Ecological systems: How pairwise interactions can indirectly affect complex ecosystems

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Introduction

1. Core Concepts:

The focus of our lesson is on ecological systems and how some species interactions may be affected or modified by other species interactions or changes in the abiotic environment. Keller (2014) shows that the competitiveness of a plant species against its neighbors can be increased when the dominant competitor associates with a mutualistic bacteria. These interactions highlight the role of abiotic nutrients in these competitive interactions, with the bacteria supplying nitrogen to the dominant competitor. This paper provides an approachable framework from which to discuss how systems operate as a network of biotic and abiotic components without requiring excessive explanation or details. It is hoped that the students can adapt this framework to other biological systems of interest and learn to build upon these simpler systems by factoring in additional components.

It is assumed that students will be able to interpret a pie chart and bar graph, understand that individuals in an ecosystem compete for resources, and have a very basic understanding of plants, bacteria and fungi as organisms in a plant-soil ecosystem. Students are expected to know how to construct a box and arrow model and the difference between predictive and descriptive models. It is not necessary for the students to know how to read a scientific publication, nor are they required to be familiar with legumes or rhizobia.

2. Misconceptions:

Due to our own negative interactions with microorganisms (e.g., human pathogens, plant pathogens, food rot, etc.), we may assume that interactions between bacteria and their potential hosts are typically negative. Species interactions are also frequently seen as only being between two parties and the nature of the interaction being invariable. Additionally, even among professional ecologists, competitive interactions and pathogens may be over-emphasized and over-simplified. This paper shows an example of positive interactions between bacteria and their plant host and how these interactions modify competitive relationships. It also addresses the question of how an environmental change such as freely available soil nitrogen impacts the competitive edge provided by the rhizobia. Interestingly, Keller (2014) found that the addition of nitrogen did not impact the competitive advantage, as one might expect, proving that there are potential misconceptions and oversights to be identified even in a more complex model of these species interactions.

3. Scientific teaching approaches

This lesson draws on several scientific teaching approaches, including working with data, modeling, hypothesizing, and designing experiments. We will first engage students with a pre-class homework wherein the students will be provided with two figures from the paper (see Supplemental Materials: Slide 1), a legend, and instructions to develop a simple, descriptive box & arrow model using the terms "*Chamaecrista*", "rhizobia", "other plants", and "compete". Students will turn in a copy of their models at the start of class as a formative assessment of their understanding. The instructors will then give a brief introductory lecture about ecological systems, species interactions, and then narrow the focus to legumes, rhizobia, and their interactions with other plants as an example. The instructors will incorporate clicker questions and think-pair-share discussions to monitor class comprehension. After the lecture, students will work in groups of 4 to develop a prediction/hypothesis about an additional model component. Groups will report out their predictions/hypotheses and the class will discuss the proposed hypotheses. The class will close with a summative assessment wherein the students will propose an experiment to test their hypothesis. Because this lesson relies heavily on group collaboration, discussion, and several different teaching methods, we are confident that not only will the lesson be approachable to a diverse student body, but that the students will be able to leverage that diversity of training and background to help eachother master the basic concepts and apply the material to the problems presented.

Lesson plan

Student learning objectives:

1. Working with data from the paper, students will construct a descriptive model of ecological interactions between plants and rhizobia.

2. Students will add an additional component to the models (e.g. nitrogen additions, an additional legume spp.), make predictions about changes in plant community composition, and explain the reasoning behind their prediction.

3. Students will design an experiment to test their predictions about their expanded model.

4. Students will evaluate an experimental design, make predictions of the outcome, work with mock data, evaluate whether their predictions were supported, and formulate conclusions based on the results.

Table 1 - Description, timeline, and learning objectives

*If the class has a lab component students can run their experiments after the lesson.

5 Es	**Description /Assessment**	**Time (mins)**	**Learning objective**
Engage	Share data of specific example (Keller 2014). Students will construct descriptive model of ecological interactions between plants and rhizobia.	pre-class	1. Work with data to construct a model
Explain	Introduce concept of species interactions (competition, mutualism).	15	

Elaborate	Students will add Nitrogen fertilization to their models, make predictions about changes in plant community composition and explain the reasoning behind their predictions.	15	2. Students will expand their model, make predictions, and explain their reasoning.
Explain	Discuss essential elements of experimental design and testable hypotheses.	10	
Elaborate	Students will design an experiment to test the predictions made from modifications of their original model.	15	3. Design experiments to test hypotheses
Explore	Students will evaluate an experimental design, work with provided data, and make conclusions.	25 (semester project*)	4. Evaluate experimental design, work with data, make conclusions.
Evaluate	Evaluation will be based on before-class homework, mid-lecture clicker questions and student reporting, and submission of carbonless notebook pages with revised models, experimental design, and data analysis.		

Instructional Design and Assessments

Engage - Interpret Data and Engage with topic
Before class, students will be provided with two figures from the focal paper. They will be asked to create a model to depict the growth of *Chamecrista* with and without rhizobia and its impact on other plants and write a figure legend relating their model to the findings of the paper. This model will be turned in at the start of class as homework.
Assessment- A rubric will be developed to assess the accuracy and completeness of the model.

Explain - Interactive lecture to introduce background material (15min)
The class session will begin with a short lecture about different types of species interactions and specifically the legume-rhizobia mutualism.
Assessment - The instructor will use clicker questions (see Supporting Materials: Slide 6) and think-pair-share to assess student learning of key concepts and address misconceptions.

Elaborate - Students will expand their model of species interaction (15min)
On whiteboards, students will work in groups to build a new model(s) (not necessarily box-and-arrow) that elaborates on the original simple model using the terms: "*Chamecrista*", "Rhizobia", "competition", "Nitrogen fertilizer", and "other plants". The model(s) should include both descriptive and predictive elements, whether as separate models or a combined model.
Assessment - Groups will report out about their models and predictions and the class will discuss the key elements of each. Students will draw their models into their carbonless notebooks, including figure legends, and turn in a copy of each model.

Explain - Discuss experimental design (10min)
The instructor will lead a brief interactive lecture on the key elements of experimental design, focusing on controls, replicates, and quantifying results.

Elaborate - Students will design an experiment (15min)
Students will design an experiment to test the prediction from their previous model.
Assessment: Students will write/diagram the experiment in their carbonless notebooks to turn in at the end of class. They should include the number of replicates, the different treatments, and what data will be collected. A rubric will be developed to evaluate the experimental designs.

Explore - Students will work with hypothetical data provided and evaluate their hypothesis (25min)
Students will be provided with an hypothetical experimental design and asked to predict the results. They will then be provided with hypothetical data (see Supporting Materials: Data) from that experiment. Students will graph the data and determine whether or not their prediction was supported. Ideally, if the course contains a lab component, the students will refine their own experimental design based on instructor feedback and then perform the experiment that they designed as a semester project as a follow up to this lesson.
Assessment: Students will record their predictions, graphs, and discussion of the results on carbonless paper to turn in at the end of class.

Evaluate - Summary of assessments
Instructors will evaluate student learning during class with mid-lecture clicker questions, think-pair-share, whiteboard modeling, and reporting out. Students will submit the before-class homework, their expanded models, their experimental design, and their analysis of the hypothetical experiment for the instructor's evaluation after the completion of the lesson.

Teaching discussion

NA

Supporting Materials

1. Powerpoint slides
2. Data

Rhizobia treatment	Nitrogen treatment	*Chamecrista* biomass (g)	Other plant biomass (g)
No	No	200, 300, 250, 400, 225	100, 125, 80, 95, 110
Yes	No	500, 450, 550, 525, 475	95, 80, 75, 90, 100
No	Yes	225, 200, 250, 275, 210	250, 300, 325, 275, 310
Yes	Yes	400, 350, 300, 375, 410	200, 275, 300, 250, 285

3. Final Exam Question

Ectomycorrhizal (EM) fungi are plant-associated fungi that transport water and Phosphorus from soil to their host plant(s) in exchange for Carbon from the plant. Each species of EM fungi associates with a small number of plant species. In this example, the EM fungus is the Death Cap Mushroom *Amanita phalloides* and it's host is an Oak tree. The Death Cap does not associate with Maple Trees.

1. Assuming that you are in a forest of Oak and Maple trees, construct a descriptive model of this species interaction using the following terms: <u>Oak</u>, <u>Maple</u>, <u>Death Cap</u>, <u>Water/Phosphorous</u>, and <u>compete</u>.
2. Write a hypothesis for how drought would affect the forest system modeled in part 1.
3. Design an experiment to test your hypothesis. (Be sure to include your controls, number of replicates, and the data you would collect.)
4. Draw a predictive model of your expected results. Include figure legends.

References

Keller, KR. 2014. Mutualistic rhizobia reduce plant diversity and alter community composition. Oecologia. 176:1101–1109. DOI 10.1007/s00442-014-3089-1