practiced by practitioners of the discipline. To address this issue we have established a long-term field experiment that addresses topics of ecological succession in abandoned farm fields. The purpose of this article is to:

1. Argue the need for long-term field experiments in undergraduate ecology curricula.
2. Describe the field experiment in long-term succession that we have set up to address this need.
3. Report the findings from the first year of our project.

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Value of Long-Term Field Experiments for Ecology & Therefore Teaching

There is little emphasis in ecology curricula on *long-term field experiments* compared with laboratory experiments or purely observational field experiences. Field experiments involve the controlled manipulation of experimental treatments under the natural, but seasonally variable, climatic conditions of the environment (Pigott 1982). Long-term field experiments, i.e. those that are maintained over many years, perhaps decades, provide a wealth of ecological information (Leigh & Johnston 1994).

A survey of published ecological research showed that field experiments were used in 25% of the studies (Tilman 1989). Experiments (both greenhouse and field) were used in 41% of a later survey (Stiling 1994). Clearly, field experiments are important to the practitioners and researchers in ecology and so it follows that the methodology should form an integral part of its teaching. Ebert-May et al. (1993) wrote, "*. . . the most critical aspect of ecology education is the learning of how ecologists come to 'know.' We envision no better way to do this than to 'do what ecologists do'.*"

The advantages of incorporating a well-designed *long-term field experiment* into the teaching of ecology include:

- A high degree of realism is provided, far more so than in a greenhouse or laboratory.
- Experimental treatments are tightly controlled.
- Students experience statistical rigor and hence facility to analyze data in a meaningful manner.
- An increasingly large and valuable data set accumulates as the experiment is operated over several seasons. Such long-term experiments can reveal many important environmental effects.
- Precise concepts can be illustrated (i.e. based on the treatments).
- Students can learn a variety of data collection procedures.
- Concepts that operate only over the long term can be illustrated.
- 'Set-up' and 'take-down' for each lab is minimized.
- Many student groups (e.g. K–12 and college undergraduate and graduate students) can use the same experiment providing the exercises are individually tailored for each group and academic level.

Few field experiments are incorporated into ecology curricula. Laboratory manuals for ecology do not include field experiments of this type (Philips 1964; Rolan 1973; Cox 1990; Rosenthal 1995). This is perhaps because of the perceived time and financial commitment necessary to maintain an ongoing experiment. When used by educators field experiments are extremely valuable and the value of a long-term teaching area can hardly be overestimated. For example, Ebert-May et al. (1993) have designed a wetland habitat near Flagstaff, Arizona as a student research site, specifically for teaching introductory ecology. The site is modeled after the nationwide network of NSF-Long Term Ecological Research sites. They noted the following advantages to using their own 'LTER' teaching site:

1. Long-term data bases become available for student use.
2. Large numbers of students become involved.
3. Course field trip mileage costs have decreased.
4. Students have easy access to the site on their own.

On this basis, use of a long-term field site may be attainable for teachers at school or college.

Perhaps the best field experiment set up for teaching is the Nettlecombe Experiment in England, established in 1968 by Crothers & Lucas (1982) in a small pasture. Over the 28 years through which the experiment was run, student groups amassed a large data set that in addition to showing the effects of four mowing treatments upon the grassland, showed the interaction with long-term climatic changes (Crothers 1991). Crothers and Lucas (1982) maintain that this experiment lends itself to several different teaching approaches. The traditional approach involves the teacher asking the biological question and showing the students how the design relates to and assists in addressing the question. A second approach is in the form, 'problem not given, method given, solution not given.' Students are led to understand that there should be a logical relationship between the problem being investigated and the experimental approach used and are asked to provide appropriate designs for follow-up experiments.

Succession as a Framework for Teaching Ecology

Succession is the process and pattern of changes following a disturbance in communities through time at a site. It is an integral component of natural ecosystems and forms an important part of both traditional and modern theories of ecosystem structure; see recent reviews by Glenn-Lewin et al. (1992) and McCook (1994). The topic is an integral part of ecological curricula and covered in all undergraduate ecology and environmental science textbooks albeit with a number of misconceptions (Gibson 1996). It was ranked joint first in order of importance, along with the concept of limiting factors, in the examination syllabus for high school science in Great Britain (Hale & Hardie 1993).

As a teaching tool, succession allows students to understand the changing nature of communities, as well as to conceptualize the result of species interactions (Gibson 1996). Succession also helps students appreciate the long-term nature of many ecological phenomena, such as the response to disturbance. The teaching of succession is usually through mensurative field observations of ecosystems following a disturbance such as fire. Some teaching guides suggest the collection of data from e.g., fields of different ages since abandonment (Rosenthal 1995). However, this 'space-for-time' substitution (Pickett 1989) often involves questionable assumptions about the process, incorporates a high degree of pseudoreplication (Hurlbert 1984), and does not illustrate the dynamic nature of ecological systems (Crothers & Lucas 1982).

The Approach That We Are Taking

We are using a long-term field experiment as a teaching tool to enable life science students to achieve a number of important pedagogical objectives. A general goal is to encourage students to become more ecologically literate through a specific hands-on experience. Specifically, students who participate in the long-term field experiment project will be able to:

- Use the scientific method.
- Better assess the adequacy of field experiment designs.
- Understand the value and limitations of the field experiments, especially long-term experiments in testing environmental and ecological hypotheses.

Furthermore, the students will have a better grasp of the objectives common to all ecological training, viz.:

- Analyzing, presenting and reporting scientific data.
- Recognizing the value of native ecosystems for scientific research.
- Undertaking methods of environmental and ecological data collection.

- Appreciating the role of scientific research in understanding the natural world.
- Integrating research data and results into an understanding of ecology and environmental science as a whole.

In addition, we have a set of ecological objectives that provides the scientific basis and conceptual framework for the project. To assist in best meeting the pedagogical objectives, the ecological objectives are designed to test areas of current interest and importance in understanding the topic of succession.

Students who participate in the long-term field experiment will be able to:

- Describe and articulate the process of succession.
- Design further experiments to test concepts of succession.
- Recognize the long-term nature of successional mechanisms.
- Identify biotic and abiotic interactions effecting succession.

The Field Experiment

The success and practical simplicity of the mowing treatments used in the Nettlecombe Grassland Experiment (Crothers & Lucas 1982; Crothers 1991) prompted us to use it as a model for our long-term field experiments. We added a fertilizer application treatment that was included to investigate the role of soil nutrients in old-field succession (Reed 1977; Carson & Barrett 1988). An earlier study had shown that these treatments would have an immediate and clear effect upon the pattern of succession in these old-fields (Dunbar 1981).

The long-term experiments were established in old-fields at two contrasting study sites: an upland ridge and a bottomland. Historically, both sites were forested, but were cultivated until recently. The upland ridge is located 16 km south of the Southern Illinois University at Carbondale campus. Following purchase of the land by the university in 1949–54, the 1.2 ha area was used as a horse pasture until 1977. The field was plowed in Spring 1981 and mowed annually until 1987 when it was abandoned. Prior to our experiment it was partially invaded by shrubs, especially the exotics autumn olive *(Elaeagnus umbellata)* and multiflora rose *(Rosa multiflora)*. The bottomland site is a 3 ha old-field <1 km west of the university campus. It is on land owned by the university and was last farmed, with a crop of *Sorghum bicolor* var. *sudax*, in 1987. Since then, the field has been mowed in the spring and summer. Prior to setting up the experiment the site was dominated by goldenrod *(Solidago canadensis)*.

The upland site was prepared in Spring 1996 by disking. Autumn olive trees were removed by pulling them up with a tractor before the disking and hand pulling of the smaller stems. Experimental treatments were established using a split-plot experimental design (Figure 1). Seventy-two plots of 0.01 ha were established in eight blocks of nine plots each. Within each block, nine plots corresponding to the combination of mowing (spring only, spring and fall, and no mowing) and fertilizer (hand broadcast of a 51N: 46P: 60K mixture annually, in the first year only, and no fertilizer) treatments were established. Because of the high soil moisture level, the bottomland site could not be prepared until Summer 1996 by which time the vegetation was so thick that the field required plowing before disking and smoothing with a field cultivator. Sixteen 0.01 ha plots were marked out. Fertilizer was

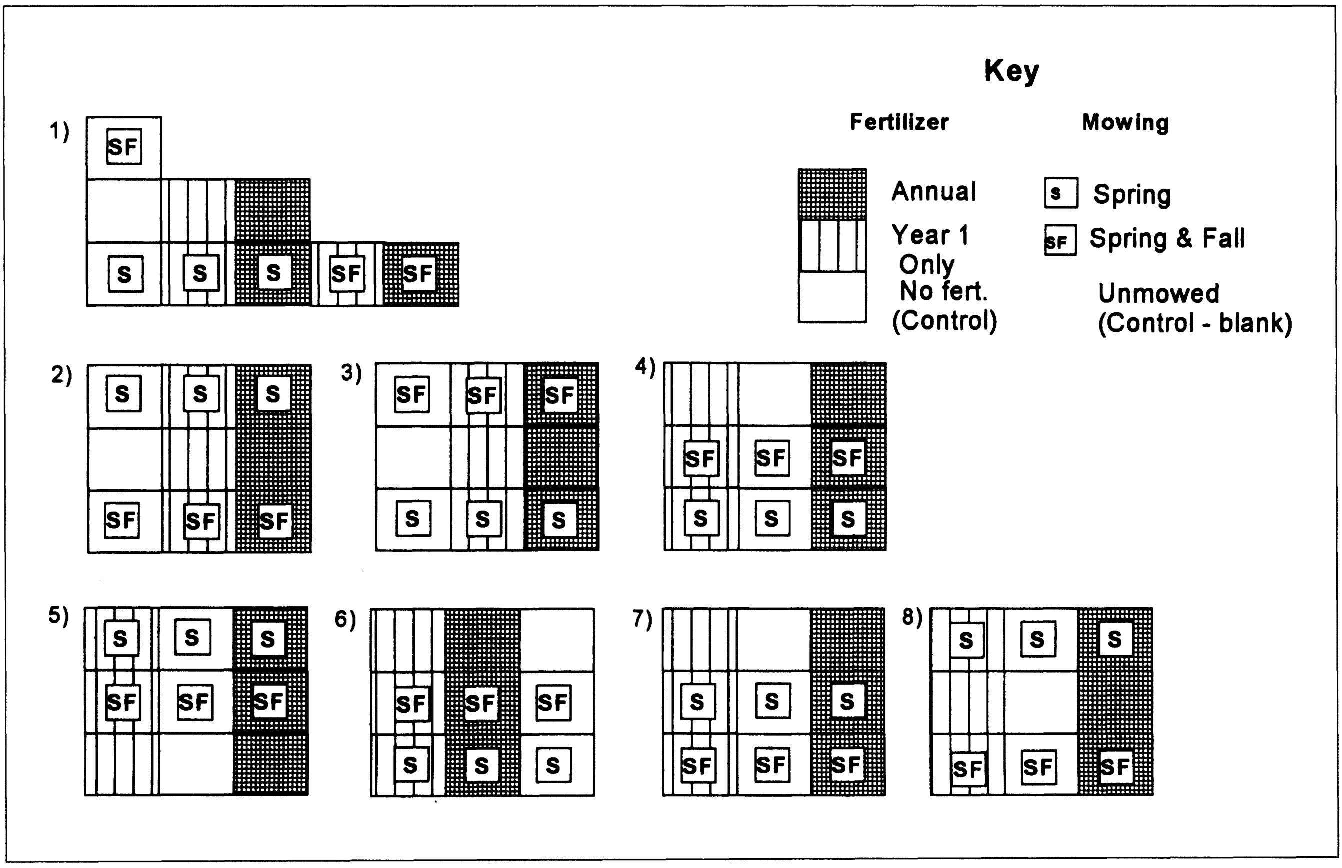

Figure 1. Experimental design at the upland field site. Each of the eight blocks is comprised of nine 0.01 ha plots. Each plot is assigned to one of the nine mowing by fertilizer treatments (see key).

applied using the same treatments as for the upland site. Because of the wet soil, the bottomland site can only be mowed in the summer. The second treatment consists of mowing once a year in the summer, disking once a year in the summer, and no disturbance.

Baseline data are collected at each site. These data can be used by students in subsequent classes. Soil/air temperature and rainfall are measured weekly, while light at the soil surface is measured and photographs are taken from permanent stations monthly. Biomass, species cover and reproductive effort are measured annually. The biomass samples clipped from 0.25 m^2 plots within each plot that were outside of the 5 m^2 circle were used to estimate species cover. Undergraduate students, supervised by graduate students, are responsible for these measurements. All these data are entered into a data base and are available on our Web site (see below).

Use of the Field Experiment in Teaching Ecology

In the first year of the project (1996) over 1200 students visited and participated in activities at one or both of the field sites. These students were enrolled in courses from three Colleges (Agriculture, Education & Science) and were predominantly lower division undergraduates. The courses ranged from high enrollment, multiple lab section courses such as nonmajors botany (approximately 500 students per semester), and majors botany (400+ students), to smaller, specialized courses such as our local flora and field ecology courses (20+ upper division students in each). Pre- and in-service teachers visited the field sites as part of a week-long workshop in ecology during intersession (20 students) and as part of a course in science training for elementary teachers (25 students). An even greater number of students visited the field sites from these and some additional courses in the second year of the project (1997).

We have designed activities for the students that address the goals outlined earlier in this article. We have tried to use the inquiry teaching approach as much as possible. A three-lab ecology sequence for students enrolled in our General Biology course for science majors was taught entirely using this approach. In this sequence, students were asked to design, conduct, analyze and report on two experiments over the three weeks. For the first experiment the students were asked to determine the importance of environmental factors (biotic or abiotic) on the growth of seedlings. After eliciting ideas from the students through class discussion of the likely factors (e.g. light, soil moisture, competition from other plants), student groups were given three-day-old seedlings of Wisconsin Fast Plants™ *(Brassica rapa)* and access to a variety of ecological field equipment (rulers, light meters, etc.). The students were guided through the scientific method being asked to first come up with a hypothesis to test before thinking about the experimental procedure that they would follow. The vegetation of the contrasting experimental treatments (mowing and fertilizer) provided the setting for their experiments (Table 1). For the second experiment, the students were asked to test a hypothesis of their own regarding the effects of environmental factors upon an aspect of ecosystem diversity. Again, the field experiment provided the setting. The students turned in a written report on the first experiment and made an oral presentation in the lab on the results of the second experiment.

Our Field Ecology course for upper division life science students is taught almost entirely using the inquiry approach with our field experiments as a setting. In this course we ask students to design experiments to test hypotheses that they have designed on ecological theories (Table 1). These students also participate in the collection of the baseline field data from each site and are asked to work with it in either providing a foundation for the hypotheses that they are testing, or to provide the basis for new hypotheses.

Courses that only have a single two-hour lab devoted to ecology (e.g. nonscience majors botany) are more difficult to teach using the inquiry approach. For these courses we used directed inquiry (Germann 1991) and have avoided asking the students to follow a 'cookbook' lab. In these courses we introduce the students to the field site prior to the labs with a short video. We start the lab on site by asking the class to come up with a list of factors that affect diversity,

Table 1. Representative student hypotheses. Students in two undergraduate biology courses designed and tested these hypotheses using our field sites as a context. The hypotheses are presented here verbatim.

Organismic and Ecological Biology (lower division course for science majors)

Hypotheses regarding the growth of rapid cycling Brassicas (Brassica rapa).

1. Plants given fertilizer treatments would grow taller than unfertilized plants.
2. Clipping of the leaves will slow down the growth rate due to an inefficient supply of photosynthetic processing *[sic]*.
3. Wind exposure will be detrimental to the plant's growth.
4. Plants grown in shady plots will grow less than plants grown in sunny plots.
5. Plants grown in condensed [*sic:* = compacted] soil will grow more slowly than those in noncondensed soil.

Hypotheses regarding diversity in experimental plots.

1. Plant life will be more diverse in mown plots than unmown.
2. There would be more invertebrates in unmown compared with mown plots.
3. There is a difference in growth of *Beta vulgaris* between fertilized and unfertilized plots.
4. Higher vegetation will have more insects than lower vegetation.
5. Foxtails *(Setaria faberi)* would grow and bloom better in an unmowed environment than a mowed environment.

Field Ecology (senior level undergraduates): Population Ecology Hypotheses

1. Late boneset *(Eupatorium coelestinum)* is more reproductive in an upland site than in a lowland site.
2. Quantities of foraging Hymenoptera are affected in a given area in different fertilizer treatment plots.
3. Species composition (richness and density) varies from one fertilizer treatment to the next.
4. Stem height and fruit production of *Oenothera biennis* is affected by fertilizer application in unmowed plots.
5. Soil moisture is affected by annual disturbance or mowing and percent ground cover.

and then move to a discussion on how diversity and vegetation could be measured. After coming up with a list of factors and potential methods we ask the students to develop a hypothesis regarding the effects of one of the treatments (mowing or fertilizer) on either diversity, vegetation structure, or biomass (the parameter varies with each class). We then help the students test their hypothesis over the course of the remaining lab time. Depending on the course the results are either summarized at the end of the lab, in a later lab, or in a written report.

The data in Table 2 were collected by students in a general botany class. In this class the students tested the null hypothesis that fertilizer application does not affect species richness of grasses and forbs at the lowland field site. The data show that there were consistently more species of forbs compared with grasses. For two lab sections, species richness of forbs was higher in the plots that were not fertilized. These student class data have been retained as part of the baseline data for the study plots that will be used by classes in subsequent years.

In the education courses, we stress the application of the field setting, the process of succession, and the scientific method in teaching K–12 students. The students are asked to perform a simple exercise (such as comparing earthworm behavior in different environments such as mowed versus unmowed) before having a class discussion on the efficacy of using a similar ecological setting to teach the scientific method in their own classroom. It is important here for the students to try and adapt our experiment to the level of the students that they teach.

The field experiments provide an ideal setting for individual projects. We encourage motivated students to test hypotheses that they come up with at one or both field sites. Completed or in-progress independent projects by students include: the effect of vegetation structure upon the growth of rapid cycling brassicas, the fractal analysis of earthworm movement patterns, seed dispersal by deer, and the effect of fertilizer upon vegetation color. In addition, two graduate students are using the field sites as the basis for their research.

Conclusion

We were motivated to set up the field experiment in an effort to improve the teaching of ecology and our students' acquisition of science process skills. However, we also wanted the students to enjoy learning about ecology. Although this project is still in its infancy, we feel that we are meeting these goals. We are developing a suite of evaluation tools that we are using to capture and document student responses to the intervention. A multiple choice test based upon Germann's (1989) Process of Biological Investigations Test is being used to measure the students' knowledge and familiarity with the scientific method as applied to concepts of ecological succession. We also ask students to provide anonymous, written feedback on note cards in answer to two short questions asking them to 1) compare their experience with this style of field-lab with other science labs, and 2) write out a new hypothesis that could be tested given the results of the lab that they have just experienced. These cards are filled out in the van on the way back from the field. We have also conducted focus group sessions with randomly selected students. The results of these evaluations will be reported in a later publication.

A key component to our project is the long-term nature of the field experiment. As with other long-term studies, it will become more valuable as the years go by. By experiencing a real experimental study, the students get a sense of actually taking part in a scientific endeavor. By testing their own hypotheses the students obtain a 'hands on' experience in ecology (indeed, 95 of 352 students reported on the response cards, unprompted, that they appreciated the hands-on nature of their experience). This type of invigorating experience is often lacking in the more traditional, 'cookbook' labs that students are asked to undertake.

Field experiments such as ours could be also set up in K–12 school settings that have some land available for ecological studies and the grounds crew available for routine maintenance. Long-term experimental plots provide an inexpensive foundation for students to become involved in "doing science." Students can be introduced to the experimental sites, then either allowed to inductively decide on the data that are required to contrast different plots and how those data can be gathered, or be provided with some basic techniques to examine or collect data, and quantify observations. These observations can be used to generate a list of explorable questions that can serve as a basis for student-designed experiments. This model is consistent with teaching and assessment strategies recommended by the National Science Education Standards (National Research Council 1996). These Standards emphasize the need for teaching that *"guide(s) students in active and extended scientific inquiry(,) provide(s) opportunities for scientific discussion and debate among students (and) share(s) responsibility for learning with students."* (p. 52). Student conducting and reporting of the results of individually or collaboratively designed experiments facilitates assessment of *"scientific understanding and reasoning, (and) learning what students understand"* (p. 100) about the concepts explored and the scientific enterprise. Long-term experimental plots allow students to be involved in real research and provide a framework upon which students can ask their original questions and carry out experiments of their own design. Teachers become the facilitators of the learning.

When experiments like this are established, it is important to put in

Table 2. Mean species richness ± 1 SD per m^2 by plant type (grass or forb) in fertilized (NPK) versus unfertilized plots at the bottomland long-term field site, October 1996. * = significant difference between means of fertilized and unfertilized plots (two-tail *t*-test at P = 0.05). [These data were collected by undergraduates in three lab sections of a General Botany course (Mark Basinger, Teaching Assistant)].

		Species Richness	
Section	*Plant Type*	*Fertilized*	*Unfertilized*
1	grass	3.8 ± 1.0	3.9 ± 1.0
	forb	4.7 ± 1.6	6.2 ± 2.1*
	total	8.4 ± 0.5	10.1 ± 0.5*
2	grass	3.8 ± 1.2	3.8 ± 1.5
	forb	5.4 ± 1.2	5.0 ± 1.5
	total	9.1 ± 0.6	8.6 ± 0.6
3	grass	4.1 ± 0.8	3.6 ± 0.9
	forb	5.1 ± 2.1	6.1 ± 0.5*
	total	9.1 ± 0.5	9.6 ± 0.5

place one or more defined experimental treatments according to a rigorous statistical design that includes adequate replication and appropriate controls. We also find that timing is very important when using the directed inquiry teaching approach since it is easy to take too long on one aspect of the class or another, such as class discussions to elicit hypotheses.

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