Ecology 101

Note: Dr. Harold Ornes is the editor of Ecology 101. Anyone wishing to contribute articles or reviews to this section should contact him at the Department of Biology and Geology, University of South Carolina–Aiken, 471 University Parkway, Aiken, SC 29801; phone (803) 641-3299; fax (803) 641-3251; e-mail: haroldo@aiken.sc.edu.

In the following article, Jeffrey Gerwing, Pamela Lockwood, and Christopher Uhl describe a rather unusual ecology laboratory/field exercise that utilizes abundant oak habitats of central Pennsylvania. For those readers not blessed with an abundant supply of oaks nearby, perhaps other species could be substituted.

The exercise is unusual in two ways. It offers a new undergraduate ecology activity, and it offers opportunities for students to relate other disciplines to their science course.

In "the good old days" of higher education each discipline offered its menu of courses and expected students to make appropriate connections among the courses of their major, minor, and general education. In today's educational atmosphere of integrated curricula, linked courses, and cross-disciplinary programs, the following exercise may serve as an example of linking an ecology course with sociology, anthropology, English, and mathematics.

ACORN FORAGING AS A MEANS TO EXPLORE HUMAN ENERGETICS AND FORGE CONNECTIONS TO LOCAL FORESTS

The following is a description of a field exercise that we have been using for several years in an undergraduate field ecology course. During this exercise, students imagine themselves as a group of indigenous woodland people attempting to gather food stores that will carry them through the winter. In doing so, they grapple with issues of human energetics, foraging strategy (i.e., optimal foraging), carrying capacity, and experimental design. In addition, they will gain experience manipulating data and making calculations. We developed this exercise for use in central Pennsylvania forest dominated by white oak (*Quercus alba*), red oak (*Q. rubra*), and chestnut oak (*Q. prinus*), but it should be adaptable to any setting where sources of wild plant foods are available. We conduct the exercise in October after the acorns have fallen.

Background

The most important survival issue facing any animal involves eating enough to meet its energy demands. Given the high potential energetic costs of finding and processing food items, optimal foraging theory predicts that natural selection will favor the development of food-gathering strategies that maximize net energy intake (i.e., the total energy present in food consumed minus the energy required to obtain and process that food) (Begon et al. 1986).

Throughout the majority of our evolutionary history, humans have met their energy needs by hunting and foraging in natural ecosystems. In central Pennsylvania, nuts (e.g., acorns, hickory nuts, black walnuts), seeds of annuals (e.g., lambs' quarters, amaranth), and wild fruits (e.g., grapes, blueberries, blackberries) would all have been important food sources for Native Americans. The abundance of these wild foods would have defined the foraging area needed by a group with a given population. Viewed in another way, abundance of sources of wild foods could have, in large part, determined the human carrying capacity of the region.

Introducing the problem

The year is 500 BC. Your students are members of a group of Woodland Native Americans. We conduct this exercise with a group of approximately 20 students, but any size class would work. We have the students imagine that they are part of a small, 40-person clan of Woodland Indians. The clan is composed of 5 children too small to forage, 5 elders who remain in camp at all times, 5 adults who remain in camp engaged in child rearing and camp chores, 5 adults who are "full-time" hunters and supply 20% of the camp's nutritional needs, and 20 adults who forage for the plant foods that make up 80% of each group's diet. Students in the class assume the role of the 20 foragers.

The "problem" your students will address is: how to survive the approaching winter? They have only 2 months to gather enough food to carry them through the following 3 months of winter. After 2 months, the land will be covered with snow, and the energy expended in food gathering will exceed the energy returns from the food that is gathered. We assume that hunting continues to provide 20% of the group's energy needs during the winter, so foragers need to focus on the remaining 80%.

Procedures

The exercise is most successful with students working in groups of 3–4. The following three activities can be conducted in a 3-4 hour laboratory period, leaving time for a wrap-up discussion at the end. To conduct this activity during a 2-hour laboratory period, students could be given the first part of the exercise to prepare in advance; do parts 2 and 3 in 2 hours; the follow-up discussion could be held on a different day. The materials required for this exercise include plastic bags, hanging scales (1–5 kg capacity), 50-m measuring tapes, calculators, and clipboards.

1) Calculate the group's energy needs. The first step in determining whether a group will be able to gather enough food to survive the winter is determining the group's energy needs. We provide the following energy requirements for adults (based on Phillips 1954, Clark and Haswell 1970): heavy work (e.g., foraging and hunting), 1004 kJ/h; light work (e.g. camp chores and food processing), 794 kJ/h; sitting, 335 kJ/h; and sleeping, 272 kJ/h. One calorie is approximately 4 joules (239 calories = 1 kilojoule). The requirements for children are assumed to be 60% of the adult values.

The average daily energy requirement for each subgroup of people within the 40-person clan (e.g., elders, children, etc.) can be calculated using Table 1) To do this, students will need to make assumptions about the composition of each subgroup's daily routine. Given that plant material will provide 80% of the clan's total energy needs, we ask the students to calculate the total amount of energy that will need to be gathered during the next 2 months to meet requirements for the entire 5-month period.

Estimated values for the entire clan's daily energy needs will be about 510 MJ (Table 1). Thus, the clan's total energy requirements would be about 78.5 GJ (gigajoules) for 5 months, of which 61.1 GJ would be obtained through foraging.

2) Develop foraging strategies for acorns. The students' next task is to investigate the effectiveness of various foraging strategies. An effective foraging strategy is one that maximizes return on effort. We ask students to conduct an experiment, using alternate foraging strategies as "treatments" with appropriate "controls."

A simple foraging treatment might, for example, consist of restricting foraging to forest patches with high oak basal area. The control for this treatment would be randomly located foraging patches. Foraging treatments might also investigate the effects of incorporating simple technological advances. For example, our standard issue foraging sack is a plastic grocery bag that is held in one hand while acorns are picked with the other. A simple improvement to this foraging system could involve attaching the bag to the forager, thus freeing both hands for acorn picking. Another possible foraging treatment at our site is provided by a monoculture stand of white oaks in a park setting with a mown lawn understory. Students forage in this setting to simulate the benefits of specifically managing forest composition both to reduce competition on oak trees and facilitate acorn collection. Harvesting yields are compared to control harvesting in the adjacent natural forest.

We have found that it is important for students to proceed slowly in developing their experiments. We encourage them to refine their foraging treatments and require that they confer with us before committing to an experimental design. Frequently, students' first attempts at an experimental design will include treatments that confound several variables. For example, as a treatment, they might propose foraging in pairs, with one person moving leaves and one person picking acorns in a patch of high oak tree density. As a control, they propose randomly located individual foraging. In this case, the instructor can encourage them to focus on a design that will allow them to separate the effects of foraging in pairs from the effects of foraging in an area of high oak density. Another common design flaw that arises is that students, in their enthusiasm for trying diverse experimental treatments, fail to incorporate adequate replication into their designs. This can be easily corrected with some instructor guidance.

We provide the following ballpark conversion factors to calculate the return on effort for each foraging "treatment." To convert from acorn gross fresh mass (i.e., whole nuts with shells) to net dry mass (i.e., usable acorn meal), multiply by 0.25. To calculate the energy available in

Table 1. Sample worksheet for estimating energy needed per day by a clan of 40 Woodland Indians. For each subgroup, estimated hours engaged in each activity were multiplied by the energy used in that activity to calculate daily energy needs per activity. Then the sum for all the activities was multiplied by the number of people in that subgroup to get total energy used per day per subgroup. Summing the daily energy needs for all subgroups yielded the clan's grand total.

Subgroup of the clan	Heavy work		Light work		Sitting		Sleeping		No. people in group	Total MJ/d
	h/d	MJ/d	h/d	MJ/d	h/d	MJ/d	h/d	MJ/d		
Children	0	0	4	3.20	12	4.02	8	2.17	5	46.99
Elders	0	0	10	4.77	4	0.80	10	1.63	5	36.02
Camp adults	0	0	12	9.54	4	1.34	8	2.17	5	65.27
Hunters	8	8.033	4	1.34	4	1.34	8	2.17	5	73.64
Gatherers	8	8.033	4	1.34	4	1.34	8	2.17	20	294.50
Grand total										516.42

acorn meal, multiply by 14.64 KJ/g dry acorn meal. Using these conversion factors, 50 g of acorns would yield 12.5 g of acorn meal that contained a total of 184.1 kJ. If the mean acorn collection rate of a given treatment were 50 g/min, then an average of 11 MJ/h would be collected. Given that foragers expend 1.004 MJ/h while foraging, this collection rate would result in a net energy gain of 9.99 MJ/h. Assuming that the 20 foragers in the group spent an average of 6 hours per day actively foraging, they would need 46 days to collect the 61.1 GJ that would supply 80% of the clan's energetic demands for 5 months.

3) Calculate the clan's land requirement. The final objective of this exercise is to calculate the forest area needed to provide for the harvesting of total energy needs of the 40-person clan for the next 5 months. To do this, students will need to estimate the availability of acorns per unit area (hectare). There are two methods for obtaining this estimate. The first method, inspired by an activity in Rosenthal (1995), involves inventorying the diameters of oak trees in a known area and estimating per-tree production from diameter at breast height based on the following equation for white oak (modified from Goodrum et al. 1971):

acorn fresh mass (in kg) = -3.8 + 0.2 x tree dbh (in cm)

Thus, a tree with a diameter at breast height (measured at 1.3 m) of 30 cm would yield 2.2 kg of acorns. This method assumes constant year-to-year acorn production and complete capture of all acorns by the foragers. It would be more realistic to assume that 25–50% of the total acorn crop would be lost to animals, insects, and fungi.

A second method of determining acorn abundance is to have students harvest all the acorns in randomly located 1-m^2 plots. This method has the advantage of allowing the instructor to assemble a multiyear data set that could be used to demonstrate the concepts of annual variation in acorn production and masting (for a relevant reading, see Sork et al. 1993).

Table 2. Comparison of annual per hectare energy inputs and returns for acorns gathered in natural forest and for two crops produced in the united States (crop data from Pimentel 1986).

Crop	Yield (kg)	Food energy yield (GJ)	Energy input (GJ)	Energy input/ output ratio	Labor input (person-hours)
Acorns	100	10.367	0.033	11	33
Wheat	2022	28.030	10.460	2.7	6

Based on their estimates of per hectare acorn availability and their calculations of total energy requirements for the 5-month period, students can calculate the total area of foraging lands needed by their group to survive winter. Using the above equation, we estimated that our study plot produces approximately 200 kg of acorns/ha. Assuming that 50% of these acorns were harvested, applying the appropriate conversion factors resulted in a yield of 366.1 MJ/ha in acorn meal. Thus, a total foraging area of approximately 160 ha of forest could provide for the total energy requirements of the 40-person clan for 5 months.

Laboratory follow-up

When students have finished their work, we usually remain in the forest for a half-hour wrap-up discussion where each group presents the results of its foraging experiment. If time is limited, students can conduct their calculations on their own and the exercise can be discussed during a separate meeting. This discussion provides an opportunity to critique the strengths and weaknesses of each group's experimental design.

The exercise also provides an opportunity to compare the estimated yields and energy and time budgets of acorn harvesting with present-day agriculture in a world heavily subsidized by fossil fuels. It is obvious that the per hectare yield of acorns is substantially lower than that of an agricultural crop (Table 2). However, the low energy investment in acorn collecting results in gathering acorns having an energy output:input ratio five times higher than conventional grain cultivation (Table 2). If one is interested in carrying this topic of discussion even further, Giampietro et al. (1992) provide a nice analysis of the social and ecological concerns associated with different agricultural production practices.

We have our students present the findings of this exercise as a short research paper. The following questions can guide their interpretations and discussions of their results:

1) Will the group be able to survive for the next 5 months? This is the central question of the exercise; students should provide the results and calculations to support their answers.

2) Which of your foraging methods yielded the highest net energy gain?

3) How much time will group members need to spend foraging to meet their winter energy needs?

4) How much foraging area does the group need to sustain itself?

5) What are the key assumptions that have gone into making these calculations (e.g., estimates of activity budgets and acorn availability) and how might errors in these assumptions affect the results?

6) How might one alter the environment to improve food harvesting in the future? (i.e., are there ways that the forest could be managed to facilitate acorn harvesting and provide more acorns?) One example is the use of fire as a forest management tool. In addition to maintaining a relatively

open forest understory, periodic burning might favor oaks over other tree species with less resprouting ability and thinner bark (Abrams 1992).

7) As a present-day ecologist, what further experiments could one conduct to better understand the role that wild plant foods might have played in Native American subsistence patterns in this region? One obvious direction here would be to investigate the seasonal and interannual fluctuations in the availability of wild plant foods to better understand how diets might have varied during given years and between years. Another possibility would be to look for evidence of Native American forest management activities as suggested by the present-day distributions of species of oaks and other nut-bearing trees (Wykoff 1991).

Conclusion

Experiment-based approaches to teaching undergraduate ecology often focus on providing hands-on experience with ecological concepts and building research skills (e.g., Beiswenger 1993). At the same time, it is also important to design learning experiences that foster students' sense of being a part of the natural world. This exercise, designed around foraging for wild plant food, attempts to forge a personal connection between the students and the subject matter. This connection can both increase students' enthusiasm for the experience and provide them with an opportunity to further develop their "ecological identities" (Chipeniuk 1998).

For the majority of our history as a species, humans have existed as foragers in natural systems. Foraging was a way of being that connected us to our surroundings and forced us to live within the productive limits of those surroundings. A taste of this connection might be experienced by following this exercise with a dinner where the harvested acorns are eaten. Several recipes for acorn preparation can be found in Gibbons (1962).

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Jeffrey J. Gerwing
and
Pamela Lockwood
Interdepartmental Graduate Program in Ecology
208 Mueller Laboratory
Pennsylvania State University
University Park, PA 16802
E-mail: jjg156@psu.edu

Christopher Uhl
Department of Biology
208 Mueller Lab
Pennsylvania State University
University Park, PA 16802
E-mail: cfu1@psu.edu