TIEE

Teaching Issues and Experiments in Ecology - Volume 20, February 2024

EXPERIMENTS

A Field Lab Designed to Guide Student Research from Sweepnet to Statistical Analysis

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Field Ecology students compare arthropod communities associated with adjacent cut (lawn) and uncut (meadow) vegetation. Arthropods are sampled using sweep nets along 5m transects and identified using iNaturalist and printed field guides. Data are curated in Google Sheets and analyzed in R. (Photo credit: Michelle Jewell)

ABSTRACT

Students are generally excited to learn hands-on field methods. However, the nuanced logistics required to curate collaborative datasets are considered more tedious; and many students find data analysis and code intimidating. We designed a 3-week lab to address these challenges by empowering students to design experiments to characterize and compare arthropod communities across different habitats. We

structured assignments, activities, and assessments to support team building through methods practice, project development, data collection, statistical analysis, visualization and interpretation. This extended lab is completed at the beginning of the semester to coach students through every stage of place-based research and lays the groundwork for subsequent collaborative research projects.

FOUR DIMENSIONAL ECOLOGY EDUCATION (4DEE) FRAMEWORK

- **Core Ecological Concepts:**
    - Communities
    - Landscapes

- **Ecology Practices:**
    - Natural history
    - Fieldwork
    - Quantitative reasoning and computational thinking
    - Designing and critiquing investigations
    - Working collaboratively
    - Communicating and applying ecology

- **Human-Environment Interactions:**
    - How humans shape and manage ecosystems

- **Cross-cutting Themes:**
    - Spatial and Temporal Scales

CLASS TIME

MULTIWEEK - three 4.5-hour lab sessions and two 75-minute lectures

OUTSIDE OF CLASS TIME

8.5-14 hours - Students read an article (1-2 hours) to discuss during the initial field lab, that will inform their question and methods development; complete 5 R for Data Science modules (0.5-1 hour per module) to learn coding basics and get familiar with the R environment; identify arthropods and enter species count data into a shared spreadsheet (1-3 hours); and work with group members to write up the results and interpretations of data analysis (4 hours).

STUDENT PRODUCTS

Students create a shared Google Sheet where they curate arthropod data collected in the field. Students then adapt provided base code to analyze the class data in RStudio, creating figures to visualize the data and selecting appropriate statistical approaches to test their group's hypotheses (10 points each for figures and R script). Each group turns in a collaborative write-up in Google Doc to present and interpret their results in the context of the literature (100 points). In addition, students earn credit for completing the preparatory reading (5 points for 5 annotations in Hypothes.is) and R for Data Science modules 1-5 (5 points each), and for recording arthropod data in their field notebook (5 points).

SETTING

The field work can be completed in any habitat with enough space to plot multiple 5-meter transects for sweet net sampling, ideally from at least two different conditions (e.g., vegetation height, size of patch, etc.) Sweep net sampling cannot be conducted during precipitation or when vegetation is wet. Students analyze class data using R in the following week(s).

COURSE CONTEXT

Field Ecology and Methods (AEC 460) exposes senior students to the diverse field approaches used to address ecological questions. The course considers and implements a variety of field approaches to characterize communities of interest, from microcosm experiments to forest systems. The course comprises a single lecture + lab section with enrollment capped at 25, and we complete this lab first to lay a foundation for collaborative project development, data curation and analysis that will be practiced across the remainder of the semester. We collected data at the North Carolina Museum of Art (NCMA) park, though we refer to "field site" in the Detailed Description of the Experiment for Students below.

TRANSFERABILITY

This experiment can be readily scaled across class sizes and adapted for majors, non-majors, intro or upper division courses. The comparative premise also translates readily across geographic regions or to urban environments, though the method requires dry conditions and temperatures warm enough to support arthropod activity. The field site can be selected to support students of varying abilities, and the methods and data analysis activities can be adapted for a variety of pre-college environments. We ask students to complete 5 R for Data Science Modules that are curated by NC State University Libraries and only available to NC State affiliates via Shibboleth-protected access. However, we have identified free Data Analysis with R modules on Coursera that cover similar concepts.

ACKNOWLEDGEMENTS

Madison Polera helped Erin develop the original methods and base code for this experiment in fall 2019 during their first semester teaching AEC 460 at NC State University. Madison also refined the base code in fall 2021 when we adapted the sweep net experiment to compare arthropod diversity on Western Boulevard medians in fall 2021. Those materials and experiences provided a strong foundation for the experiment and code we present here.

SYNOPSIS OF THE EXPERIMENT

Table 1. Course schedule outlining the time invested in all lab and lecture activities for a 3-week project to investigate grassland arthropod diversity

Week	Class	In-class activities	Out-of-class activities
1	Lab	Field lab: jigsaw, methods practice, planning 4.5 hrs	Preparatory reading, annotation in Hypothes.is 1-2 hrs
2	Lecture	Question and methods development; curation of class data sheet 1.25 hrs	Introduction to Data Analysis with R (Coursera) 1-2 hrs
	Lab	Field lab: arthropod collection, identification 4.5 hrs	Data Wrangling (Coursera); arthropod ID, data entry 1.5-4 hrs
3	Lecture	Intro to statistics 1.25 hrs	Exploratory Data Analysis (Coursera) 1-2 hrs
	Lab	Computer lab: data analysis 4.5 hrs	Interpretation and write-up 4 hrs
	Total	**16 hrs**	**8.5-14 hrs**

Principal Ecological Question Addressed

How do arthropod communities vary across different habitats?

- How does anthropogenic disturbance (e.g., mowing) shape arthropod communities?
- How do arthropod communities in “edge” habitats differ from mowed versus uncut vegetation?
- Does arthropod diversity and abundance vary based on vegetation height?
- Does arthropod diversity and abundance vary between sunny and shady habitats?

What Happens

- There is an initial field excursion to introduce students to the sampling method and the study site (Lab 1).
- We use sweep nets, iNaturalist and field guides to compare arthropod communities between mowed grass versus uncut vegetation.
- In preparation for Lecture the following week, students work with their groups of 3-4 to develop a scientific question and hypothesis. Then, as a class, we define

the data and methods needed to address each group's hypothesis, and curate a shared Google Sheet for all data.

- Students return to the field site to collect the data for their specific experiments (Lab 2).
- Students adapt tutorial base code to analyze and visualize data (Lab 3).
- This lab activity enables students to build data analysis and coding skills in a supportive environment. Students can then adapt skills and code to subsequent labs, culminating in independent research projects.

Experiment Objectives

1. Collect data using sweep net sampling technique
2. Analyze a collaborative dataset
3. Create R scripts to compare arthropod communities across different habitats using appropriate statistical tests
4. Produce figures to visualize trends in data
5. Interpret results of statistical tests

Equipment/ Logistics Required

See packing list below. Note that in addition to the equipment we provide, students are responsible for bringing their own field notebook, writing utensil, and smart phone with the iNaturalist app installed.

Students are randomly assigned to different groups for each lab across the semester, to ensure that they get a chance to collaborate with all of their peers in the class at least once before developing and implementing independent research projects in the last 9 weeks of the semester.

Lab materials

- First aid kit
- Tick key
- Insect repellent
- High-visibility vests (1 per student)
- Field Researcher badges (1 per student)
- Clipboards (1 per student)
- Lux meters (several per class)
- Kestrel weather meters (several per class)
- Small, medium, and large clear plastic containers with lids (1 or more per group)
- White paper (for pictures)
- Petri dishes (multiple per group)
- Lupes (1 per student)
- Sweep nets (1 per student)
- Marking flags (3 per transect)

- 5-meter transect tapes (1 per group)
- Meter sticks (1 per group)
- Southern insect ID guide
- Insects - field guide
- Audubon Society Field Guide to North American Insects & Spiders
- Audubon Society Field Guide to North American Wildflowers
- Newcomb's Wildflower Guide

Student materials

- Rite in the Rain field notebook
- Pen or pencil
- Smart phone with iNaturalist app installed
- Pants
- Closed-toed shoes

Summary of What is Due

- Each student reads one of two assigned research papers (Joern 2013 or Prather 2019) and annotates the article before class using Hypothesis.is (a free online social annotation tool). Students are randomly assigned to read either paper, such that each group includes students who have read both papers.
- Students individually complete five R for Data Science modules to learn and practice coding in R, an open software environment for statistical computing and graphics. The R for Data Science modules are hosted by NC State University Libraries. The first five modules cover (1) importing data into R, (2) data joining and tidying, (3) graphing, (4) data transformation, and (5) functions.
- Students work in small groups (assigned by the instructor) to develop a research plan that includes:
    - Research question
    - Testable hypothesis
    - Specific data (i.e., measurements, including units if applicable) that each group needs to collect to answer the research question.
    - Other specific approaches or additional steps that the group needs to use to answer their question (e.g., balanced transect sampling, sweep nets and field guides / iNaturalist to identify and count arthropods that all groups use)
- Each student has a Rite-in-the-Rain notebook to collect field data using a shared class data table format. We develop this table together while we map each group’s question, hypothesis, and methods in class during week 2.
- Each individual enters their field data into a shared Google spreadsheet (created by the instructor and TA), which includes all variables from the full class discussion and data table development. This enables all students to access and

analyze the full class dataset, maximizing the sample size per variable across all student groups.

- Students work individually (seated with group members) to complete the "base code" R script tutorial created by the TA and instructor. Individuals turn in their completed R script and the figures that are most relevant to their group's research question and hypothesis.
- Students work in groups to adapt the base code to address their research question. Each group must submit the documented R script they used to analyze their data.
- Each group collaboratively writes a single final document, following the structure of a scientific paper, to explain and discuss their research results. Each student must contribute equally to the final write-up; instructor and TA check contributions using version history in Google Docs.

Below is a list of assignments that are due each week.

Week 1

- arthropod articles, annotated with Hypothes.is

Week 2

- R for Data Science module #1
- R for Data Science module #2
- Group research plan
- R for Data Science module #3

Week 3

- field notebook – data table
- Field data entry
- R for Data Science module #4
- R for Data Science module #5
- tutorial figures
- tutorial R script

Week 4

- Write-up (1 per group)

DETAILED DESCRIPTION OF THE EXPERIMENT

Introduction

For our first group project, we'll be studying arthropod abundance at a field site. We will complete this project over the first three weeks of class, providing an extended period of time to get to know your groupmates and build collaborative skills as you settle in to the semester. For this first project, everyone will practice the same field methods, and your TA and I will provide base code and lots of in-person support to help you learn to analyze your data in R; but you'll have the freedom to develop your own scientific questions and hypotheses to direct your research.

Arthropods are the most abundant animal group on the planet and contribute important biodiversity and functionality to many terrestrial ecosystems, including grasslands (Whiles & Charlton, 2006). Arthropods have evolved diverse morphologies, feeding strategies, and circadian rhythms to fill niches associated with grasslands' complex vegetative structure. We can therefore gain insights into evolutionary and ecological processes (including disturbance) and interactions (like competition and predation) by collecting, identifying, and classifying grassland arthropods.

The Piedmont region of North Carolina was historically covered by prairies. However, most of those open grassy areas have been converted to agricultural, commercial, and residential land use to support growing human populations (Joern & Laws, 2013). What grasslands remain tend to be smaller, isolated patches associated with power line easements or parks that specifically maintain naturalized areas.

Our first lab focuses on project development. Each of you will read one of two different published articles (Joern & Laws, 2013; Prather & Kaspari, 2019) to learn about grassland arthropod systems, and add at least five annotations to your article using the Hypothes.is app, before we meet for Lab 1. Wear closed-toed shoes and long pants and bring water and snacks. I also recommend that you bring a hat and sunscreen. You'll spend the first 15 minutes on-site discussing your assigned reading with the other "experts" in class who read the same article. Then, you'll shuffle into your assigned research groups and take turns teaching each other your papers and synthesizing a shared understanding of arthropod-grassland ecology.

After you complete the jigsaw exercise, we'll distribute field equipment so you can practice the sweep net technique. Everyone will use the same methods to collect arthropods with sweep nets along 5-meter transects. You will each practice your sweep net technique in cut (mowed grass) versus uncut vegetation. Use the provided tupperware to hold your arthropods, and transfer specimens to the small petri dishes to use the lupes and take pictures for identification with iNaturalist. This is a great chance to get used to handling the equipment and isolating arthropods without letting any escape. It's also an opportunity to build a "reference bank" of identified specimens in iNaturalist – which will hopefully make your "real" data collection next week more efficient. After you practice the methods, use the last hour of lab to explore the park with your groups and develop your project for next week. You can investigate the effects of any variable you can find at the field site – vegetation height, edge effect, proximity to trees or greenway trails – as long as you can collect the data necessary to test your hypothesis. Make sure to complete your group's research plan in your shared Google Drive folder before lecture starts next week.

During class, we'll map each group's scientific question and hypothesis to identify what methods and metrics you'll use to collect the data for your project. We'll use that information to draft our packing list and build a shared Google Spreadsheet for the full class dataset. We'll return to the field site next week, for Lab 2, to collect your arthropod field data! The following week, we'll spend Lab 3 inside as a data analysis workshop. You will work through an R script tutorial with documentation to practice using the code you will need to graph and analyze your data. We expect you to adapt this base code to analyze all other field data for the rest of the semester – including your independent research projects.

Materials and Methods

Study Site

The field site for your study may vary depending on which habitats are available on or near your campus. The original experiment on which this module is based was conducted at the North Carolina Museum of Art (NCMA). NCMA maintains uncut prairie patches adjacent to mowed grass lawns just south of the greenway that runs west-to-east through the park. One uncut patch, west of the triple arch *Gyre* sculpture by Thomas Sayre, contains a smaller patch of mowed grass near the *No Fuss* sculpture by Mark di Suvero, which is accessible by two paths mowed through the surrounding uncut vegetation. Another uncut patch runs further east, south of the *Gyre* arches.

Overview of Data Collection and Analysis Methods

See Table 1. Course schedule outlining the time invested in all lab and lecture activities for a 3-week project to investigate grassland arthropod diversity.

Arthropod lab overview

Arthropod lab guide for students in the field during Week 1

Week 1

Lab 1

- Before class: read and annotate either A) Joern 2013 or B) Prather 2019 and look at shared Google Earth map before lab
- Lab activities: Meet at teaching lab → load equipment and ride bus to field site
    - Jigsaw activity to discuss both papers (20-25 minutes)
    - Regroup as a class (20-30 minutes)
        - Compare notes
        - Identify research questions
    - Explore adjacent lawn and uncut environments
        - Record and discuss observations
        - Plot transects on shared Google Earth map
        - Practice sweep net technique
            - Collect arthropods into tupperware; photograph each

            - Upload photos to iNaturalist → build a database for faster ID next week
            - Record species and abundance encountered
                - Compare any unidentified specimens with other groups to avoid false inflation of species richness
        - Share and discuss scientific questions, experimental design ideas
- Assignment: draft a research plan with your group (due before next class starts)

Week 2

Lecture

- Before class: complete R for Data Science modules #1 and #2; complete draft of group research plan
- During class:
    - Share and compare scientific questions and data / measurements needed
    - Draft class data spreadsheet
    - What data curation and statistics are needed for each group to test their hypothesis?
    - Revise and update group research plan as needed

Lab 2

- Before lab: Complete R for Data Science module #3; tag sweep net sites on shared Google Earth map
- During lab:
    - Meet at the teaching lab to pick up equipment → bus to field site.
    - Disseminate to your group's designated sampling sites.
    - Gather data
        - Note GPS location, weather / conditions
        - Measure height of vegetation at ends and midpoint of each transect
        - Perform sweep net sampling per class protocol
        - Collect arthropods into tupperware; isolate and photograph each
        - Upload photos to iNaturalist
        - Record taxonomy and abundance encountered for each unique arthropod
            - Be sure to note any unidentified specimens
    - Regroup (in shade!) to compare unidentified specimens (avoid repeats!)
        - The goal is class consensus.
        - Without consensus, we risk overestimation (false inflation) of species richness.

- Data entry assignment: add arthropod species identification and abundance to class spreadsheet by midnight.

Week 3

Lecture

- Before class: complete R for Data Science modules #4 and #5
- During class:
  - TA gives lecture on data analysis and how to select the appropriate statistical tests for your data
  - Students discuss which plots and statistical tests are most appropriate for their question and data.

Lab 3

- Computer lab: data analysis workshop
  - Work through the tutorial "base code" provided by the instructor and TA. Make sure you can produce the plots and complete the practice prompts.
  - Work with your group to adapt the base code to analyze your dataset. Use Google Sheets to create a pivot table and use the filter() command in R to create data subsets where necessary to address your hypothesis.
  - Partway through the lab, the instructor gives a mini lecture on data visualization.

Upload your personal Rscript with documentation, and any figures you have produced, to your group's project folder at the end of lab.

Questions for Further Thought and Discussion:

Observations

As we explore the field site, make sure to observe the environment.

1. What factors might affect arthropod diversity?
   a. How can we measure each factor?
   b. What arthropod requirements and characteristics would be helpful to refine these predictions?
2. What niches are available to arthropods in the lawn vs uncut environments?
3. Are there broader drivers (beyond the conditions in each environment) that might affect or drive arthropod diversity and distribution?

Project development

After completing your pilot sweep net data collection, consider the following prompts with your group to start drafting your research plan.

4. What scientific question does your group want to investigate?
5. Where should you plot your transects to sample and compare different "treatments"?
6. What data do we need to collect as a class, in order to address your question?
7. How should we curate the class data in a shared spreadsheet?

Group research plan

8. What scientific question does your group want to investigate?
9. What is your null hypothesis?
10. What is your alternate hypothesis?
11. What equipment do you need to collect these data?

Synthesis questions

12. Do your results support your hypothesis and predictions? If not, can you explain why not? (Is there another ecological force at work that we didn't consider before?)
13. What do your statistical results tell you about arthropod diversity at the field site? Specifically, how do the different "treatments" impact arthropod diversity?
14. What do your results tell us about arthropod ecology and adaptation?
    - What traits or behaviors are favored by the different "treatment" conditions?
    - Does one "treatment" support increased richness (i.e., more different niches), increased Shannon diversity (i.e., more complex communities), or specific ecological roles or functions?
15. What impact does human land use and resource management have on arthropod diversity and community ecology and function? Based on your results, what specific suggestions would you make to different stakeholder groups (e.g., homeowners, park managers, restoration ecologists) to support diverse arthropods and other species of interest (e.g., birds, snakes)?
16. What pitfalls or confounding factors did you encounter in your study? How might you address those challenges in a future study?
17. What future research would you recommend, to build on your findings or fill knowledge gaps from this project?

References

Joern, A. and A. N. Laws. 2013. Ecological mechanisms underlying arthropod species diversity in grasslands. Annual Review of Entomology 58:19–36. https://doi.org/10.1146/annurev.ento.51.110104.151136

Prather, R. M. and M. Kaspari. 2019. Plants regulate grassland arthropod communities through biomass, quality, and habitat heterogeneity. Ecosphere 10:e02909. https://doi.org/10.1002/ecs2.2909

Whiles, M. R. and R. E. Charlton. 2006. The ecological significance of tallgrass prairie arthropods. Annual Review of Entomology 51:387–412. https://doi.org/10.1146/annurev.ento.51.110104.151136

Additional resources and links

Auker, L. A. and E. L. Barthelmess. 2020. Teaching R in the undergraduate ecology classroom: Approaches, lessons learned, and recommendations. Ecosphere 11:e03060.

Borror, D. J. and R. T. White. 1998. Peterson Field Guide to Insects: America North of Mexico. Houghton Mifflin Harcourt, 2nd edition.

Muff, S., E. B. Nilsen, R. B. O'Hara, and C. R. Nater. 2022. Rewriting results sections in the language of evidence. Trends in Ecology & Evolution 37:203-210.

Wheater, C. P., J. R. Bell, P. A. Cook. 2011. Practical Field Ecology: A Project Guide, John Wiley & Sons, Inc.

Recommended readings: Choosing a study topic and developing aims, objectives, and hypotheses (pp. 1-7); Project design and data management (pp. 18-20); Time management (pp. 16-18); Types of data (pp. 20-22); Sampling designs (pp. 22-28); Planning statistical analysis (pp. 28-33)

iNaturalist app (available on Google Play and Apple Store)

Video: Catch Invertebrates on Vegetation (5:31)

Video: Sweep Net Technique (1:34)

Helpful hints for developing scientific questions

Data Analysis with R (Coursera)

Tools for Assessment of Student Learning Outcomes:

Work together to write up your results in a double-spaced report that is 4-5 pages long (not including figures, tables, or references). This may feel short! It can be challenging to write clearly and succinctly, so I want to give you several opportunities to build science communication skills in this class. This write-up is a chance for you to work together to hone your writing skills as well as your coding and data visualization skills. Highlight only the most important results and relate those results back to arthropod and grassland ecology by citing appropriate supporting literature.

We have provided a specification checklist so you know how to earn the full 100 points for this assignment. Please use the Section headers we have provided, and make sure to collaborate in a shared Google Document in your group folder, so that we can track your individual contributions using the version history. Your write-ups are due before class starts on Tuesday. We will give clear feedback, both so that you understand any instances where full points were not awarded and to offer suggestions and constructive feedback to help you improve your writing.

Table 2. Specifications Checklist for Write-up

Section	**Requirement**	**Value (points)**
Abstract*	specific and concise	1
	summarizes major points of the paper	2
	provides main results, in context	2
Introduction	background and research information	4
	statement of the problem or research goals	4
	references that are relevant to the research goal	4
	research is fit into a broader context at the beginning and the end (i.e., hourglass model)	4
	hypothesis and predictions are clearly stated	4
Materials & Methods	methods are clear and reproducible	2
	all facets of the study are described (including study area, time, and organism/topic)	4
	statistical tests are clearly defined and appropriate to data, goals and hypothesis	4
Results	figures and tables are clear and captioned to stand alone	5
	results and text are clear and appropriate	5

	the results address the study goals	5
Discussion	results are discussed in context of, and compared to, previous studies	4
	The results and the literature are synthesized to build a compelling argument	4
	any weaknesses of the study are addressed	4
	recommendations are made for future research	4
	there is a clear relationship between the results and the conclusions	4
	the discussion does not repeat the results or the methods	4
Literature	citations were located properly within the text, where necessary	3
	all references are included, and are cited correctly in the literature citation section	3
Overall	Narrative makes sense	5
	information is clearly organized into sections	5
	4-5 pages in length, double-spaced (not including references)	5
	All group members contributed equally (re: Google Doc version history)	5
	Total Points	**100**

***Abstract TEMPLATE**

(1) Flashy first sentence to capture the reader's attention and conveys the "big picture" essence of your topic (i.e., the ecological phenomenon or process you want to investigate). **(2)** One or two sentences summarizing the current status/knowledge of your chosen topic. **(3)** BUT/HOWEVER, something is missing or needed: justify the need for the work you propose. **(4)** The goal of the project – should respond directly to the BUT/HOWEVER statement (or some subset). (**5)** To accomplish this goal, we… **(6)** Sometimes authors share a hypothesis or prediction at this point. Alternate hypotheses are best, because null hypotheses are not very interesting or informative. **(7)** Single sentence to summarize the main results / big takeaway from your study. **(8)** Relevance: importance of the work in a larger context, how advancing our knowledge of this topic can contribute to a greater understanding of ecology, and/or the development of more effective/sustainable management strategies.

NOTES TO FACULTY

Challenges to Anticipate and Solve

1. Identification: Many students have never used a field guide to identify arthropods before. The instructor and TA can explain the process of using morphological features to classify a specimen. In addition to field guides, we also demonstrate how to upload a picture of the specimen to iNaturalist to crowdsource identification from expert users.
2. Data curation: Many students have never organized or entered data into a spreadsheet before – much less a spreadsheet shared by multiple contributors. In addition, any arthropods that cannot be classified must be referred to consistently throughout the shared class database. The instructor and TA demonstrate how to create and curate a spreadsheet in a format that uploads readily to R for analysis and send several reminders to students to work together and communicate across groups to assign consistent identifiers to unknown specimens. However, every year we find and correct inconsistent arthropod specimen IDs and language (i.e., both “cut” and “Cut” used to describe mowed lawn). We suggest that the instructor and TA set aside time for students to review the spreadsheet at the beginning of Lab 3 to identify inconsistencies, to reinforce the importance of careful curation. The class can then verify when the spreadsheet is ready to download for data analysis. This final review can be done before class to save instructional time; but the students learn more when they have to address inconsistent entries themselves.
3. Fear of data analysis: Most students have never written code or used R before and are highly intimidated. The instructor and TA provide a tutorial with documented base code to help students learn to analyze data and provide personalized help throughout the 4.5-hour data analysis workshop.
4. Interpreting statistical results: Many students misunderstand the meaning of the p-value. For example, students might mistakenly assume that a p-value greater than 0.05 means their results “do not mean anything”. The TA explains the meaning of the p-value and gives examples of how to interpret p-values during the lecture on statistics and data analysis. We also provide an optional reading (Muff et al., 2022) with examples for how to translate significance language to evidence language in ecological contexts. The instructor and TA also guide students’ interpretation of their results during the data analysis lab.

Comments on Introducing the Experiment to Your Students:

I introduce the experiment on the first day of class, after reviewing the course syllabus and structure. I start with an overview of the labs I've planned across the semester, which enables us to practice several distinct techniques used to characterize different systems. I have designed each lab to incorporate marketable skills (from telemetry to data analysis in R), and the assessment formats mirror different real-world applications (from a 1-page project proposal in the style of the NSF GRFP, to an executive report on water quality in the style used by the Department of Environmental Quality). From the graphical diagram of the semester's labs, I hone in on the first 3 weeks of class, during which students will use sweep nets to characterize and compare arthropod communities across distinct habitats / environmental conditions at NCMA. On the first day of class I focus on logistics, so students understand what they need to accomplish during the first field lab and how it fits into the bigger 3-week picture. During the first lab, I introduce ecological theory during the jigsaw exercise, when students discuss and teach each other different assigned research articles relevant to the grassland arthropod system. After practicing the sweepnet technique and identifying a representative sample of arthropods, students spend the last hour of lab synthesizing place-based context and observation with their discussion of published research and ecological theory to develop scientific questions and hypotheses that will guide the following week's data collection.

Comments on the Data Collection and Analysis Methods:

We have provided a sample schedule for this lab in our Overview of Data Collection and Analysis Methods, which includes all preparatory assignments, activities, and assessments for this lab. We recommend that instructors visit their field site in advance and review our class spreadsheet and tutorial code to assess what place-based questions might be asked, whether any variables should be changed, and which data analysis and visualization techniques might be most appropriate to your specific context. Instructors may also need to provide or identify alternatives to the R for Data Science modules, which we have found helpful for students to gain a basic introduction to R and the "grammar" of code.

Comments on Questions for Further Thought:

Comments on Question 1: What factors might affect arthropod diversity?

Students may draw from the assigned readings or ecological theory (e.g., grazing, fire regimes) – or they may be inspired by specific conditions observed at the field site (e.g., mowed lawn vs uncut meadow, sunlight vs shade).

Comments on Question 1a: How can we measure each factor?

Encourage students to consider what equipment is available to them (e.g., meter sticks, lux meter, infrared thermometer, etc.) and the units for different measurements. This exercise challenges students to progress from a scientific question / hypothesis, to which methods and metrics we can use to address that question / hypothesis, to drafting a packing list and formatting a spreadsheet to collect data. These logistical considerations are necessary in any project, to move from concept development to research practice.

Comments on Question 1b: What arthropod requirements and characteristics would be helpful to refine these predictions?

Consider niche-specific evolutionary adaptations, feeding strategies, and any traits or variables discussed in the assigned readings.

Comments on Question 2: What niches are available to arthropods in the lawn vs uncut environments?

Again – encourage students to connect their observations back to the assigned readings and broader ecological theory. Students might identify plant diversity, plant height, or temperature as environmental variables that change in response to different landscape management regimes, with consequences for arthropod diversity.

Comments on Question 3: Are there broader drivers (beyond the conditions in each environment) that might affect or drive arthropod diversity and distribution?

- How is the field site habitat similar to the ecosystems discussed in the readings?
- How is our field site different?
- How might those differences affect arthropod diversity and distribution?

Comments on Question 4: What scientific question does your group want to investigate?

Are there specific habitats or conditions you want to compare? Or are you interested in modeling a broader phenomenon that affects arthropod diversity?

Comments on Question 5: Where should you plot your transects, to sample and compare different "treatments"?

Do you need to measure any characteristics before you can plot your transect? (How far from the edge do you have to be, to measure "uncut meadow" versus "cut lawn"? How will your group define "sunny" versus "shady", or "short" versus "tall" vegetation?) How many transects are feasible to complete in a 3-hour field lab?

Comments on Question 6: What data do we need to collect as a class, in order to address your question?

In addition to transect characteristics, what additional measurements or counts do you want your classmates to collect? For example, do you need to count the abundance of each type of arthropod or calculate the total abundance or richness per transect? Do you need to classify each arthropod specimen into categories to test your hypothesis? What units are you using?

Comments on Question 7: How should we curate the class data in a shared spreadsheet?

What consistent terminology do you want your classmates to use? What names should we use in each column header, to describe the data you'll be collecting? Is there a specific order that we should list the columns from left to right?

Comments on Question 8: What scientific question does your group want to investigate?

Have you noticed a specific pattern or difference between different habitats?

Comments on Question 9: What is your null hypothesis?

Sometimes it helps to start by describing if there was no relationship between your variables.

Comments on Question 10: What is your alternate hypothesis?

Now, describe a relationship between your variables. (You can add more detail by predicting whether you expect that relationship to be positive or negative.)

Comments for Question 11: What equipment do you need to collect these data?

Remember that you can access our equipment inventory on the Moodle course page. That spreadsheet (as well as the lab guide) includes the equipment we brought for the practice / reconnaissance lab in Week 1.

Comments for Question 12: Do your results support your hypothesis and predictions? If not, can you explain why not? (Is there another ecological force at work that we didn't consider before?)

Students will generally base their responses on whether their statistical results are significant. For example, if students predict that uncut meadow habitat supports greater arthropod diversity than mowed lawn habitat and calculate a p-value <0.05 for a t-test or ranked Wilcoxon test comparing alpha diversity metrics between the two "treatment"

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groups, then they will declare that the results support their hypothesis and predictions. Students who calculate higher richness or Shannon diversity values for the uncut meadow, but do not calculate p-values < 0.05, may still propose that their trends support the prediction but that additional research (with greater sample size) is needed to verify that the trend is significant.

Comments for Question 13: What do your statistical results tell you about arthropod diversity at the field site? Specifically, how do the different "treatments" impact arthropod diversity?

Here, we hope that students will invoke ecological principles to explain trends and statistical results across habitats. For example – taller vegetation provides more niche space in the form of vegetation structure, which in turn supports a greater diversity of arthropods in uncut meadow compared to mowed lawn habitat. Students might also discuss temperature or resource availability as restrictive environmental conditions in mowed lawn compared to uncut meadow.

Comments for Question 14: What do your results tell us about arthropod ecology and adaptation?

- What traits or behaviors are favored by the different "treatment" conditions?
- Does one "treatment" support increased richness (i.e., more different niches), increased Shannon diversity (i.e., more complex communities), or specific ecological roles or functions?

Students might propose that higher temperatures / greater heat exposure associated with mowed lawn would select for species with greater thermal tolerance, whereas uncut meadow provides more shaded refuge and may thus support a greater variety of species and/or increased activity throughout the day.

Students may also discuss the comparative diversity of feeding strategies or trophic levels supported by each habitat. For example, increased plant biomass and structural heterogeneity in uncut meadow would support greater diversity and biomass of herbivorous arthropods, which in turn would support more predators.

Comments for Question 15: What impact does human land use and resource management have on arthropod diversity and community ecology and function? Based on your results, what specific suggestions would you make to different stakeholder groups (e.g., homeowners, park managers, restoration ecologists) to support diverse arthropods and other species of interest (e.g., birds, snakes)?

- Mowing lawns reduces niche space by removing plant biomass (resources) and decreasing height and heterogeneity of vegetation (habitat). By contrast, the uncut meadow habitat included many different species of taller plants with more foliage and different flowers, which support diverse herbivore and pollinator species – which, in turn, support more predatory arthropods. The greater diversity and more complex food web associated with uncut meadow habitat probably support more different species interactions and perform more diverse functions, which together make communities more resilient to disturbance.

- Our results suggest that homeowners could forego mowing or even plant more diverse / perennial vegetation in place of monoculture grass lawns, to promote more diverse arthropod communities. The increased arthropod diversity could attract birds (even without birdfeeders, which can be problematic for bird health).
- Park managers and restoration ecologists can likewise protect and/or replant vegetation including species of different heights, that flower or produce seeds, to support diverse arthropod communities which, in turn, can feed a variety of mammals, birds, and herptiles.

Comments for Question 16: What pitfalls or confounding factors did you encounter in your study? How might you address those challenges in a future study?

- Every year students discuss low sample size, season, time of day, and weather conditions as possible confounding factors. Future studies could include more transects, sampled across multiple days or seasons. With greater sample size, time of day could also be taken into account to test whether time of day impacts observed arthropod diversity.
- Students collect data from a single field site, so their results cannot be generalized beyond that field site. Future studies could incorporate data collection across multiple field sites to test whether current findings are generalizable.
- Students might also mention that field site visitation by the public may disrupt arthropod communities or behaviors. (This is particularly relevant for public parks.) Future studies could compare field sites with high human traffic and anthropogenic management regimes, to unmanaged field sites with less human visitation. However, it’s difficult to find “pristine” reference sites to compare “treatments” to.
- Field guides and reference databases (e.g., iNaturalist) may not be sufficient to classify arthropods to the species level. It would be useful to have more time for iNaturalist users to verify arthropod classification. Future studies could also include an entomologist collaborator to help classify arthropod specimens.

Comments on the Assessment of Student Learning Outcomes:

- It's very important to review the shared spreadsheet after the data entry deadline. In addition to addressing inconsistencies (i.e., using both "cut" and "Cut" to referred to mowed lawn), every year a couple of students do not complete their data entry and I have to remind them that no one can begin to analyze data until the entire class dataset is complete. I award 5 points for data entry (both to motivate students to complete it on time, and to acknowledge their effort outside of class). This leaves the ability to deduct 1 point for inconsistencies, 1-4 points for incomplete entries, and to withhold all 5 points for missing data.
- We review students' R scripts to verify that they have added documentation (#comments to explain the code to themselves, articulate reminders of how to interpret or troubleshoot, etc.) and written code in response to several practice prompts. Ideally, we should be able to run every student's code to re-create the figures they submitted, and to ensure that they were able to run all statistical analyses.
- While grading the write-ups, we document standardized comments to explain any instances where full points were not awarded. We find that it is faster and more consistent to develop and document standardized point deductions, particularly since we base everything on the specifications list that was shared with students to inform their collaborative writing.

Comments on Translating the Activity to Other Institutional Scales or Locations:

(1) translating this experiment to larger scales if you teach at a smaller school and vice versa

My course is currently capped at 25 students (a single lab section). As our departmental enrollment grows, I can scale discussions and group activities during lecture. However, I will need to create additional lab sections. The NCMA park is large enough to accommodate multiple groups at a time; but it may become more important to emphasize that students must take care not to trample the meadow vegetation to maintain the habitat across the two weeks of our visits.

(2) using this lab in different regions of the country or world, in different seasons, or using different study species or systems

Instructors in different parts of the world may have to adjust the timing to align with your growing season. We have presented this lab at the NCMA park, but I have previously run it in urban environments (specifically, medians along Western Boulevard in Raleigh, NC) to address questions about anthropogenic impacts on patch size / fragmentation.

The sweep nets require dry conditions, so the lab may be difficult to conduct in rainy climates or high dew point conditions. (Perhaps in those areas another method such as pitfall traps might be implemented.)

(3) using this activity to teach ecology to students with physical or other disabilities

I consider physical, emotional, and neurodiversity when I design labs and course materials.

- We reserve a bus to transport all students and equipment to the field. I provide a Field Site Assessment and Google Earth map to describe and visualize the features and potential challenges associated with each field site, including estimated walking distance; environmental hazards (e.g., exposure to the elements, biting insects); availability of restrooms, drinking water, or air-conditioned shelter; and location of nearest emergency room / medical center.
- I provide assigned readings in readable PDF format (with OCR functionality for screen readers) and ask students to read and annotate the article before lab to ensure that students have time to engage with the material (and each other, via the free online Hypothes.is annotation app) asynchronously. This preparation assignment encourages student conversation without requiring students to volunteer to share out loud in front of the full class – and gives students time between their initial reading and annotation, and discussion of the article in small groups, to reflect and prepare for in-person conversation.
- Similarly, I assign students small groups for each lab (1) to ensure that each student gets a chance to work with and get to know every other student in the class across the first 10 weeks of the semester, and (2) to remove any social pressure or anxiety from the process of self-selecting groups. (No one likes to be picked last.) I also provide guidelines for communication, to smooth the way for students who find social interaction challenging. This document has been particularly helpful for students who find themselves navigating difficult conversations about inequitable commitment or contribution to group work.

(4) using this activity to teach ecology in pre-college settings (K-12).

- The sweepnet technique and concepts of arthropod diversity, function, and adaptation to grassland conditions and niche space can be adapted to any age (although the sweep nets might be unwieldy for students in grades K-2). Similarly, students of all ages could isolate arthropods, count and identify specimens either by using the iNaturalist app or comparing to field guides.
- The data analysis portion of this lab could be adapted to high school by replacing R Studio work with exercises to curate, analyze, and graph data in Google Sheets. Middle school students could probably graph the data. Grades K-5 might

benefit most from comparing the different types of arthropods (e.g., spiders, grasshoppers, ants, etc.) found in different habitats.