**Beans and Rice Optimal Foraging: Charnov’s Marginal Value Theorem**

*Initially developed at Dartmouth University by Craig Layne and others.*

*Additional materials, organization, and notes added by Brian Kennedy and Jens Hegg at University of Idaho*.

**Target Grade Level:**

Undergraduate level lab. At University of Idaho this is used in an upper-level (Junior/Senior) Fish Ecology course.

**Time Requirements:**

This lesson, at a minimum, should include one lecture/lab period, and one lab period. The lab report is due as homework. We often briefly introduce optimal foraging as a portion of the lecture, with the included engagement and introduction materials presented in the first lab period, followed by some time to design the experiment. The second lab period is devoted entirely to conducting the experiment.

**Lesson Objectives:**

Students will be able to identify and explain the motivation behind optimal foraging theory, and the relationship between resource density and the decision to stay or leave a foraging location based on Charnov’s Marginal Value Theorem of animal foraging. Students evaluate the predictions of this theory by designing an experiment which manipulates simulated resource patches (bins of rice), variable resources (beans of differing colors and shapes), and foragers (lab mates) to test one prediction of Charnov’s theory. Students will be able to integrate their experimental results with the expected predictions of Charnov’s theory through a written lab report.

**Key Concept(s):**

* Optimal foraging theory
* Marginal value theorem
* Patchiness of resources across the landscape
* How an animals movement relates to both local resource density and average resource density of the environment
* Use of spreadsheet programs for data recording, graphing, and analysis.
* Experimental design
* Deriving predictions from theory

**Instructional Materials and Resources**

 **For each individual**

* Lab packet
* PDF copy of Charnov, 1976 “Optimal Foraging, the Marginal Value Theorem.” *Theoretical Population Biology* **(required pre-reading)**
* Copy of “You are an Information Wolverine” blog post, PLOS Ecology Community blog. By Jens Hegg **(either pre-reading or in-lab quick read)**
* Video organizer sheet

**For each group**

* 3-5 rubbermaid tubs for foraging patches
* Enough dry white rice to fill these tubs with ~2-4” of rice
* Multiple types and sizes of beans for “prey” (kidney, pinto, lima, white, lentils, peas…)
* Cat litter scoop for removing beans from rice
* Several copies of the datasheet, or access to a laptop to record data directly into Excel spreadsheet
* Stopwatch

**Teaching materials**

* PowerPoint introduction (change to suit. Two engagement videos included)
* Prep notes outline

**Procedures:**

* **Engage:**

*Depending on the structure and schedule of your class/lab the engagement exercise and introduction of optimal foraging theory can occur during class, or it can be done entirely within the lab section. The reading, “You are an information wolverine” is best used as an attention grabbing pre-read. The Charnov paper, “Optimal Foraging: the Marginal Value Theorum” is best assigned after the introduction of optimal foraging so that students have some background upon which to evaluate it.*

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The first part of the lesson should engage students in the question of “how do animals know how to gather food and resources and when it is time to leave to find a different spot?” The intent is to provide video content and an out-of-the-box reading that gets students thinking about how animals search for, and find, food and other resources.

The reading, “You are an information wolverine” is a short, easy to digest, introduction to optimal foraging. It crosses disciplinary lines, showing how optimal foraging theory has been adopted to explain internet browsing. Questions it might raise among students include: whether animals really do optimally forage, or are simply random; whether the analogy between deep readers and wolverines is really correct; and whether human behavior can be categorized as optimal foraging, especially online behavior. It can be used as a required pre-reading or as a quick in-lab read-and-discuss, depending on whether your students are prone to actually read it ahead.

Numerous videos exist of animals foraging in the wild. This lesson includes two related to fish ecology, but it could easily be tailored to terrestrial animals, birds, or any other taxa. The first is a video of a great white shark dramatically capturing a seal. It’s engaging, exciting, and gets students attention. I have opened with, “how it is that a great white travels thousands of miles through open ocean, yet knows where to go to find the food it needs.” This can begin engaging students in the idea that resources are patchy, and vary in abundance, making the foragers job much harder.

The second video shows a yellow goatfish foraging for marine crustaceans in the sandy patches of a reef. The video is short but illustrates how resources are patchy (the fish in only finding food in the sand, not the reef), and how it exploits the patch and then decides to move on. Ask the students to think about how the fish is finding resources, and how it knows where to go and when to leave. How many food morsels might it have left behind? Some, or none at all? How thoroughly did it search? Have them organize their thoughts and questions in the video organizer handout. Play the video a couple times so they can observe multiple times. Their observations are a great way to begin a class conversation on how an animal must optimize its foraging, and how it might accomplish that goal. The organizer should be informal, formative assessment and not graded.

This engagement through the pre-reading and/or videos should lead into a discussion of optimal foraging. This is a great time to gauge the prior knowledge of the class. Have they been exposed to the idea of optimal foraging before, or is this something new? What questions or doubts do they have about the general idea? What preconceived ideas do they have that are incorrect? This discussion/debate can continue directly into the introduction of the theory.

* **Explore:**

This lesson is designed to force students to create a scientific protocol, using tubs of rice as “resource patches” and their classmates as “foragers,” to test one of the predictions of Charnov’s Marginal Value Theorem of optimal foraging. It further requires students to master data collection and basic analysis in Excel and to synthesize their results in comparison to the expected predictions of Charnov’s theory.

After introducing optimal foraging through the engagement exercise it is critical to continue the discussion into an overview of Charnov’s theory and the predictions it makes. In order to develop a reasonable experiment, the students must understand the predictions Charnov makes and what variables relate to each one. These are outlined in the Powerpoint. I prefer to continue the discussion that was started during the engagement exercise directly into the Powerpoint, keeping discussion open and using the Powerpoint to present the major points *only.*

I spend most of this introductory lesson actively engaging the students in helping me to “build” the figures in the Charnov paper, from the x and y-axes through to the meaning of the curves in terms of animal activity. *Be sure to talk about the graphs in terms of what animals are doing, using specific examples and/or by picking a species and referring to it throughout.* Don’t be afraid to let the students take the lead in building these graphs before you actually show them what they look like. Ask leading questions and let the class puzzle it out as you draw what they tell you.

By actively talking *with* the class to sort through the complexity and meaning, not lecturing to them, I have found that they internalize the material faster and more completely. I do insist that at a minimum they take notes verbatim from the PowerPoint slides so that they have them to refer to when designing their experiment.

After the introduction to the marginal value theorem introduce the materials and the purpose of the lab activity. Their goal is to work in teams to pick one of Charnov’s predictions from the marginal value theorem and test it. Their tools are “habitat patches” made up of Rubbermaid tubs filled with white rice. The “resources” are beans and peas mixed into this rice substrate. The “foragers” are other members of the class.

It is important to introduce the materials so that everyone understands what is available. We have, in the past, conducted a quick demonstration to give students the idea of how to record data and how to pick a single variable to test at a time (*We have found that data collection is a critical piece for students to be able to plot and analyze their results later. Making sure they understand data collection beforehand saves lots of headaches and office hours later on. We have taken to giving them a data collection template on paper and in Excel to ease this process*). Make sure that you talk about independent and dependent variables and what the response is before groups begin designing an experiment. A common error is for groups to vary two variables at a time, not realizing that the results will be uninterpretable later.

Once the groups are familiar with the materials set them free to design an experiment. Let them get creative. They can vary the density of prey, get creative to find ways of increasing travel time between patches, test multiple types of forage for “giving up time”, make foragers use chopsticks or tweezers, bulky gloves or blindfolds to change their foraging efficiency. Let them get as creative as they want but circulate and get involved to reign in projects that are too ambitious for the time-frame and to make sure they are developing a workable protocol. This is the instructor’s chance to conduct formative assessment and to practice scaffolding to help correct misconceptions of optimal foraging and experimental design.

***Make sure all groups have a clear datasheet and written experimental protocol before the end of the lab period is critical***! All the groups should show the instructor their plans and be able to explain the prediction they are testing, as well as which independent variable they are varying, what the dependent variables are and how they will be collecting data. (*It is a good idea to collect a copy of these protocols and give them back during the next lab period for those groups for whom the protocol mysteriously vanishes over the week*)

The next lab period is reserved for the groups to set up their experiment based on their protocol and to conduct it. It’s a good idea to go over the protocol with each group quickly to make sure they are still on the right track. *Have groups practice their data collection at least once, all the way through one replicate.* Continue to engage groups and be available to answer questions and make sure things are running smoothly. By the end of the second lab period groups should have collected all of their data and be ready to analyze.

* **Explain:**

*Explain how you will guide students to share what they have learned and connect their learning to the objectives and key concepts of the lesson.*

The intention of the lab is to create a situation in which students can explore and deeply understand the idea of optimal foraging. It also demonstrates their ability to formulate an experiment and use tools like Excel spreadsheets for data analysis. The first concrete indication that students are able to communicate their learning is the group experimental protocol. I treat this as a formative assessment, to ensure that students are “getting it” and that there are no ideas that are way off-base. Any problems should be corrected before they leave at the end of the first lab period.

The main opportunity for students to demonstrate their understanding of the material is the lab report. The assignment should be short (2-3 pages). This is *not a scientific paper*. They do not need to include references or apply their results to ecology more generally. The introduction should show an understanding of optimal foraging, and the ability to communicate and generalize Charnov’s theories to animal behavior and state a hypothesis. Methods should be clear and explain their relationship to the hypothesis. Results should clearly explain the results, refer to figures from the data, and provide clear evidence for whether the hypothesis was falsified or not. Conclusions should discuss the findings in relation to Charnov’s theory. Did the test actually test what they expected it to test? Did the results support or provide evidence against Charnov’s marginal value theorem? How do these results compare and contrast with data collected from animals…did the experiment provide realistic data or not? Why?

* **Elaborate:**

*Describe activities that will engage students in applying the concepts that they have learned to new situations/problems. If this will occur in subsequent lessons, identify this and briefly describe how this will occur.*

The lab report is designed to provide students a way to express what they have learned from the lab. You should stress that the report Introduction and Conclusion sections should reach beyond the experiment itself and talk about how this experiment applies to optimal foraging in animals. Their conclusions should link back to whether how their results inform the use of Chanov’s marginal value theorem in animal populations.

* **Evaluate:**

*Describe how you will assess what students have learned through this lesson.*

The lab packet provides a general rubric for summative assessment of students learning through grading the final lab report. Points can be assigned on this rubric to fit your grading scheme. We usually assign points for turning in an approved experimental protocol since it is a critical outcome upon which the rest of the lab depends.

Formative assessment should occur through direct interaction during the engagement and exploration sections of the lab. Because this lesson occurs over multiple days it helps to take some brief notes of where you see students having problems or what concepts seem to be missed so that these can be referred back to on subsequent meetings. Try to approach groups and ask probing questions throughout the experimental design phase to help scaffold their approach toward a workable experiment. Points can be assigned for participation and group-level work during the design and testing periods if you prefer, or this can be left as a formative activity.