A PRIMER OF EXPERIMENTAL DESIGN

WHY DO EXPERIMENTS?

Say you are a manager of a preserve such as CERA, and are interested in answering the following question: How does fire influence prairie plant diversity and growth? There are two approaches that you could take to answer this question.

1. You could find areas of your preserve that have burned recently (due to lightning strikes), and compare the prairie plant diversity and growth to unburned areas.

2. You could deliberately, experimentally burn parts of your preserve and compare the diversity and growth of prairie plants to unburned areas.

Both of these approaches will tell you something about the effect of fire on prairie plant diversity and growth. However, experimental burning would be preferable for one simple (and very important) reason.

WITHOUT DOING AN EXPERIMENTAL MANIPULATION, YOU CANNOT DETERMINE CAUSE AND EFFECT!

Think about this statement in the context of the question that you are trying to answer. Say you compare naturally burned and unburned areas (approach #1), and find significant differences in prairie plant diversity and growth. Based on this comparison, can you definitively attribute differences in plant diversity and growth to the presence and absence of fire? No. Those sites that naturally burned may differ from those that did not burn. For example, sites that naturally burned might be drier (lower soil moisture) than those that did not burn. In this case, you do not know if fire or variation in soil moisture is causing the observed differences in plant diversity and growth. You cannot determine cause and effect.

Alternatively, say you compare experimentally burned and unburned areas (approach #2) and find differences in prairie plant diversity and growth. Based on this comparison, can you definitively attribute differences in prairie plant diversity and growth to the presence or absence of fire? Assuming that you followed some basic principles of experimental design (which we’ll discuss later), the answer to this question is yes. By experimentally manipulating the fire regime, you avoided or minimized any covariance with other ecological factors (such as soil moisture). You can ascertain the cause (presence vs. absence of fire) of a certain effect (variation in prairie plant diversity and growth).

Although we have been discussing the importance of experiments in the context of fire and prairie plants, experimental manipulation is always necessary to definitively determine cause and effect, regardless of the question being addressed. Having said that, descriptive (non-experimental) studies are a very important part of biological research. Some factors cannot easily be experimentally manipulated, and descriptive studies can provide important background information for an experimental study. Field biologists use both types of studies interactively to better understand natural systems and their constituent species.
**How do you design experiments?**

Before discussing how to design experiments, we need to define some terms.

1. **Treatment**—Your experimental manipulation. In the fire-prairie plant study, fire was the treatment, and there were two treatment levels (burned and unburned).

2. **Experimental unit (EU)**—The piece of the experimental material to which you apply your treatment. In the fire-prairie plant study, the experiment unit was a plot of prairie that was either burned or not burned.

3. **Replicate**—One of a series of experimental units to which you apply the same treatment. In the fire-prairie plant study, the series of prairie plots that were burned (or not burned) are your replicates.

For any experiment you design, you should be able to state what your treatment is, what your experimental unit is, and the number of replicates of each treatment level.

Armed with this terminology, we’ll cover the three basic principles of experimental design.

1. **The experimental unit should be the piece of experimental material to which the treatment is independently applied.**

   The experimental unit is defined by how the treatment is applied. If we set a single fire and burned half of our prairie preserve, we would have two experimental units—one burned and one unburned. Alternatively, if we divided the prairie into 20 plots, 10 of which were individually (and therefore independently), burned, we would have 20 experimental units—10 burned and 10 unburned. Although half of the prairie was burned in each of these scenarios, the number of experimental units was dramatically different! The take-home message is to think hard about how you apply your treatments, as your decision can have a large effect on the number of experimental units you end up with! It is generally preferable to have more independent experimental units (see #3, below).

2. **Your treatment should be randomly applied.**

   The importance of randomization in experimental design cannot be overemphasized. Because natural systems are highly variable, it is very unlikely that your 20 prairie plots are identical. They probably vary in nutrient, water, and light availability, plant species composition, and herbivore and pollinator communities. If you just choose 10 plots to burn without randomizing, the plots you choose may be a biased subset of all of the plots. For example, you might unconsciously choose to burn those plots where the plants look less healthy, which could bias your results. But if you randomly choose which plots to burn, the plots you choose will be an unbiased subset and your results should also be unbiased. You can randomize by flipping a coin or using a random number table generated by a computer.
3. **Your treatment should be replicated.**

You should have multiple (more than one per treatment!) experimental units that independently receive the treatment. Replication is necessary for the same reason that randomization is—to avoid bias. Say you set one fire and burn half of the prairie preserve, creating two experimental units—one burned and one unburned. You find differences in prairie plant diversity and growth between these two experimental units. In this case, you cannot definitively say that fire caused the differences in prairie plant diversity and growth. The burn treatment is confounded with location in the prairie. An equally valid explanation for the differences in plant diversity and growth would be that the two halves of the preserve are just different. Having many replicates per treatment gets around this possible bias. In addition, having many replicates makes it easier to separate out the effect of your treatment (fire) from the background variation that is very common in natural systems.

*Armed with these three basic principles—experimental units, randomization, and replication—you should be able to design an experiment to answer any question that interests you.*

Below is a map of a 6-year old experiment at CERA on the effects of burning on a reconstructed prairie. [Part of the experiment also addresses how a second management practice, mid-summer mowing, affects the prairie community, but we'll not be working in that part of the experiment.]. You will once again be working in teams to take different types of data on these plots. On Wednesday, we'll suggest measures that might be interesting for you to take. By Monday, you'll have to come up with *additional* types of measurements to take relevant to your study question.
Research Groups for the Burn Experiment

Group 1 – Sameet, Claire, James B.

Group 2 – Katie, Brendon, Brendan

Group 3 – Michelle, Jessica, JJ

Group 4 – Julie S., Erin

Group 5 – Emma, Monique, Julie P.

Group 6 – Junior, Julie E., James A.

Group 7 – Elise, Steffi, Hanghang

Group 8 – Jake, Savanna

Your specific assignments will be given to you on Wednesday at CERA. Make sure you have read the above handout carefully! You will be responsible for designing the method of sampling each plot, so consider how you would do that.