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Abstract

For over 40 years, Professor Bernie Patten, offered a course on Field Systems Ecology at the University of Georgia in Athens, Georgia, USA. The course combined systems analysis approaches and natural field ecology in a way that gave the students new perspectives on making conceptual and formal models of the natural world. The course employed extensive use of outdoor field laboratories at a nearby park, which had multiple ecological habitats. The main progression was to go from simple observations to “seeing systems” to modelling by learning to ask pertinent systems-oriented questions. This started with a structured walk through the six identified subsystems (forest ridgetop, forest slope, field, lake, stream, and wetland) and proceeded to specific field sampling techniques for the terrestrial and aquatic environments. In addition to the field labs, the course required two weekend camping trips, one to the Great Smokey Mountain National Park in the Appalachian Mountains and one to the Okefenokee Swamp/Cumberland Island National Seashore. The idea was to use the two weekend trips to frame the local watershed scale processes at the continental scale. In this manner, students could observe and measure ecosystem processes and interactions at multiple scales. The notes, which are reproduced below, have been further modified for use at Towson University which utilizes a local park in Baltimore County called Oregon Ridge. The general approach of these notes should have universal appeal to anyone teaching or taking a systems ecology course.

Keywords	systems ecology, field ecology, class laboratory exercise, models, observation and measurement
Taxonomy	System Model, Lake Ecosystem, Stream Ecosystem, Terrestrial Ecosystems

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Highlights

- Pedagogical notes for a course in field systems ecology
- Guidance for asking systems-oriented questions in various ecological environments
- Progression from observation to model making
- Class exercises for field systems ecology

Notes from an introductory course on Field Systems Ecology

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Abstract
For over 40 years, Professor Bernie Patten, offered a course on Field Systems Ecology at the University of Georgia in Athens, Georgia, USA. The course combined systems analysis approaches and natural field ecology in a way that gave the students new perspectives on making conceptual and formal models of the natural world. The course employed extensive use of outdoor field laboratories at a nearby park, which had multiple ecological habitats. The main progression was to go from simple observations to "seeing systems" to modelling by learning to ask pertinent systems-oriented questions. This started with a structured walk through the six identified subsystems (forest ridgetop, forest slope, field, lake, stream, and wetland) and proceeded to specific field sampling techniques for the terrestrial and aquatic environments. In addition to the field labs, the course required two weekend camping trips, one to the Great Smokey Mountain National Park in the Appalachian Mountains and one to the Okefenokee Swamp/Cumberland Island National Seashore. The idea was to use the two weekend trips to frame the local watershed scale processes at the continental scale. In this manner, students could observe and measure ecosystem processes and interactions at multiple scales. The notes, which are reproduced below, have been further modified for use at Towson University which utilizes a local park in Baltimore County called Oregon Ridge. The general approach of these notes should have universal appeal to anyone teaching or taking a systems ecology course.

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INTRODUCTORY LAB SESSIONS
for a Systems Approach to Field Ecology

OUTLINE

Introduction: Background and overview

Lab 1: Survey and Reconnaissance

Goals:
For students to see their study area for the course in a historical (dynamic) context.
For students to experience how ecological questions are asked.
For students to gain an intuitive grasp of what it means to view habitats as systems.

I. Historical Overview

A. Geologic time
B. Ecological time
C. History of the park
D. Human impacts on the park

II. Introduction to the ecosystems of Oregon Ridge Park
A. Asking questions
B. A walk through the park (6 subsystems)
Station 1. Forest Ridgetop
Station 2. Forest slope
Station 3. Lake
Station 4. Field
Station 5. Stream and Riparian Zone
Station 6. Pond and Wetland

Homework 1

Lab 2: Terrestrial sampling techniques

Goals:

For students to become acquainted with terrestrial sampling methods.
For students to get an idea of which methods are appropriate to their own questions about the ecosystem.

I. Sampling

Homework 2

Lab 3: Aquatic Sampling Techniques

Goals:
For students to become acquainted with aquatic sampling methods.
For students to get an idea of which methods are appropriate to their own questions about the ecosystem.

I. Lake and Pond Sampling
II. Stream and Wetland Sampling
III. A Model for Flows

Homework 3

INTRODUCTION: BACKGROUND AND OVERVIEW

The goal of the Ecosystem Ecology class is to give the student the background necessary to be able to look at a particular habitat and understand, at least on a small scale, the linkages that make it a functioning unit within the whole of nature. In order to get this understanding, our way of looking at nature must be altered from that of individual units and their interactions to that of the whole. What is a unit in one study may become the whole in another (that is the basis for hierarchical organization). Thus, a global study, with the earth as the whole, may consider each continent as a unit, while a study of the Mid-Atlantic United States may consider the Piedmont a unit among various landscape types. Although we may work on vastly different scales, we cannot forget that what is outside our defined whole can influence the processes within it. The textbook that accompanies this course, *Environmental Systems* by White, Mottershead, and Harrison (1992), does an excellent job working down in scale from global to local interactions and will be referred to frequently in this handout.

The field portion of this course takes one area as the whole, Oregon Ridge Park in Baltimore County, Maryland, and asks you to disassemble it into its various units. The 422 hectare (1043-acre) park consists of a forest, a field, a lake, two streams, and a pond; so, on one scale the park consists of six units (habitats). By the end of the course, you should be able to walk through these areas and list the important subunits of each area and have general notions of the functions and interactions of the subunits and finally, some idea of how the units link together.

Oregon Ridge Park, like every ecosystem, is an open system, meaning energy and matter flow within and across its boundaries. Biological and ecological structure within the ecosystem is maintained by the importation of a high-quality, low-entropy energy source. Energy enters the system primarily as solar radiation captured through photosynthetic activities of the primary producers (autochthonous input). Some biomass energy enters Oregon Ridge actively (animal migration) or passively (wind, rain, fluvial, slope processes). Such external input is called allochthonous. All energy input that is ecologically-entrained can be accounted for as an increase in the biomass in the system or as output from the system either as organic matter or as heat. Therefore, an equation balancing input and output of energy can be derived for the system and each of the subsystems. The forest, lake, and pond cycle material through the ecosystem. This material, which can be thought of as currency, is accepted, used, possibly transformed, and then passed on within the ecosystem and eventually outside the system boundary as output. Currency can come in many forms such as carbon, biomass, water, nitrogen, heat and other forms of energy. The experiments and the ease of measurement decide which currency is used. Once the class has decided on a currency, the groups will each model the movement of this currency through different habitats keeping in mind that all models could be integrated at the end. One way to look at this is to think of a jigsaw puzzle. You will need to identify the pieces and how they fit together. You will then put these pieces together into a systems model that will give you the big picture of the park system.

This handout covers the first three periods of fieldwork at the park. It contains a brief history of the area, maps, descriptions of sampling techniques for terrestrial and aquatic habitats, and questions to give some structure to your initial wanderings around the site.

LAB 1: SURVEY AND RECONNAISSANCE

I. Historical Overview

Maryland is part of six distinct physiographic provinces: (1) the Atlantic Continental Shelf Province, (2) the Coastal Plain Province, (3) the Piedmont Plateau Province, (4) the Blue Ridge Province, (5) the Ridge and Valley Province, and (6) the Appalachian Plateaus Provinces. These extend in belts of varying width along the eastern edge of the North American continent from Newfoundland to the Gulf of Mexico.

"The Piedmont Plateau Province is composed of hard, crystalline igneous and metamorphic rocks and extends from the inner edge of the Coastal Plain westward to Catoctin Mountain, the eastern boundary of the Blue Ridge Province" (Maryland Geological Survey). Towson University and Oregon Ridge Park are located in the Piedmont Plateau Province. "Bedrock in the eastern part of the Piedmont consists of schist, gneiss, and other highly metamorphosed sedimentary and igneous rocks of probable volcanic origin… Several domal uplifts of Precambrian gneiss mantled with quartzite, marble, and schist are present in Baltimore County and in parts of adjacent counties" (Maryland Geological Survey).

The topographical features evident in the county are the result of differential erosion of these contrasting rock types, which provides a variety of mineral resources. Mining activities in the past excavated building stone, slate, and small deposits of nonmetallic minerals, base-metal sulfides, gold, chromite, and iron ore. Currently, the region is a source of crushed stone for aggregate, cement, and lime. The area also supplies of small to moderate amounts of groundwater (Maryland Geological Survey).

A. The Maryland Piedmont through geologic time

You will be exploring some area of the Maryland Piedmont for most of your fieldwork for this course. For the sake of context, we will review briefly the geologic history of the Piedmont so that you will have some idea of what has happened to this area before you got here, and what kind of events might occur in the future. Most of the following geological information is available in *A Sierra Club Naturalists Guide: The Piedmont* (Godfrey, 1982) as well as other sources.

About 1.1 billion years ago two supercontinents collided, resulting in a massive uplift that stretched from Labrador to Mexico, termed the Grenville Orogeny (Watson et al., 1999). The mountains produced in this uplift were probably the size of the Himalayas. However, since there was no vegetation present to control erosion (the first land plants evolved ~450 MYA), the mountains eroded to the sea within about 100 million years. Following successive uplifts and erosional cycles, about 350 million years ago, two supercontinents collided again; these were not precisely the same landmasses that had collided before, and they did not collide in the same way. The resulting land mass has been termed Pangaea. The Appalachian Orogeny – or our current Appalachian Mountains – resulted from the uplift produced by this collision. The continents separated again, leaving behind the massive Appalachian Highlands, which have since eroded down to the relatively low mountains we see today. The Piedmont that we know today, therefore, has remnants of another continent and volcanoes as well as the original continent within it. This was the last massive geological event in the area.

More recent geological history includes the Pleistocene ice ages, the most recent starting about 20,000 years ago and lasting until 10,000 years ago. During this ice age, much of the North

American Pleistocene megafauna – mastodons, wooly mammoths, etc. – became extinct. North American Indians may also have contributed to this extinction.

By 8,000 B.P. (before present) or so, there were significant populations of Native American Indians in the Piedmont. Several thousand years later, large mound-building civilizations were present. By 1492, many of these populations were already in decline. The arrival of Europeans led to disease epidemics that caused further declines in Native American populations.

B. The Maryland Piedmont and Oregon Ridge through ecologic time (taken from History of Oregon Ridge 1720-2001, Center for Archaeology, Baltimore County Public Schools)

Oregon Ridge was once part of two extensive land grants (John and Thomas's Forest patented to the Colgate family in the 1720s and the Long Tract patented in 1737 by John Boring). Most likely, a large portion of all the lands was farmed during the eighteenth and nineteenth centuries. Ore deposits had been discovered by 1820 (possibly much earlier). In 1849, a hot-blast anthracite coal furnace was built at Oregon Ridge. Oregon Furnace produced a record yield of pig iron for 1855. In 1856, Henry Bessemer invented a new steel making process that increased efficiency and resulted in a higher quality final product. Oregon Furnace ceased operation in 1857. Mining of iron ore continued until 1884. In 1892, Thomas Kurtz purchased the 457-acre Oregon Farm, which included one large stone house, a farmhouse, a barn, a stable, and twenty tenement houses. He operated a store providing dry goods, hardware, medicines and foodstuffs for local residents, which remained in business until the 1930s.

C. History of Oregon Ridge Park

In 1969, the Kurtz family sold the property to the Baltimore County Department of Recreation and Parks and designated Oregon Ridge as parkland. The swimming quarry, which has been closed since the 1950s, was reopened, and then closed again in 2014. The nature center was constructed and opened in 1980. In 1983, an archaeological program began involving students from Baltimore County Public Schools.

Most of the land in Oregon Ridge is in various states of succession. The forest is a mosaic of different ages, and one can see different stages of succession as one walks through it.

D. Human Impacts on park and lake

Along with natural cycles, humans greatly affect what happens in the Park. There are still many reminders of past use. Look for some of these during your walks. There are several visible results of humans causing long-term changes, beyond the obvious of the iron ore mines or two utility line swaths through the center. For example, people tended to take the shortest route between two points. Trails went straight up hills, as did horses and bicycles. Erosion gullies on the slopes are still visible. Erosion can be accidental due to poor management and inattention. Horses and dirt bikes are now excluded from the park because they tend to damage trails faster than foot traffic.

<u>Homework 1 (part)</u>: Observe human use of the park today and speculate how this affects the area. You should be able to formulate at least three observations in each substation.

II. Introduction to the ecosystem of Oregon Ridge Park from a Systems Perspective

A. Asking questions

You should walk though a series of habitats found in Oregon Ridge Park. In each habitat, you should ask yourself, a barrage of questions. You don't have to know the answers, but you should think about the questions and how you might go about answering them. You will spend most of the course attempting to answer some set of ecological questions – hopefully, a set you and your classmates have chosen to ask. During the next two lab sessions, you will be exposed to some of the methods and techniques you will have at your disposal for answering your questions.

Here is a sample of some general, systems-oriented, questions of the kind you might ask:

What is the system of interest? (e.g., the lake, the forest, the park, the Piedmont)
What are the boundaries of the system we are looking at?
How do we determine the boundaries? How "fuzzy" or distinct are they? Are they real or do we have to make them up?
In the sense of physics, is the system open or closed?
What are the inputs and outputs of the system to and from the outside?
What processes are going on inside the system?
How might you measure the state of the flows in and out of and the changes within the system?

Here are more habitat-oriented questions:

- What sort of habitat are you looking at now?
  Forest? – What types? What stages? Lake? Field? Stream? Pond? Wetland?
- What flows occur between these different habitats?
  Matter (e.g., water, carbon, nutrient elements), energy, populations…
- For example, in the forest, pick up a handful of leaves. What are the flows that gave rise to those leaves – from what to what? (trees→litter→detritivores→soil→back to trees). Note that you can tell something about the rates of flows: organic matter is accumulating under the trees; the amount of organic matter can be assayed using a combustion oven; you can determine the age of the largest trees since the area was farmed (records, coring); therefore, the rate of accumulation of organic matter can be estimated.
- For example, near the Lake – what are the flows of water into the lake? From the stream? From the land? Are there differences in nutrients between the sources of flows? What are some properties of water that make it such a useful medium for life? What are the flows of water through organisms, like the fish? What are the flows of water throughout the lake? What are the flows of water out of the lake? Is the lake homogeneous, or are there different zones in the lake? What are the flows (of water, energy, materials, populations, etc.) between these different zones? How could you measure some of these flows?
- What kinds of organisms are in each habitat? How do they interact? Do they eat each other? Do they pollinate other organisms? What else do they do? What are the basic types of interactions between organisms? What are the basic types of interactions between organisms and their abiotic environment?
- What trophic (feeding) flows are there in the lake? What eats x? Where does it go from there? Does anything else eat x? Where does it go from *there*? How does the second path influence the first path? Can you build up a picture of a food web from these lists? Think of following one substance (a nutrient, or energy as currency) through the food web. How efficiently does each part of the web use that nutrient or energy? How is each part of the web influenced by

the concatenation of multiple food chains? What are possible results of disrupting different parts of the webs? Can you think of a food web for another habitat (like the forest, stream, or field)?

- What role do humans play? What role do their dogs play? For example, consider the nitrogen cycle around the lake. Nitrogen is produced by N-fixing symbionts. Nitrogen is also produced by animals (e.g., dogs) swimming in or near the lake. The N flows: into the stream→ down the stream→through the marsh→into the lake→out of the lake. Each of these is an input-output system. Where are the N inputs and outputs in each case? What happens to the N as it passes through each particular system? What about other inputs and outputs, for example other materials, water, and energy, or organisms?
- What is the input-output unit, i.e., what is the system boundary?
  - of the Stream? Marsh? Lake?
  - of the stream-marsh-lake system?
  - of the watershed?

  What makes the system boundary (or unit of study for ecosystem dynamics) appropriate?
- Questions of scale – space and time:

  One could choose the entire watershed as the input-output unit (or system of interest). Alternatively, one could look at other smaller, interacting units. Which would be easier to deal with? What advantages and disadvantages would there be for each choice?
- What are the dominant organisms in the particular habitat or system you are looking at? What are the population dynamics of the organisms in the system? What are the successional dynamics of the system? How can we examine these various characteristics?
- Is what is dominant in each habitat now what was dominant 30 years ago? Are the habitats themselves constant? Can you predict what will be dominant 30 years from now? How might you predict what will happen 30 years from now? How in general do we examine dynamics – how things change over time? How do the changes interact? What effect does choice of scale have in answering these questions? For example, consider the similarities and differences between a mud puddle, small pond, lake, and watershed.
- Other ecological concepts that come up when asking questions about scale and dynamics include island biogeography and habitat fragmentation. Do all organisms respond the same way to fragmentation? Do all organisms respond the same way to succession? How can we look at island biogeography in terms of input-output dynamics? Population source-sink concepts apply between organisms in different habitats.

B. A walk through the park

Chapters 10 (*The Catchment Basin Systems*) and 18 (*The Ecosystem*) in your textbook should provide helpful background for Lab 1. Chapters 13 (*The Fluvial System*), 19 (*The Primary Production System*), 20 (*The grazing-Predation System*), and 21 (*The Detrital System*) as well as others, are also relevant, but give more details then you need right now.

At the park, you will take a structured walk through the forest. This is a first attempt to get you to *look at the landscape-scale system as composed of many parts that combine to form an integrated whole*. How this happens is the grand question of Ecosystem Ecology.

There are six stations, representing more or less distinct subsystems or habitats in the Forest. You will be asked to spend 15–20 minutes observing the area around each station and taking cues from the previous section, writing out questions about the structure, function, and organization of the local ecosystem. You may have difficulty with this at first, but should get the idea by the last station. Your questions are to be turned in as the homework for this laboratory. They will help you later in your modeling efforts for the course.

Station 1. Forest Ridgetop

Is this a single-aged stand? Is it a deciduous or evergreen forest? Is it dominated by one or a few species? How much sunlight reaches the ground? Does it have a vertical structure? How thick is the litter layer? What material(s) might be used as a currency ("numeraire") for this system? What is the role of wind? Of gravity? What other vegetation is there besides trees? How rapidly do resources turn over? What drives this system? Does currency created by the system remain within it or leak outside its boundary? What organisms might be important in cycling organic matter?

Station 2. Forest Slope

Most of the above questions can also be asked here. In addition, you might consider slope processes such as erosion and their impact on spatial heterogeneity

Station 3. Lake

What are the boundaries of this system? What sort of currency exchanges are taking place at the boundaries? From what sources does the lake receive inputs of energy and matter? What are the sources and rates of water inputs and outputs? Does rainfall contribute much in the way of nutrients? Do most nutrients have internal or external origin? Is there much cycling in the lake? Are there nutrient *immobilization* or *regeneration* (organic→inorganic conversion) mechanisms? What does wind do? What are the sources of primary and secondary production? Is the lake well-mixed from top to bottom, or *stratified*. Can you compare its vertical structure with that of the other communities? What about horizontal zonation? What kinds of biota are in the lake? Are they randomly or uniformly distributed, or more heterogeneous? What do they do ecologically? Are turnover rates generally long or short? How leaky of energy and matter is the system?

Station 4. Field

What is driving the system? Is there high or low species diversity? What about vertical structure? What is an appropriate currency that might be employed in modeling? How do turnover rates compare with those of the forest and aquatic system processes?

Station 5. Stream and Riparian Zone

Many of the questions for the above subsystems also apply here. How distinct are the stream's boundaries? Are the sources of its input mainly external (*allochthonous*) or internal (*autochthonous*)? What about primary and secondary production? How open is the system compared to the others? Is there vertical structure or gradients? How about horizontal? Are turnover rates fast or slow? What seasonal changes might you expect? How would these affect the biota? What are some organism adaptations that make stream life possible?

Station 6. Pond and Wetland

What are the principal inputs and outputs? Do nutrients come mainly from outside (allochthonous, exogenous) or inside (autochthonous, endogenous) the system? What can you say about species diversity? How about vertical structure? What about substance turnover rates? What components of the pond have counterparts in the forests and field? How open is this system? How much of its ecological activity is biotic as opposed to abiotic? Can you see evidence of conbiota? Is the wetland a swamp, marsh, fen, bog, or what? If nutrients come mainly from rainfall the wetland is *ombrotrophic*; if from runoff, it is *minerotrophic*.

Which do you think? How might sediment-water column relationships here differ fro those of the lake and stream?

Homework 1: In addition to considering human impacts (above), each student should devise a set of poignant questions about the structure, function, and ecological organization of the 6 subsystems visited in the Oregon Ridge Forest. What are their notable similarities and dissimilarities? To get the most benefit from this exercise it is you may want to return alone an hour or two perhaps with your textbook or other reference material in tow and quietly absorb your surroundings as you ponder the mysteries of how they became integrated, one with another. You will be graded on the originality of your questions and the breadth and depth of your field acumen as reflected in these. Also, for one subsystem **diagram a simple input-output model listing the major parts and flows** (describe the boundary and indicate your currency).

LAB 2: TERRESTRIAL SAMPLING TECHNIQUES

Goals: For students to become acquainted with terrestrial sampling methods.
For students to get an idea of which methods are appropriate to their own questions about the ecosystem.

For this laboratory exercise on terrestrial methods you will collect data on the physical environment and use various techniques to sample plants and animals in the field. We cannot, obviously, cover all methods, but only want to give you an idea of quantitative sampling for different kinds of organisms. Also, if you know of some things that we do not that may be useful, please communicate these to the group. The name of the game in systems modeling is cooperation – making use of all the available skills of everybody involved. As you use these various procedures, think about the particular system you plan to model and the currency (carbon, biomass, etc.) you will employ as a numeraire.

I. Sampling

You must know what questions you are asking before you start collecting data. Once you have a clearly defined question, implementing a sampling regime is generally cookbook. An appropriate sampling regime gives a fairly good idea of the parts composing the system given limitation of time, money, and people power.

Ecological sampling concerns collecting, identifying, and making physical measurements on organisms, and recording abiotic data. Sampling may be either qualitative or quantitative. Qualitative refers to description, or natural history. In Lab 1 you qualitatively sampled (more or less) the Oregon Ridge ecosystem, as you asked questions about the six stations. You now have an idea of the topography and the various habitats and an idea of the species present and their abundance and distribution. Although this information is useful in the broad sense, it does not help in the quantitative aspects of modeling.

Quantitative sampling (numerical, based on counts, measurements, ratios, rates of transfer, etc.) generates the numbers needed for modeling. You will not, despite your best efforts, be able to get all you need for your model, so you will have to rely on the literature and intuition. Qualitative observations enhance the latter.

The model you will be building for Project #2 is a *compartment model*, not unlike a food web. It requires that you break the system into compartments, which are abstract categories that seem to fit together. The envirogram (Project #1) is therefore designed to get you going in modeling focusing on a concrete organism. Ideally, each category forming the compartments of a compartment model is sampled to estimate the amount of currency in the compartment. These *standing stocks*, you will see, become the *state variables* of the model. Inputs and outputs to and from each compartment represent transfers of currency between compartments and with the external environment. These transfers or flows of currency are time-based measures of the rates of currency movement per unit time in and out of the compartments.

As a highly simplified example, if you are interested in measuring energy flow in a field you could break the system three compartments – grass, insects that eat grass, and birds that eat insects. For the grass compartment you need to know the standing stock of grass, the rate of accumulations (by photosynthesis and nutrient uptake), and the rate of loss (by death and consumption). Similar measurements would be taken for the insect and bird compartments. The three compartments are then linked together, with outputs from the grass compartment equaling inputs to the insects, and outputs from the insects equaling the input to the birds. You have a simple food chain: grass→insects→birds. Often the data gathered in the field only give indirect measures of the currency exchanges.

Some basic questions that can be answered by sampling are:

- What organisms are present?
- How many of them are there?
- What is their age or size-class distribution (on some organisms)?
- What changes occur over time?

Questions that more specifically pertain to modeling might include:

- How are the organisms spatially distributed (clumped, random, regular)?
- What is their production rate (how fast do they grow)?
- How much material (such as leaf litter in the forest or suspended seston in the lake) is present on an area or volume basis?

Scale (space and time) is important in sampling. The choices run in a gradient from microscopic to global and are directly related to the questions being asked. If forest heterogeneity is being studied, then one meter square plots are too small for a statewide study. A one kilometer square plot is too large for a study in Oregon Ridge Park. The entire forest would be contained within a few plots, analysis of the species composition would be extremely time consuming, and statistics would not be possible since there are too few samples. Within the forest itself, plot size would vary for studies of herb, shrub, and tree diversity.

The appendix to this handout from Brower and Zar (1984; 1a ecological sampling) deals with sampling principles. There are "3 Cs" of modeling, as you will learn, and "3 Rs" of sampling; the latter are **Randomize, Replicate, and Repeat**. *Random sampling* attempts to eliminate sampling bias. A common method to randomly sample a plot is to use a random numbers table, or a calculator's random number generator. Numbers from the table give the *x* & *y* coordinates to locate the sampling site in the plot. Each location or organism sampled has no greater chance of being chosen than any other; this eliminates any tendency to cluster or regularly group sample sites.

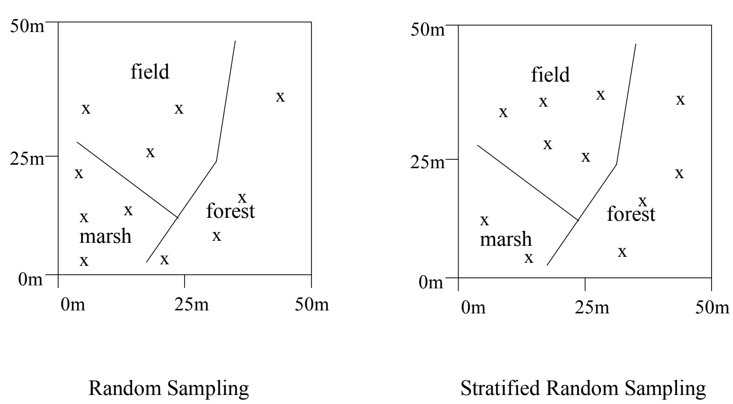

Figure 1. Representation of random sampling and stratified random sampling

Random sampling may be totally random or stratified. Suppose, at Oregon Ridge Park you are interested in the salamander population numbers in an area composed of three different terrestrial habitats. The field is 40% of the area, say, the marsh 20%, and the forest 40%. Totally random sampling does not differentiate between different habitats, whereas stratified sampling takes into account habitat size by adjusting the number of samples taken per habitat (Fig 1). Why would one sampling regime be preferable over another?

Replicating samples allows you to deal with inherent variation in each sample. If you weigh 20 mice, each mouse will have a slightly different weight for any number of reasons. When you have replicated samples, you can get mean weights and perform a number of other statistical tests on your data.

Repeatable sampling ensures that another person could take your methods, sample in the same area, and come up with similar results.

Other sections in the Brower and Zar appendix give brief treatments of two common terrestrial sampling techniques; plot (3a) and transect (3b). Plot sampling is used most frequently for terrestrial vegetation and sessile organisms. An area of known size is randomly selected and everything of interest (herb species, tree species, number of burrows, acorns, etc.) within the boundary of the plot is quantified (counted, measured, and identified). This is then replicated in a number of plots. Transect sampling may be used when plots are impracticable, when dealing with transition zones, or with mobile vertebrates. The three major transect types are belt, line-intercept, and strip census. The basis for all three is the same; a line of a given length (e.g., 50m) is marked in the field. A belt transect quantifies all vegetation of interest for a fixed distance (e.g., 5m) on either side of the transect, in effect becoming a rectangular plot. A line-intercept only quantifies individuals that touch the line directly. A strip census counts all organisms observed as you walk the transect line.

Homework 2: Lab 2 homework consists of

1. Posing some questions you can answer with the sampling techniques learned.
2. A description of results obtained performing the exercises (on a separate sheet).

LAB 3: AQUATIC SAMPLING TECHNIQUES

Goals: For students to become acquainted with aquatic sampling methods.
For students to get an idea of which methods are appropriate to their own questions about the ecosystem.

Five environments in Oregon Ridge Forest could be appropriately sampled by aquatic methods: 1) Lake, 2) Baisman Run stream, 3) the small stream near the Nature Center, 4) small pond on Ivy Hill, and 5) small wetland near the Nature Center.

I. Lake and Pond Sampling

Physical stratification of most temperate lakes occurs seasonally. The resulting temperature and chemical gradients can influence biological distributions. Bacteria and algae, which have little mobility, are distributed by water movements and can be maintained on density discontinuities in the water column. Zooplankton, consisting primarily of crustaceans (copepods and cladocerans), rotifers, and protozoans, swim and orient themselves to light, temperature, and some chemicals, such as oxygen.

Biological effects of predation by fish can influence zooplankton directly by their removal and indirectly by selecting for avoidance behaviors such as diurnal vertical migration. High quality food algae such as small flagellates and single cells can promote zooplankton population growth, while large and filamentous blue-green algae can interfere with zooplankton and can be toxic.

In the lake and pond areas, it is appropriate to sample at various depths along the entire water column since much of the heterogeneity in such systems occurs with depth. It is also appropriate, especially in the case of the Lake, to sample the water column and sediment both in the near shore environment and closer to the center of the lake. A nearshore station can be used as representative of shallow water areas. A deeper station could be sampled from a boat (if available) or from the platform. Look at the map and observe the shoreline and watershed land use while walking/paddling around.

Sampling should be done in the order specified in the sampling protocol at the end of these Lab 3 directions to avoid disrupting the vertical distribution of organisms and other characteristics. Be sure to record additional observations and standard information (date, weather, general lake conditions, time of sampling, sampling location, etc.) in your field notebook. All samples collected must be labeled with the name of the habitat, sampling station, type of sample, date, and collectors. After collection, all samples should be kept cool and shaded, as should the instruments.

From the shore additional information can be gathered, including:

- Determining the sources of input to and outputs from the lake
- Characterizing and mapping the vegetation and land uses surrounding the lake
- Whole water samples of inputs and output for water chemistry analyses and other comparisons, and
- Sampling and characterizing associated habitats.

II. Stream and Wetland Sampling

Your sampling efforts here may require some innovations, as the stream and marsh are very small. Variation will probably be found primarily along the length of the stream, rather than with depth as in the lake.

Some procedures for gathering information about the stream are similar to those used in the lake. Oxygen and temperature will still be measured with an oxygen meter. Whole water samples may still be collected for assessment of bacterial concentrations, phytoplankton, and various chemical analyses (e.g., pH, ammonia, phosphorus, chlorophyll). In the stream, whole water samples can be collected in the bottles in which they are to be stored: working from downstream to upstream, take a small sample of water to rinse the bottle and lid, pour the water onto the ground, then move slightly upstream to avoid any disrupted sediment and fill the bottle carefully. Move slightly upstream to fill the next bottle. Plankton samples may be taken with a net, placing the open diameter perpendicular to the streamflow.

Invertebrate macrofauna can be sampled by carefully turning over rocks and examining their undersides; vertebrate and invertebrate macrofauna can be sampled by placing a mesh completely across the stream flow and disrupting the habitat a bit upstream from the net (dislodging and shaking rocks, or dislodging and collecting leaves to sort through later). In a larger stream, the standard method would be to use a kick net for capturing a specific area of dislodged material.

Depending on the questions you have decided to address, you may want to sample the stream at different segments where different flow conditions prevail (riffle areas of rippling water, run areas of smooth fast water, pool areas where slow floe or back eddies predominate, or areas where leaf litter accumulates). Streams are at least as heterogeneous as lakes, so if you are looking for organisms you will want to sample several within stream habitats. Once you have identified groups of stream invertebrates, you can consult the literature to get information about the ecological roles of each group to see what processes predominate within the stream.

Measuring light penetration may be of interest to assess differences in water color or turbidity between different habitats. Keep in mind, however, that the amount of light passing though water is dependent first on the amount of light available; this can obviously be influenced by cloud cover, canopy closure, time of day, and season. Another way to compare water color or turbidity between two samples is simply to take whole water samples and compare them to distilled water in a spectrophotometer at various wavelengths (you could determine the peak absorbances of the samples and measure them at those wavelengths for a better comparison).

Sediment samples in the stream or marsh can be taken quantitatively with a wide cylindrical corer (easily made is one is not available); in aquatic systems one frequently needs to include a flat piece to cover the bottom of the sample before it is brought up. In the absence of suitable equipment, qualitative sampling can be accomplished with a shovel or spade. Note any changes in the sediment with depth: e.g., where does the anoxic layer begin? Small samples or subsamples of sediment may be stained with Rose Bengal and preserved in 95% alcohol to examine invertebrates.

Flow rates of water in the stream can be determined with a flow meter or current meter, or more roughly with a small floating device (e.g., ping-pong ball) and measuring tape. Choose a fairly straight section of the stream with smooth, approximately laminar flow rather than turbulent flow to make your measurements. With the ping-pong ball method, release the ball at the upstream end of the chosen section, and note the time required to travel to the downstream end of the section. Measure the distance traveled and the cross-sectional area of the stream to calculate water flow in terms of the volume of water passing a given point in a measured time period; report in standard units (m^3/sec).

The wetland usually only has a small amount of standing water, collecting water samples may therefore be difficult. Accessing water flow through the marsh will also be problematic, but one may be able to make some reasonable assumptions to come up with an approximation is needed.

III. A Model for Flows

Given the sampling tools you now have, you should be able to ask interesting questions about the processes occurring within habitats, between habitats, and between habitats and their surrounding environments. These measurements processes can be represented mathematically, or viewed in terms of a model. A very general input-state-output example follows from a collection of "minimodels" devised by H.T. Odum (2000).

The model is called, appropriately, TANK. The time (t) rate of change, dx/dt, of the standing stock or storage, x (a nonnegative state variable), of substance (currency) in a compartment is given as the difference between the nonnegative input flow function, z(t), and the output flow function, y(t) (Eq. 1). This basic structure: [change of state over time = input – output] has universal application for all processes. This can be refined by formulating the outflow, y(t), as a positive constant (k) fraction of the stock, x (Eq. 2):

$$\mathbf{dx/dt = z(t) - y(t)} \quad [1]$$
$$\mathbf{dx/dt = z(t) - kx} \quad [2]$$

Both sides of this (or any) equation must balance dimensionally. In the mass (M)-length (L)-time (T) dimensional system, mass storages per unit area (densities) have dimensions ML^{-2}, storages per unit volume (concentrations) ML^{-3}, and flows have dimensions of fluxes ($ML^{-2}T^{-1}$ or $ML^{-3}T^{-1}$). With this, it is apparent that each term on the left and right-hand sides of the above equation have flux dimensions, i.e., $ML^{-3}/T=ML^{-3}T^{-1} - (1/T)ML^{-3}$. Units corresponding to these dimensions might be g $m^{-3}h^{-1}$ for matter flow, and kJ m^{-3} y^{-1} for a flow of energy.

When you learn to use the STELLA software (© isee systems) you will never have to write out such an equation as the above. You will form your model with icons, and STELLA constructs the equations from your symbolic diagrams. The diagram corresponding to the TANK model is given in Figure 2.

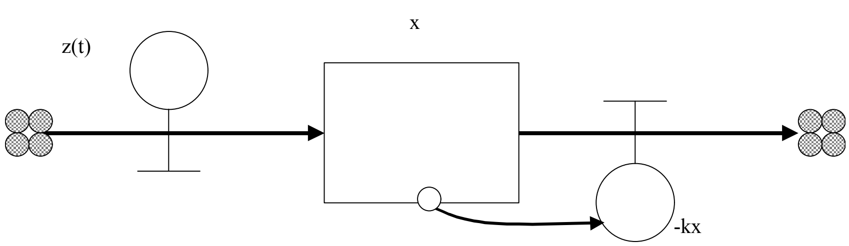

Figure 2. A model representation using STELLA-like icons. The state variable, x, receives input, z(t) and generates output, −kx.

As an example, in the case where the Lake is a storage compartment containing water, the change in the amount of water in the Lake over time is dx/dt, the input is represented by the function z(t), and the output is represented by –kx. One can measure the flow of water into the lake, z(t), and the flow out from the Lake, –kx. If one were to estimate the volume of the lake (x) by bathymetry and surface area estimates, then one could then solve for k. Note, that this same simple model could be used to explain the water level in your washbasin, or the dynamics of any currency in any storage and flow system.

After establishing the simple model, we could add another input term to it to represent rainfall, and another output term to represent evaporation. Input from rainfall can be estimated by putting out a simple rain gauge (volume of water collected in a cylinder divided by the area of the cylinder's opening) and extrapolating to the area of the watershed that directly drains into the Lake. Flow into and out of the Lake will probably also change after a rain. Since we know that dx/dt must, at equilibrium, come to zero because of the drainage system in the lake, we can estimate the rate of evaporation taking place from the surface of the lake. Physical constants for evaporation given measurements of temperature, surface area, and relative humidity can be found in tables and used to calculate evaporation rates. Many numbers can be derived indirectly when making models, with a little ingenuity.

An aquatic model could also be integrated with a terrestrial model using the same currency – in this case water. For example, water theoretically available to the lake from the surrounding watershed may be lost to transpiration by forest vegetation instead. How might you incorporate this expenditure of water into your budget?

Monthly averages for temperature and rainfall from the nearest weather station could be used to create a seasonal or annual water budget for the lake. One could also build a more complete water model for the whole set of aquatic habitats available at the Oregon Ridge Park by treating each habitat as a subsystem or compartment within a larger model. You can visualize the linking up of such diagrams as the above, or, implicitly, their corresponding equations. One might want to consider the input of the entire watershed in such a model.

While we have discussed water as the currency in this example, it is worth noting that any measurable conservative substance can be used as a currency to construct a model. However, you will need to employ the same currency throughout, or be able to convert between them is multiple currencies are used. It is especially worth noting that if the rates of water flow (volume of water movement) in a chosen aquatic system are known, then any chemical parameter (for example, nitrogen) measures at appropriate points within the system can be put in those terms also (i.e., stated in amounts rather than concentrations). This is often much easier to work with in a model.

Homework 3: Lab 3 homework consists of

1. Posing some questions you can answer with the sampling techniques learned.
2. Constructing balance equations for the state variables in one of the subsystem models you constructed in Homework 1.
3. A description of results obtained performing the exercises (on a separate sheet).

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References

Baltimore County Public Schools. History of Oregon Ridge 1720-2001, Center for Archaeology.

Godfrey, MA. 1982. *A Sierra Club Naturalists Guide: The Piedmont*. Random House, Inc.

Maryland Geological Survey. Maryland Department of Natural Resources. Retrieved May 14, 2017. www.mgs.md.gov/geology/

Odum HT. 2000. Modeling for All Scales: An Introduction to System Simulation. Academic Press.

Watson JW, Hoffman PF, Schaetzl RJ, Zelinsky W. 1999 (last revised 2016). Encyclopedia of Britannica. Retrieved May 14, 2017. www.britannica.com/place/North-America/13-billion-to-950-million-years-ago#ref469373.

White ID, Mottershead DN, Harrison SJ. 1992. *Environmental Systems*, 2nd Edition. Stanley Thornes, Ltd., London.