Causal Patterns in Ecosystems

Lessons to Infuse into Ecosystems Units to Enable Deeper Understanding

Second Edition

The Understandings of Consequence Project
Project Zero, Harvard Graduate School of Education

This module was originally created by Tina Grotzer with contributions from Kiki Donis, Sarah Mittlefehdlt, Rebecca Lincoln, Rebekah Gould, and Dorothy MacGillivray. This second edition contains updates and additional resources developed by Tina Grotzer with assistance from Jacob Holzberg-Pill and Sean Kramar. It has also benefitted from conversations with Megan Powell, Therese Arsenault, Erin Carr, Matt Shapiro and Amy Kamarainen. We had additional support from many talented individuals. David Perkins provided insightful comments on the nature of the causalities involved. Belinda Bell Basca, Susannah Shaw, and Margot Sudbury assisted in analyzing the data that we collected on the efficacy of teaching the concepts in these lessons. Susan Mattson, Dan Perlman, and Kass Hogan offered helpful comments on the biological aspects of the work. Dorothy MacGillivray provided invaluable editorial and design assistance. The teachers in the Burlington, MA schools, especially Mary Ann Bernstein, Elaine Sheehan, and Anita Mason worked with us to test the concepts with their students. We thank the many students who shared their ideas and thinking with us. Finally, in memoriam this edition is dedicated to Esther Kiviat, without whose inspiration many years ago, the lead author may never have pursued this line of inquiry.

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INTRODUCTION

This introduction provides an overview of the module. It gives a rationale for why it is so important to teach the concepts presented here and makes suggestions for how to encourage a classroom culture that supports the development of the understanding goals of the module.

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Overview

This curriculum module contains lessons to be infused into a broader unit on ecosystems. It is divided into eight sections. Each section addresses one of a set of broad and persistent misunderstandings that students have about ecosystems. These misunderstandings stem from how students reason about the nature of causality. The module sections introduce understandings about the nature of causality in ecosystems that students need to develop in order to overcome the misunderstanding and to deeply understand ecosystem concepts. Research shows that students who are taught about the nature of the causal patterns while learning science achieve a deeper understanding than students who are just taught the science.[1]

The sections are formatted as follows. Typically, a section contains one main activity that is the equivalent of one lesson. Some activities are spread across multiple lessons. Additional reinforcement activities are provided. Background information is given to help teachers recognize the misunderstanding and how it typically shows up in students' reasoning about ecosystem concepts. Each section includes a list of goals for understanding the subject matter and the nature of the causality involved. The sections are sequenced to build understanding but with minor adjustments can be used out of order to accommodate the needs of individual classes. The module is aimed at upper elementary but can be modified for use with other ages.

The lessons include a special set of activities called RECAST activities. These activities are designed to REveal CAusal STructure or help students RECAST their understandings so that they fit with the causal patterns that scientists use. RECAST activities have outcomes that do not fit with what students typically expect, so they can be an impetus for students to restructure their understandings.

The curriculum is designed around *best practices in science education*. Lessons include inquiry-based activities that ask students to make observations and construct understandings. Lessons begin by having students examine their current beliefs. Student discussion is a central activity and teachers are encouraged to create an environment where students are comfortable sharing their ideas. Through discussion, students will realize that science involves revising one's ideas based on the relevant evidence to best explain the phenomenon in question.

Challenges in Understanding Ecosystems

Research shows that students have difficulty understanding certain ecosystems concepts because they don't reason about causality in the same ways that scientists do. So even if students are taught accurate information, they tend to structure the information differently and end up distorting it. Experience alone does not help students understand how to structure the concepts. Students need support to get beyond the cognitive hurdles involved. The activities in this module are designed to provide this support. The following sections outline the difficulties that students face. These include learning to understand different patterns of causality as well as a set of related supporting causal concepts.

Understanding Different Patterns of Causality

Understanding ecosystem relationships as scientists do involves reasoning about forms of cause and effect that most students are unfamiliar with. Students typically reason using simple linear cause and effect, where one thing directly makes another thing happen. However, understanding ecosystems involves more complex patterns of causality. This module introduces domino, cyclic, and two-way patterns of causality.

- ***Domino Causality***. In a domino pattern, a triggering event initiates a domino of effects that in turn act as causes to precipitate further effects.[2] Domino causality is important for understanding the process of energy flow in food webs and the important link from the sun to green plants as the source of that energy. It offers a means to think about the far reach of certain events within an ecosystem, such as when the producers die out and have no replacements.

- ***Cyclic Causality***. In a cyclic pattern, a cause precipitates an effect that in turn has an effect on the initial cause. For instance, in ecosystems, plants grow and then die. Decomposers decay them and release nutrients within the plant back into the soil affecting the growth of other plants.

- ***Two-Way Causality***. In a two-way pattern, one event or relationship has mutual, and often simultaneous, effects. Each component has an effect on the other, so each acts as both an effect and a cause. For instance, two-way causality can be seen in symbiotic relationships where an event or action (such as a bee pollinating a flower) results in effects on both organisms (the bee and the flower). It differs from a cyclic model in that the focus is on how one event (a bee pollinating a flower) or relationship (a tick sucking blood from a dog) has mutual, and typically simultaneous, effects (bee gets nectar and flower gets pollinated or tick gets nourishment and dog is weakened). Some two-way relationships might also involve cyclic causality if viewed over the long-term relationship.

Students' tendency towards simple linear causal reasoning makes it unlikely that students will notice these more complex causal patterns on their own. They tend to miss the connectedness within systems, noticing direct, but not extended domino patterns.[3] Similarly, they tend to break cyclic patterns apart into linear patterns, thus missing essential parts of the relationship. They often miss two-way causality, by focusing only on one side of the equation and not noticing the other side, or (as explained later) focusing on individual organisms rather than at a population level.

Understanding Related Causal Concepts

Recognizing the causal patterns outlined above is complicated by a set of related concepts that are usually hard for students to grasp. These are outlined below and include indirect effects, time delays, non-obvious causes, reasoning about populations, reasoning about balance and flux, and applying particular causal patterns.

- ***Indirect effects.*** Ecosystems are characterized by connectedness, and in ecosystems, causes often have many indirect effects. Students tend to focus on direct effects to the exclusion of indirect effects. This reinforces a simple linear causal model and makes it unlikely that students will notice extended food chain or food web relationships.

- ***Time delays***. There are often significant time delays between causes and effects in ecosystems.[4] This can make it difficult to trace an effect back to its cause, or even to see the pattern of causality involved. For example, time delays make it harder to recognize indirect, extended effects in domino patterns. Students might realize that the first set of effects is related to a cause. However, the further along an effect is on the domino, (i.e., the further the effect is removed in time and space from its cause), the harder it is for students to notice the effect and to realize that it is connected to the precipitating event. It is common for natural systems to have checks and balances that dampen effects, slowing the appearance of obvious effects. So for instance, the environment may be able to absorb a certain amount of pollution before any obvious effects appear, but eventually there will be enough accumulation that the effects become dramatic.

- ***Non-obvious causes***. Ecosystems also involve non-obvious causes—ones that are hard to detect with the naked eye. Non-obvious causes can make it difficult to recognize that certain causal patterns exist. For instance, recognizing the cyclic model in decay involves recognizing tiny microbes as the primary decomposers. (It also involves dealing with the time delay in nutrient recycling). Students typically do not understand the nature of decay[5] and the role of microbes as decomposers and recyclers of carbon, nitrogen, and minerals.[6]

- ***Reasoning about populations***. Understanding ecosystem dynamics involves reasoning about what will happen to populations of organisms. A population refers to all the members of a species that live in a particular location. Reasoning about populations is hard for students. When analyzing food chains, they typically think of *the* predator eating *the* particular animal as prey, not the population of predators preying on the population of prey.[7] Reasoning about individuals often leads to feeling sorry for the prey. This makes it hard to see the food web relationships in terms of checks and balances.

  It can also make it hard to see particular causal patterns. For instance, recognizing some two-way patterns involves switching one's focus between individuals and populations, as in the following example. Mice provide energy for owls, while owls might help to maintain population size levels in the mice that can be supported by the available resources. So when an individual mouse is eaten, it does not benefit the individual. However, the mouse population, as viewed from an outside perspective, might be better off. On the other hand, the individual owl and the population of owls benefit.[*]

- ***Reasoning about balance and flux***. Ecosystems involve both balance and flux. Typically, studies of ecosystems *stress* balance. Indeed there is a great deal of redundancy and ability to adapt in ecosystems that provides balance. However, ecosystems typically include some fluctuations as well. Flux is not necessarily negative: it can create patterns in an ecosystem that are ultimately healthy. For instance, it can allow for new species to become established. Students typically reason that flux or change is bad. This can make it difficult to detect the role of flux in positive outcomes.

- ***Applying particular causal patterns***. Ecosystems involve many complex causal patterns. Students may be confused about where to apply particular patterns. For instance, it is common for students to confuse the process of energy transfer with the process of matter recycling. Energy transfer is domino-like. Green plants convert energy from the sun into a form that is usable by organisms in the food web. Energy is transferred along the food web. Energy is lost all along the way (it turns into other kinds of energy, i.e. heat energy and other forms of energy that can't be eaten) and any remaining energy dissipates as heat energy in the process of decomposition. Matter recycling is cyclic and involves reducing matter to its most basic parts, which can then re-enter the living world. Matter is conserved rather than lost.

- ***Reasoning about steady states.*** Often students are inclined to reason about events that they see happening. However, reasoning about ecosystems involves reasoning about steady states across time and monitoring those steady states. This requires a shift in how we pay attention to the environment and what we notice at any given time.

Helping students to understand the causal patterns in ecosystems and to master the related causal concepts makes it possible for them to achieve deep understanding of ecosystem concepts. The activities in this module aim to support students' developing understanding.

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*Most ecologists use the individual as the level of analysis in reasoning about natural selection. Each mouse wants to maximize its relative reproduction within the population. You could say that all populations want to maximize their relative ecological importance; however, the intentions are attributed at an individual level and the actions are carried out at an individual level. Therefore, reasoning about cumulative systems effects involves a puzzling juxtaposition of thinking about individuals and populations as "agents," although they differ substantially in how one would attribute goals and intentions. Individuals can be said to have intentions, whereas populations do not. Agency at the population level is an emergent property.

Instructional Approach

The activities in this module are best supported by a classroom culture that fits with the following suggested actions:

- Encourage students to take risks in their thinking and to test their ideas in a social context. No ideas should just be shot down. Instead relevant evidence should be considered.

- Encourage students NOT to accept ideas just because someone else says that they are so. Students should change their ideas when they find that the evidence is convincing.

- Emphasize developing understanding and the importance of transferring understanding to new contexts as opposed to *right answers*.

- Seek opportunities to engage students in scientific inquiry. The process of learning should mimic the process of discovery that scientists engage in. However, not all learning can be inquiry-based or constructivist. Students also need exposure to the models that scientists have evolved during centuries of scientific inquiry.

- Recognize that students come to class with general principles about how the world operates as a result of their own attempts to make sense of the world. Offer opportunities for them to reflect on their own thinking.

- Encourage testing and revising one's thinking over *getting it right*. Students who adopt the *right* model without deeply reasoning it through are likely to revert to their less evolved models as soon as the unit ends.

- Help students to realize that no model explains everything about a particular phenomenon. Each model has ways in which it fits and ways in which it does not fit with the concept. Critique models as a regular part of classroom discussions. Some models have more explanatory power than others, but no model captures the whole idea.

Suggestions from Teachers

Below is a list of suggestions from teachers who have tested the module.

- "Revisiting activities in the earlier lessons after completing later lessons resulted in much deeper understanding for my students. This was especially so for the Web of Life Game [Section 1]. It gave them a good basis that they expanded upon when we did the activities again."
- "It's important to think about how you time the unit. For instance, make sure that you set up the worm tanks well in advance of the end of the year and before the unit ends so you are able to include the findings in the unit discussions [Section 3]."
- "I used white boards to have students create causal diagrams, for example in the story about parachuting cats into Borneo [Section 6]. That way they could modify them easily as they understood more about the situation."
- "My students kept notes in their science journals so that they could go back and revisit previous activities after they had learned new things."
- "I had my students do lots of drawing and writing as a way to see how they were making sense of the ideas. Even though some of the ideas are complex, I had a good sense of what my students understood and they grasped a lot more than I would have predicted."

A Warning About Allergies

A number of activities in this unit involve having students observe decomposing organic matter and in some cases, touch soil or a decaying log. If you have any students with severe mold allergies, you may need to modify their participation or substitute a different activity.

Endnotes for Introduction

[1]For a review of research related to learning about ecosystems see Grotzer, T. A. & Bell-Basca, B. (2000, April). *Helping Students to Grasp the Underlying Causal Structures when Learning About Ecosystems: How Does it Impact Understanding?* Paper presented at the annual conference of the National Association for Research in Science Teaching, New Orleans, LA.

[2]Grotzer, T. A. (1989). *Can children learn to understand complex causal relationships?: A pilot study*. Unpublished qualifying paper. Cambridge, MA: Harvard University.

Grotzer, T. A. (1993). *Children's understanding of complex causal relationships in natural systems*. Unpublished doctoral dissertation. Cambridge, MA: Harvard University.

[3]Griffiths, A. K., & Grant, B. A. (1985). High school students' understanding of food webs: Identification of a learning hierarchy and related misconceptions. *Journal of Research in Science Teaching*, *22*(5), 421-436.

Smith, E. L., & Anderson, C. W. (1986, April). *Alternative conceptions of matter cycling in ecosystems*. Paper presented at the Annual Meeting of the National Association of Research in Science Teaching, San Francisco, CA.

[4]Leach, J., Konicek, R., & Shapiro, B., (1992, April). *The ideas used by British and North American school children to interpret the phenomenon of decay: a cross-cultural study*. Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, CA.

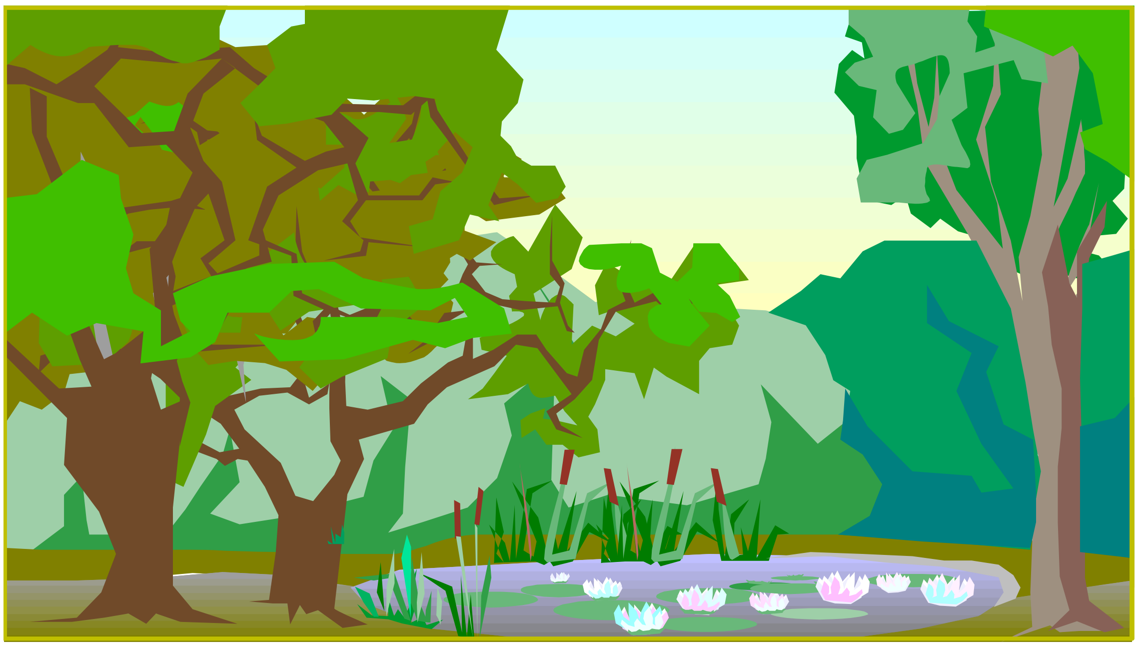
[5]Webb, P. & Boltt, G. (1990). Food chain to food web: A natural progression?. *Journal of Biological Education*, *24*(3), 187-190.
Leach, et al., 1992.

[6]Brinkman, F., & Boschhuizen, R. (1989). Preinstructional ideas in biology: A survey in relation with different research methods on concepts of health and energy. In M.T. Voorbach, & L.G.M. Prick (Eds.), *Teacher Education 5: Research and Developments in Teacher Education in the Netherlands*, (pp. 75-90).

[7]Leach, J., Driver, R., Scott, P., & Wood-Robinson, C. (1996). Children's ideas about ecology 3: Ideas found in children aged 5-16 about the interdependency of organisms. *International Journal of Science Education, 18*, 19-34.

SECTION 1

Understanding the Connectedness of Ecosystems Using Domino Causality



This section addresses students' tendency to focus on direct effects to the exclusion of indirect effects. It introduces domino causality to help students detect indirect effects of ecosystem events. It reveals that the transfer of energy in a food web is domino-like.

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Understanding the Connectedness of Ecosystems Using Domino Causality

Understanding the Connectedness of Ecosystems Using Domino Causality

This section engages students in a game and related discussion to help them understand that the transfer of energy in a food web is domino-like.

Understanding Goals

Subject Matter

- An ecosystem is a combination of living things in a community and the non-living things in the physical environment surrounding them (biotic and abiotic factors).
- Different organisms in ecosystems need certain things to survive, such as water, air, soil, food and sun.
- Organisms in an ecosystem can be put into three categories: producers, consumers and decomposers.
- There is interconnectedness in an ecosystem, and changes in one population in an ecosystem may cause changes in other populations in that ecosystem.
- Energy from the sun is transferred in a domino-like pattern.

Causality

- Causes can have direct and indirect effects.
- Causes can have far-reaching effects.
- A seemingly small precipitating cause can have extensive effects.
- In a system, isolated effects are uncommon.
- Effects often appear to propagate in domino-like patterns including ones that branch or radiate out.

Background Information

A Connected Community

The activities in this section are designed to help students understand the connectedness within ecosystems. An ecosystem is a community of different types of living things (organisms) and their physical environment (including sunlight, rocks, soil, water, hills, holes, etc.) The organisms in an ecosystem interact just as people interact in a school. Each organism has a role (or "niche") in the ecosystem. Each living thing in the ecosystem depends on other living things.

The sun plays a critical role in the ecosystem. It provides the energy for all life on Earth and thus all Earth's ecosystems. Plants convert sunlight to make their own food, which they use to support their own lives. When animals eat plants, they eat this "ready-made" food, formed from energy originally provided by the sun. The sun's energy is thus passed along to them. In this way, the sun's energy fuels every living thing. Plants are called *producers* because they produce or make their own food. Animals are called *consumers* because they consume (eat) food but do not produce it on their own. There are different kinds of consumers: those that eat only plants are called *primary consumers* or *herbivores*; those that eat only animals are called *carnivores*; and those that eat both plants and animals are called *omnivores.*

Some organisms in the ecosystem are called *decomposers*. They decompose or break down dead matter by digesting dead plants and animals. (In this sense, they are also consumers.) They break down dead matter into basic materials, which are recycled into the soil and become nutrients that can be used by plants and some other living things. Therefore, they play an essential role in the ecosystems.

Food Chains

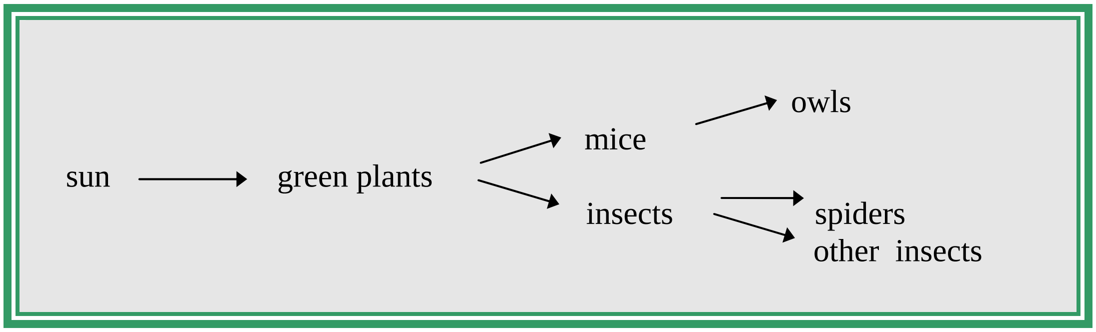
Students are usually taught about ecosystem feeding relationships in terms of food chains. For instance, they are shown a food chain beginning with the sun or green plants and extending to secondary consumers (those consumers that eat the organisms that eat green plants). Food chains address one of the difficulties that elementary students tend to have when reasoning about ecosystem relationships. Students usually focus on simple linear or direct effects (one thing makes another happen). For instance, students realize that the green plants are important to the organisms that eat green plants. However, students often don't detect indirect connections. It is common for students to reason that the green plants are not important to the things that don't eat them even if those things eat things that eat green plants. Learning about food chains helps them to see the domino-like pattern and to move beyond simple direct effects to indirect effects.

Food Webs and Domino Causality

The activities in this section introduce domino causality to help students move beyond noticing only direct effects. Domino causal models describe how, like dominoes falling, effects can in turn cause other effects. The dominoes can fall in different types of extended patterns, for instance branching or radiating. For branching patterns, events closer to the "stem" have a greater effect on the rest of the branch than ones that are further away. In radiating patterns, one event can have many direct and indirect effects.

Domino causal models provide a way to visualize more extended patterns of cause and effect. They enable students to organize more information about the system. These patterns are some of the easiest causal patterns for students to learn. However, without direct teaching, many students will not learn to recognize them.

The activities in this section also introduce food webs. Like food chains, food webs illustrate the domino-like patterns of indirect effects. Learning only about food chains can reinforce a short sighted, linear view of how ecosystem members affect each other. Students are likely to miss more extended domino-like patterns, such as branching and radiating ones. A food web shows the broader energy transfer relationships within an ecosystem. It can help in predicting how changes in a population will affect other living things.



An Example of a Food Web: Branching Domino Pattern

It is important to realize that focusing solely on domino patterns is not the answer to students' difficulties either. An overemphasis on domino patterns can make it harder to detect other types of patterns such as cyclic or two-way patterns. The trick is to help students learn different types of causal patterns (simple linear, domino, cyclic, and two-way) and when each type applies.

There are at least three other concepts that give students difficulty in understanding feeding relationships in ecosystems: The direction of the arrows, overemphasizing connectedness, and reasoning about populations vs. individuals.

The Direction of the Arrows

The arrows in a food chain or food web go from the thing that is being eaten to the thing that eats it to show the transfer of energy. When students try to reason about food webs, they often reverse the direction of the arrows to show what eats what.[1] They reason about "active", more easily visualized aspects of what happens (this eats this) rather than "passive", less easily visualized aspects (this gains energy from this). Students can be encouraged to use the arrows to "point to the mouth of the thing that eats it"[2] to help them construct the arrows in the right direction.

Missing Our Critical Link to the Sun

Some students miss our critical link to the sun. They believe that plants get their food from the soil. This seems logical in so many ways. It is difficult to picture a distant object such as the sun being the source of food for producers when there is no visible link to help students believe that there is a connection between the sun and plants. Fertilizer is often referred to as "plant food"—underscoring this notion. Some students who do know about the sun believe that once plants have energy from the sun they can recycle it in the soil indefinitely.

Overemphasizing Connectedness

It is possible to take the connectedness message too far. There is enough redundancy and flexibility in food webs that not all seemingly harmful or disruptive events adversely affect food web members.[3] Once students understand the basic idea of connectedness, this caveat can be introduced. Section six provides resources to do so.

Reasoning about Populations vs. Individuals

Young children find it hard to reason about populations as opposed to individuals.[4] When creating a food chain, they think of the predator as eating the particular animal as prey, rather than each animal representing a population of animals. It is important to reinforce the understanding that the food web shows how populations of organisms interact. Even though one organism is pictured or talked about, the whole population is being represented.

Lesson Plan:
Exploring The Web of Life

Materials

- Index cards (large size)
- Pictures of organisms in an ecosystem and their diet information: Sun; Green Plants; Insects; Mice; Toads; Owls; Snakes; Skunks; Fungi; Earthworms
- Yarn or String

Prep Step

- Read the background information.
- Review the lesson plan.
- Assemble the cards. Photocopy the pictures of organisms (pp. 31-35) and glue them to index cards.
- Cut yarn or string into pieces long enough so that when tied to the cards, students can put them over their heads and wear them around their necks.
- Cut 25 pieces of string or yarn to different lengths between 3 and 8 feet.
- Punch holes in the index cards and tie yarn or string through the holes.
- Read over the step-by-step directions (p. 28) for creating the *Web of Life*.
- Read the *Picture of Practice* (p. 25) to familiarize yourself with what to expect from the lesson.
- Photocopy the sheets, *What is Domino Causality?* (p. 38) and *A Forest Food Web* (p. 37) for each student.

Reveal and Analyze Thinking

Step 1: Define an Ecosystem

Ask, "What is an ecosystem?" Gather ideas. Arrive at a class definition. It should include the following ideas:

- An ecosystem can be thought of as a community consisting of different populations of living things. (A population refers to all the members of a species that live in a particular location.)
- An ecosystem includes the physical environment.
- Organisms fill different roles or "niches" in the system.
- Living things in the ecosystem depend on other living things in the ecosystem.

Step 2: Consider the Physical Environment

Discuss the necessities of the physical environment for an ecosystem. List students' ideas on a chart, which may include:

- Sunlight
- Water
- Soil (specifically the nutrients in the soil)
- Air
- Food sources for various organisms

Step 3: Consider How Organisms in an Ecosystem Are Important to One Another

Explain: Each living thing in an ecosystem can be put into one of three categories: Producers, Consumers and Decomposers.

Ask, "Do you know what produce means? What about *to consume*? What about *to decompose*?" Explain the importance of each group in the ecosystem, highlighting their interdependence.

Ask, "How are organisms in an ecosystem important to one another? Do not have the students answer the question out loud, but ask them to think about it in their own minds.

Pass out the sheet asking them to draw a food web. As the students are working, circulate to see what they have included in their food web. Notice whether they have included the sun and decomposers. Check to see which direction they have drawn the arrows in their food web.

RECAST Thinking

Step 4: Introduce the Web of Life Game and Construct the Web

Explain: We are going to play a game that will show how each living thing in an ecosystem relies on other living things to survive. Find an open area. Gather the students around it. Use the diagram on page 28 for step-by-step instructions on how to build the food web.

Note to the Teacher: In larger classes, you will have observers and students who are acting out the web. Teachers who have had a lot of success with this activity ask the students who are not participating as food web components to help direct the activity by telling their classmates what connections to make, making predictions, and discussing the "why" behind what happens.

Begin with the card with a picture of the sun on it. Give it to a student. Ask, "Which organisms rely directly on the sun for their food?" As students identify organisms (in this case, the green plants), give the green plants card to another student. Have the student wearing the sun card hold the end of the yarn and the student wearing the green plants card hold the other end.

Then move on to the green plants. Ask, “Which organisms rely directly on the green plants for their food?” Refer to the information on each card. Some students may not realize that only plants can make their food directly from the sun. You may need to introduce this fact.

As organisms are identified, add them to the food web and then add those organisms that depend upon them for food. Go through the cards in the following order: sun, green plants, insects, mice, earthworms, toads, snakes, owls, skunks, and fungi. Repeat the questioning and constructing until all of the connections have been made.

Step 5: Analyze the Connectedness of the Web

Draw students’ attention to the complex web that has been created with the strings. Ask, “What might happen if the owls disappeared?” Not much would happen. Fungi would have less dead matter.

Ask, “What might happen if the mice disappeared?” Owls, snakes, skunks, earthworms and fungi would be directly affected. Other organisms would be indirectly affected.

Ask, “What might happen if the green plants disappeared?” Everything except the sun would be affected.

Have the student who has the card for green plants sit down and gently tug on the strings that he or she is holding except for the one connected to the sun. Anyone who feels a tug on their string should sit down to show that they have been affected. Then those students should gently tug on their strings and anyone who now feels a tug on their string should sit down and so on.

Ask, “What does this demonstration show?” If the organisms’ food source is affected, they will be affected. Sometimes animals can turn to a different food source, but if the green plants disappear, everything will die. They are our link to the energy from the sun. What would happen if the sun did not fuel the web? There would be no energy in the entire web. Have the students return to their seats.

Step 6: Introduce the Forest Food Web Diagram

Hand out *A Forest Food Web* sheet (p 37). Explain that it shows the relationships in an ecosystem such as those illustrated in the game. Emphasize that the arrows on the food web show what gives energy to something else. They do NOT go from the *eater* to the eaten. Say, "You can remember the right direction by having the arrow go from an organism to the mouth of the thing that eats it."

Explore Causality

Step 7: Contrast Simple Linear and Domino Causality

Say, "Usually when we describe how things happen, we use simple linear or simple direct cause and effect. We say that one thing directly causes another thing to happen. For instance, green plants cause there to be energy for the mice."

Introduce the concept of domino causality. Explain that in domino causality, effects cause new effects just like in dominoes falling over. Set up some dominoes and show how one falls down and knocks down the next one and that one causes another one to fall over, and so on. Causes create effects that in turn become causes. This is important because it shows that ecosystem events can have indirect as well as direct effects.

Pass out the sheet entitled *What is Domino Causality?* for your students to read. Discuss the sheet as a class and address any questions that they have. Consider the *Questions To Think About* together.

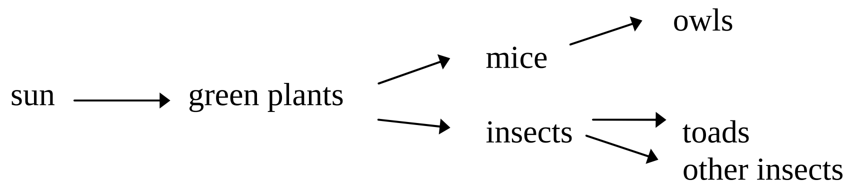
Step 8: Show How Domino Causality Explains Food Chain and Food Web Relationships

Explain that the relationships in a food web are like dominoes. One thing causes another thing, which causes another thing. For instance, the green plants cause energy to be available for mice, which cause energy to be available for owls, and so forth. If something happens to the green plants, it causes there to be no energy from green plants for mice, and that in turn causes there to be no energy from mice for owls. The term *food chain* is often used to talk about a row of dominoes that are set up in a straight line to describe a linear set of connections such as this.

green plants ⟶ mice ⟶ owls

Note to Teacher: You can create a set of dominoes using the pictures included in this section for the Web of Life Game. It would help to have duplicates of some organisms (mice, insects, toads, earthworms).

But just like with dominoes, sometimes the rows branch out in different ways. Set up some domino examples that have branches in them. For instance:



This is the difference between a food chain and a food web. In a food web, the dominoes branch or radiate out so that there can be many effects of one cause when certain dominoes fall. This web describes what happens in an ecosystem better than a food chain does.

Discuss with students how important the link to the sun is. The energy from the sun is converted into food energy by green plants. As it is passed along the food web, energy is lost. (It is converted to heat energy, which can’t be used for food.) When things decay, the remaining energy becomes heat energy that is dissipated into the environment. (The processes of life, such as growing, eating, and even sleeping, require energy and when this energy is used, heat is always a by-product.)

Step 9: Differentiate Between Matter and Energy

Explain that energy is different from matter. Matter is what things are made of—actual particles called atoms. Matter gets recycled during decay. (Section 4 focuses on this). You can't see energy. It doesn’t get recycled. Instead, as it is used, much of it gets transformed into heat energy. Eventually, so much of what was available is transformed to heat that there is no more to be used by living things. Therefore, our link to the sun is crucial because it is the first domino in the set and it represents a virtually unlimited source of energy. When we talk about energy, we explain the patterns with domino causality. When we talk about matter, we explain the patterns with cyclic causality (Section 2 focuses on this).

Even though they are different things, once matter and energy enter the living world and become “food,” they “travel together” in a sense. This should become clearer to students as they play the *Nutrient Cycling Game* in Section 2.

Review, Extend, and Apply

Step 10: Extend the Concepts to Other Ecosystems Discussions

Summarize the ideas in the lesson by revisiting the Understanding Goals. As students do other food web activities, have them consider how domino causality is involved. Consider doing some of the reinforcement activities.

Reinforcement Activities

Food Web Critique Activity Sheet (p. 51) —Pass out the page with the food web. Have the students list the things that it does well and the things that it does not do well. They should notice that it does some things well, for instance, the arrows go in the right direction to show energy transfer. They should notice that it does not do other things well, for instance, it does not include the sun or decomposers and many of the organisms are listed as individuals, not species.

Food Web Dominoes — Students set up dominoes to illustrate food web feeding relationships. Then they explore what will happen as certain ones are knocked over. Instead of always knocking over the first one, students should be encouraged to experiment with knocking over different ones. A variation is to set up a complex branching system and to challenge a classmate to predict what will go over and what will not when certain dominoes are pushed. You will need to create a set of dominoes with pictures of the sun and food web organisms. Large size dominoes can often be found in stores that sell games. The pictures for the *Web of Life* cards (pp. 31-35) can be copied and glued to the dominoes.

Food Web Connections Game (p. 39) — Students aim to construct food webs with as many levels and connections as possible. Each player gets six cards to set up in a web. These cards may be producers, consumers and decomposers. Players draw cards in turn and add them to their food web, while trying to build extensive connections as well as multiple levels of connections. Students will quickly discover that the producer cards are important to have. When the cards run out, whoever has the web with the most levels and/or connections wins. Students are encouraged to consider a set of reflection questions to help them see how aspects of the game mimic food web interactions. Detailed directions and playing cards can be found at the end of this section.

Replaying The Web of Life Game — When you have completed the lesson, or when you are further along in the module, replay *The Web of Life* game using the language that students have learned to talk about the relationships in terms of food webs, domino cause and effect, food chains, and so on. Encourage students to view the entire web collapsing as similar to a set of dominoes where the first one is pushed and many branching connections then fall, too. What events can students come up with that could cause such a collapse? Another possibility is to play the game again, this time having the students direct each other.

Measuring the Heat in a Compost Bin — An excellent way to see where some of the energy from the sun "ends up" after it goes through the food web domino is to take the temperature of the thermal energy in a compost bin and to compare it to the air temperature or to the temperature of other solids in the vicinity. Discuss with students where they think the heat comes from. Help them to see it as a transformation of some of the energy that was transferred through the food web.

Where Does the Energy Come From? (p. 52) — Pass out the sheet with the caption from a yogurt container which reads, "Some of the energy used to make this yogurt comes from the sun." Have students answer whether they agree or disagree and explain why. Next have students focus on Part II asking whether they agree that they are solar-powered. Have them explain their reasoning.

Discussion Guides (p. 53) — There are three discussion guides in this section to help you discuss with your students issues that may arise: 1) Thinking About Predator-Prey Relationships; 2) Thinking About Energy Transfer/Conservation in Food Webs; and 3) Connectedness vs. Insurance in Food Webs.

Resources for Section 1

Picture of Practice

Draw a Food Web Sheet

Web of Life Game

  Teacher Preparation
  Game Cards

A Forest Food Web

What is Domino Causality? Sheet

Food Web Connections Card Game (Reinforcement Activity)

  Teacher Preparation
  Directions
  Game Cards

Food Web Critique Activity Sheet

Where Does the Energy Come From? Activity Sheet

Discussion Guides

Endnotes for Section 1

Picture of Practice

Learning About Extended Effects in an Ecosystem: 5th Grade Lesson On Domino Cause and Effect

In this lesson, fifth graders are exploring the relationship of organisms in an ecosystem. Through a classroom discussion following the Web of Life game, they discover that an ecosystem can be described as a food web and that cause and effect relationships extend beyond the notion of a food chain. Here we look in on some of that conversation.

Ms. Nolan shows the students some dominoes.

- Ms. Nolan: How many of you have played with dominoes before? Who can describe how they work?
- Becca: You set them up in a line so that one hits another and knocks it down, and that one hits another and another and another.
- Ms. Nolan: Okay (*setting a few dominoes up and knocking them over to illustrate Becca's idea*) Now I want you to take some time to think about how these dominoes might be like the food web we created in the game. (*She gives the students think time.*) What do you think?
- Jake: It's just like, if this falls down, like pretend it's an animal that dies, then the other animal that eats it will fall down. Then that animal will die because it doesn't have that animal to eat.

Ms. Nolan sets up a string of dominoes.

- Ms. Nolan: So, let's pretend that this domino here is the green plants, and this one is the mice and this one the snakes. If the green plants die (Ms. Nolan knocks down the green plants), what happens to the mice and the snakes?
- Emma: They'll die, too?
- Ms. Nolan: Yes, sometimes it might look more like this. (*She sets up the dominoes to create a system that has two branches radiating from the green plants, and creates some connections from there.*) Now, here are the green plants. Here are insects that eat green plants, but here are the mice that also eat green plants. And on this side are the toads that eat insects, and over here we have snakes that eat the mice. Now what will happen if the green plants fall?
- Carlos: They'll all fall.
- Ian: But they won't all fall because the toads could still eat insects. They don't eat green plants.
- Olivia: Yeah, but the insects won't be there because they need the plants.
- Ian: So the toad can eat dead insects.
- Jake: And once he eats them all up what will he do?
- Ms. Nolan: Well, let's think about this. If we had the green plants but all of the insects disappeared, maybe the toad could find some other food to eat, as Ian is suggesting. Animals do sometimes change their diet. But remember that the green plants have a special name for their role. Can anyone remember what it was?

Picture of Practice

Continued from previous page

- Katie: Producers
- Ms. Nolan: Right, because they are the only ones who can take the energy directly from the sun. So what does that mean?
- Jake: If they disappear, the other things will, too.
- Ms. Nolan: (demonstrating by knocking down the dominoes). Everything else would fall like dominoes. It might take a little while, but that's what would happen. Okay, earlier when we were using the cards and string to create our ecosystem, someone said this was like a spider's web. How is it like a web?
- Jake: Because when we connected all the things that ate each other with strings, it was all connected, like a web.
- Hannah: It's like a food chain.
- Ms. Nolan: Some people call it a food *chain* and some people call it a food *web*. How is it a food chain?
- Tyler: Because one thing eats another thing, right down the line like a chain.
- Ms. Nolan: Right. That's like I showed you in the first example where we had the green plants, mice and snakes. But calling this a food web is another way of thinking about this. A food web is like what I showed you in the second example where I had to put my dominoes in more than just one row, more like a web shape to show how knocking down the green plants wouldn't just knock down just the insects, but other things that eat green plants too. So a food chain is one good way to think about it, but a food web tells us more about how things are connected.

Ms. Nolan writes "Domino Cause and Effect" on the board.

- Ms. Nolan: People call this kind of food chain and food web "domino cause and effect". What do you think they mean by that? Let's start with cause. What's a cause?
- Jack: A cause is something that makes something happen.
- Ms. Nolan: Okay. And an effect?
- Jack: An effect is what happens.
- Ms. Nolan: Okay, an effect is the thing that happens because of the cause. So, a cause is the thing that makes something happen and an effect is the thing that happens. (Setting up two dominoes). If I push this one and it makes the next one fall like this, this one is the cause that made it fall. Now if I set them up like this (setting up four dominoes) and I push this one down and they all fall, what would you say about the cause and effect?
- Emily: Well, the first one is the cause because it made the next one fall down. But then that one made the other one fall, and the other one. So those are causes too.
- Ms. Nolan: Right. This one made the next one fall, which made the next one fall, which made the next one fall. This is what we call "domino cause and effect." It's a good way of thinking about how the energy from the sun affects all of the things in the food web and what would happen if the green plants that make the link to the sun disappeared.

Draw a Food Web Activity Sheet

Name________________________________

Owls, insects, skunks, mice, toads, and earthworms are all found in an area near the school. Draw and explain the food web that includes them. Choose a few other things to include in your web to make the very best food web that you can. As you are drawing, think about what a food web needs to be sustainable. Also, think carefully about how you connect the parts of the food web and what those connections show. Include a key below to help others interpret your food web.

Key:

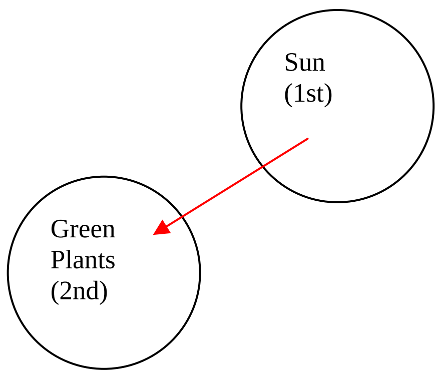
Creating the Web of Life
Teacher Preparation

Follow these instructions for constructing the web. As you create the connections, be sure to ask students what each creature eats and what connections should be made.

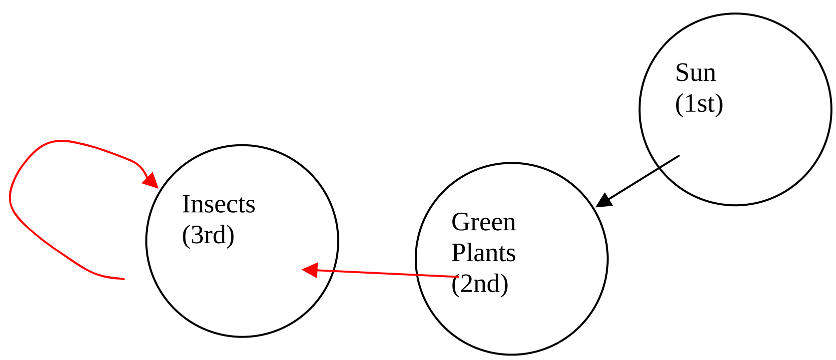
Hint: Use short strings to make connections between students who are standing close to one another and save the longer string for connections where students are standing farther apart.

---

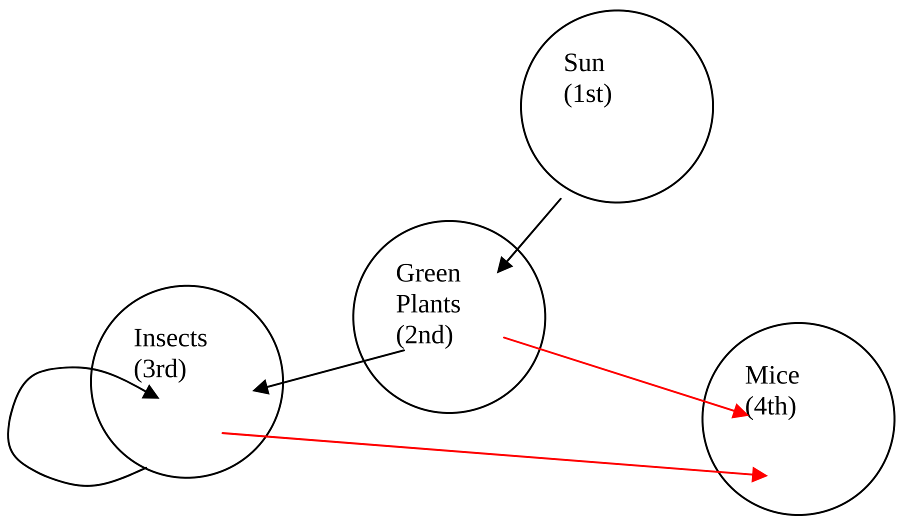
1. Start with the Sun.
2. Next hand out the green plants card. Connect the sun and green plants by having the students with those cards each hold one end of a piece of string. Connections added at each step are shown in red.



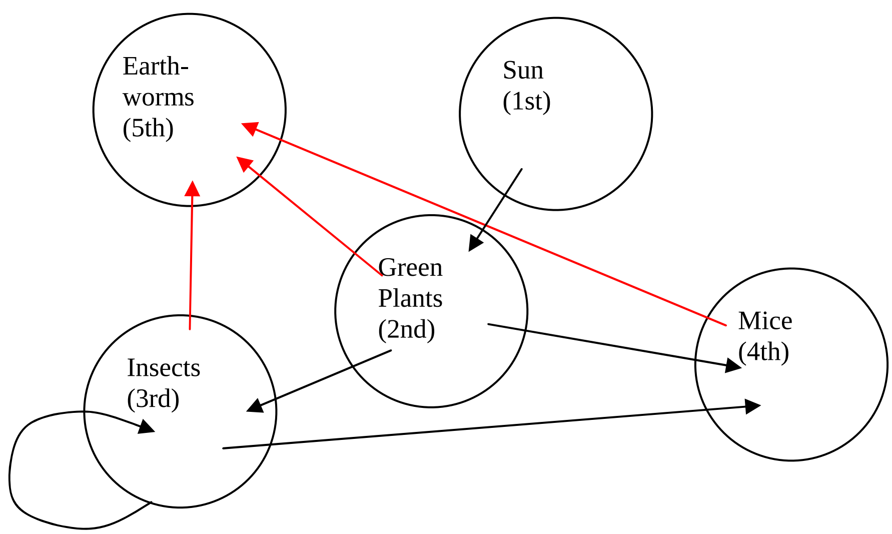
3. Next hand out the insects card. Connect the insects to the green plants by again having the students with those cards each hold one end of a piece of string. Because insects provide energy to other insects, this student should hold both ends of a separate piece of string, making a loop as illustrated below.



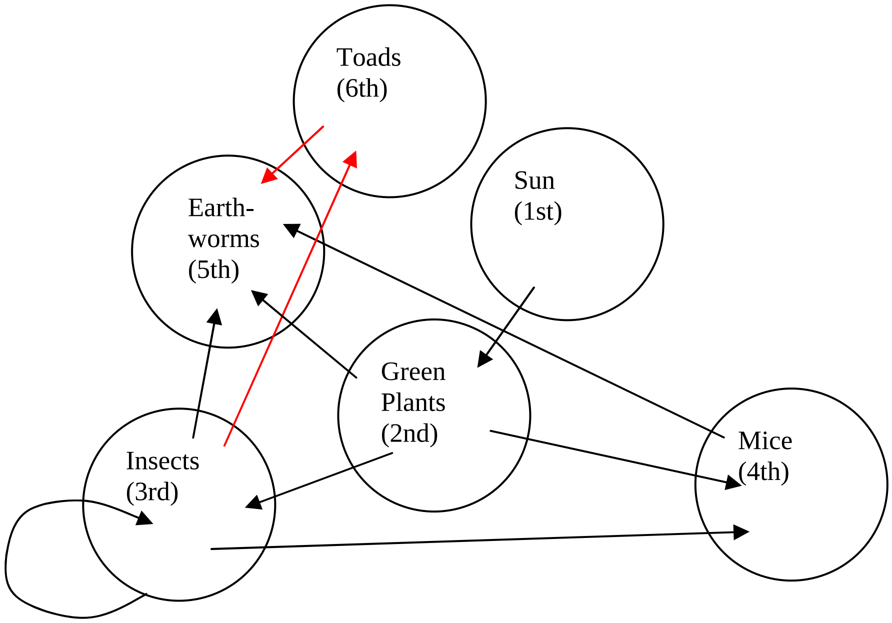
4. Now hand out the mice card. Again, connect the mice to the organisms from which it gets energy.



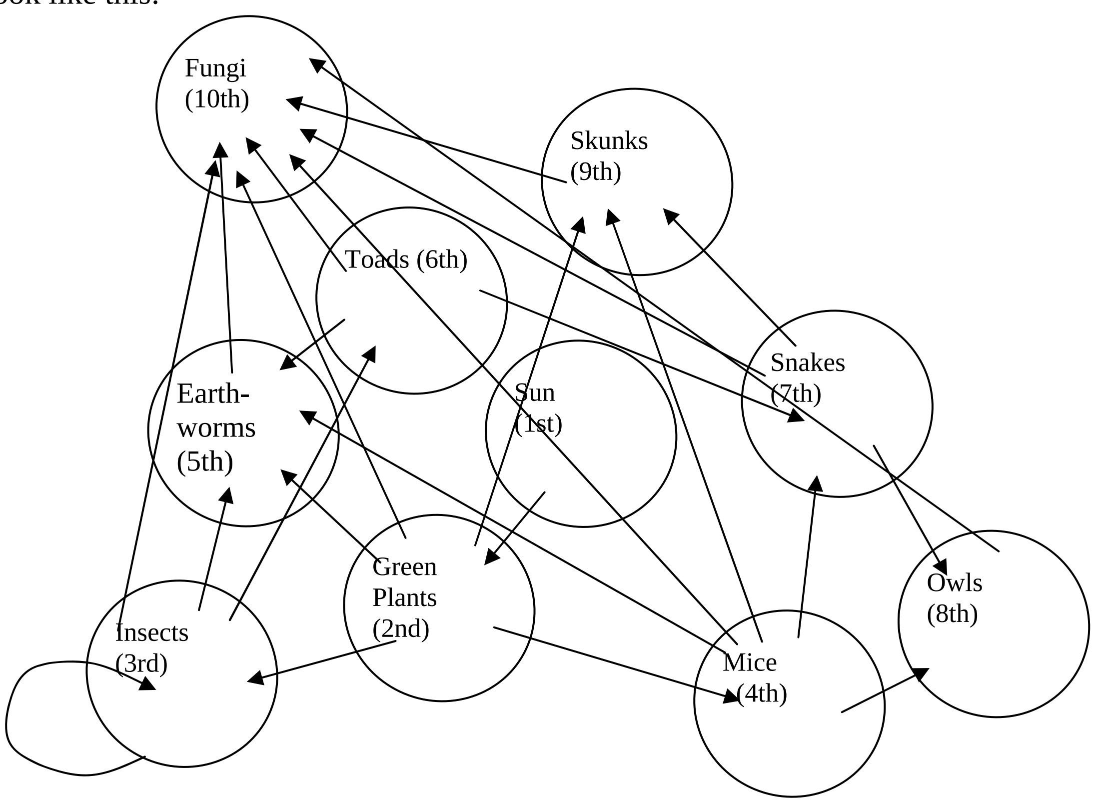
5. Now add the earthworms card. Connect the earthworms to organisms from which it gets energy.

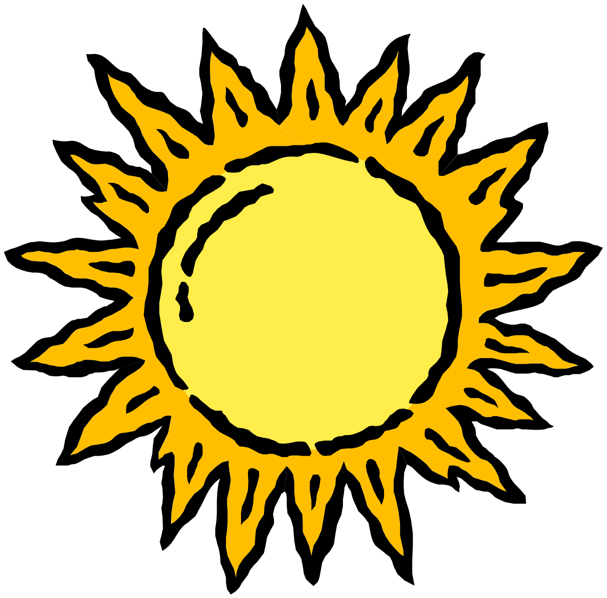


6. Now add the toads card. Connect the toads card to organisms which provide energy to it and to organisms which it provides energy to.



7. Continue adding cards in the following order: snakes, owls, skunks, and fungi. Continue to connect the organisms that receive energy and give energy to one another with the pieces of string. When all the cards have been given out the "web" should look like this:

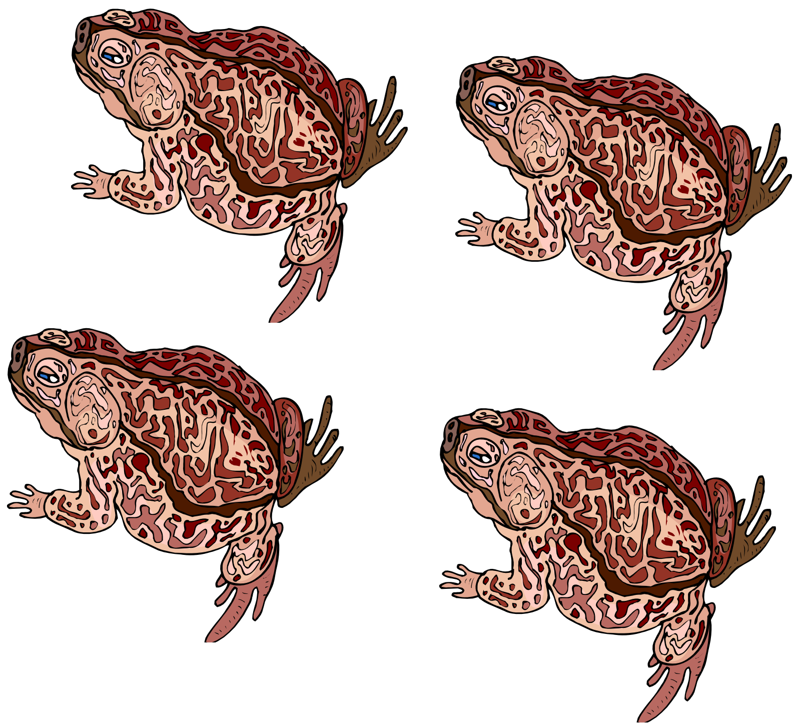




The **sun** provides energy in the form of light

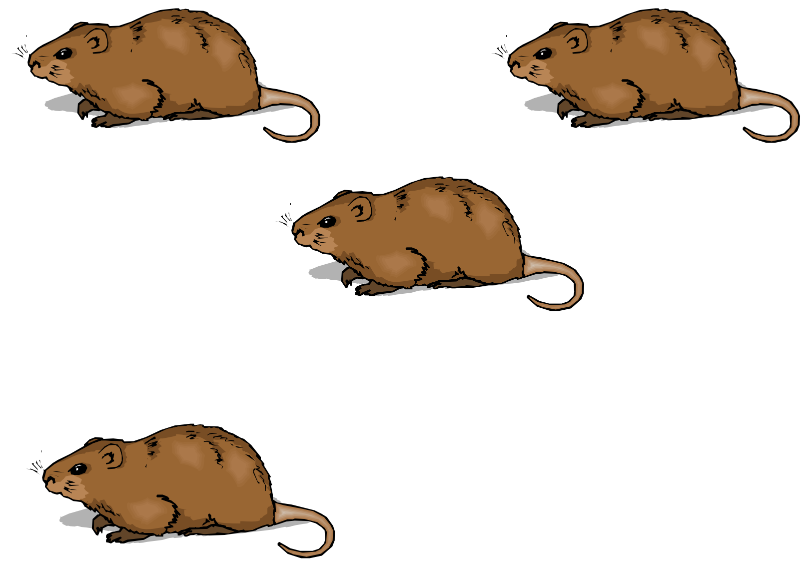
Green Plants: (or parts of green plants such as seeds and berries)

Green plants make their own food using energy from the sun. They get things that they need to grow from the soil.



Toads eat:

Earthworms
Insects

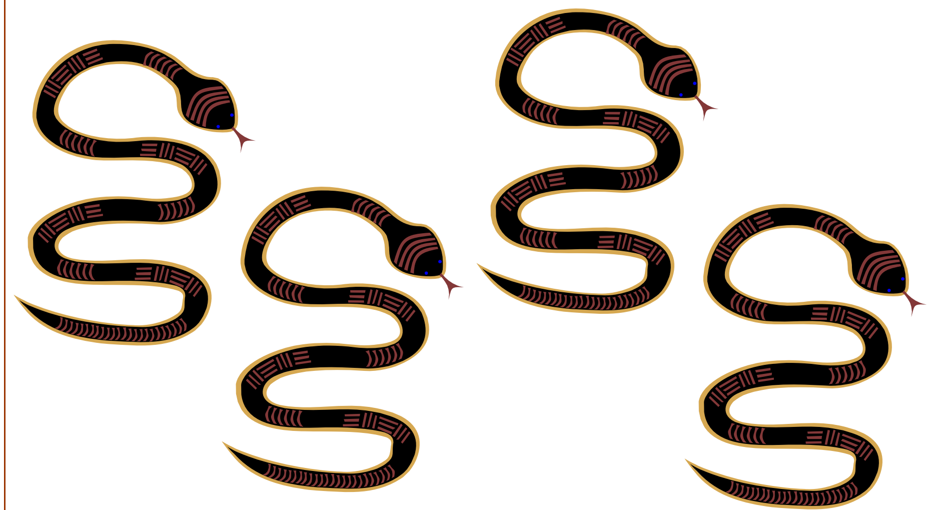


Mice eat:

Green plants
Insects

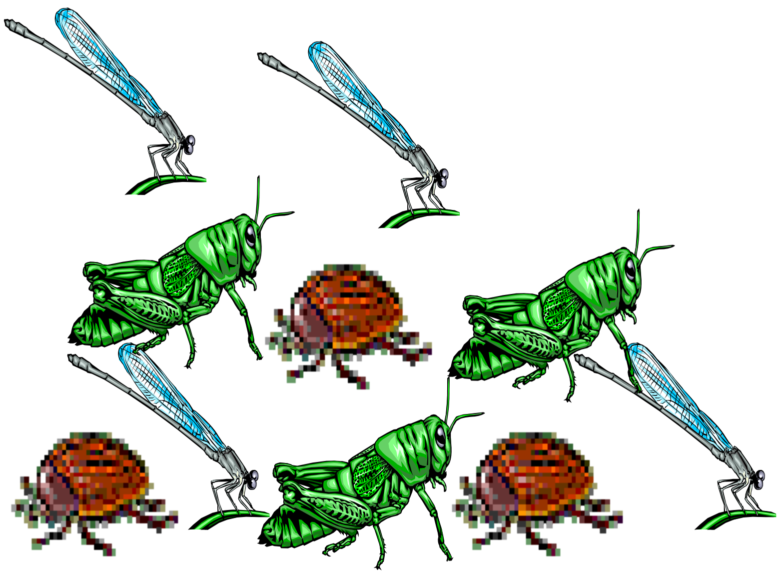
Owls eat:

Toads
Snakes
Mice



Snakes eat:

Toads
Mice

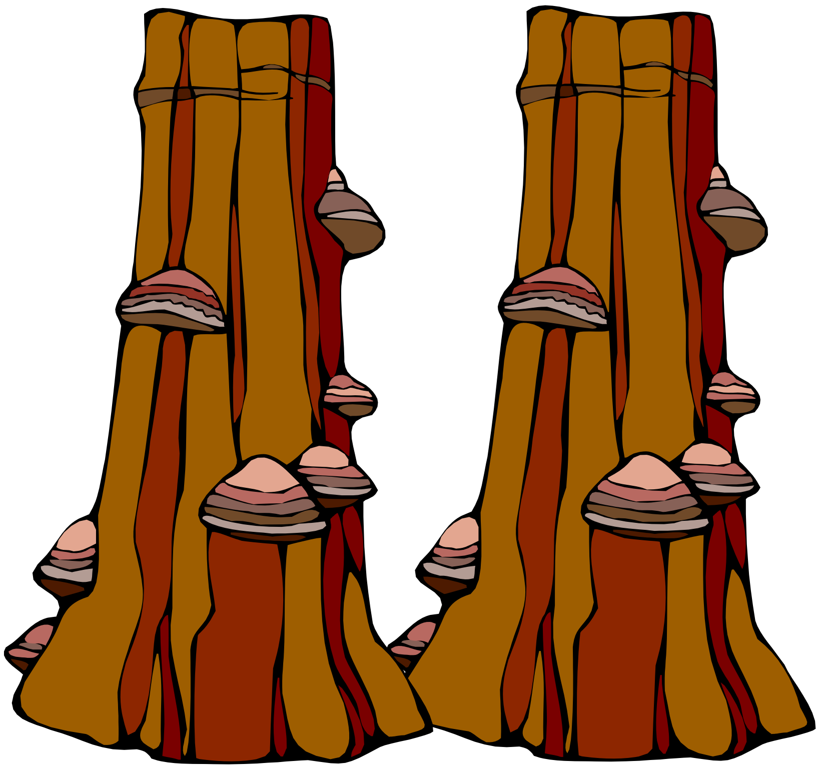


Insects eat:

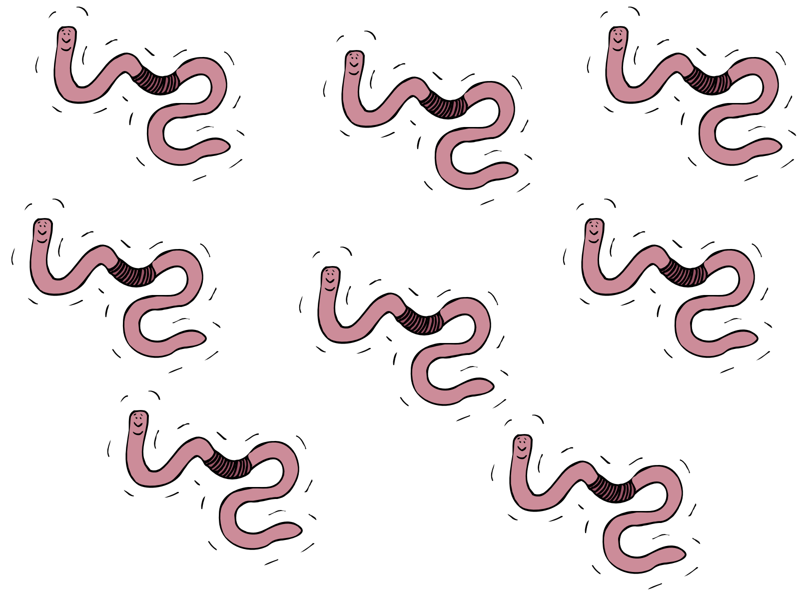
Green plants
Other insects

Skunks eat:

Mice
Green plants
Snakes



Fungi cannot make their own food. It gets energy by breaking down dead matter.



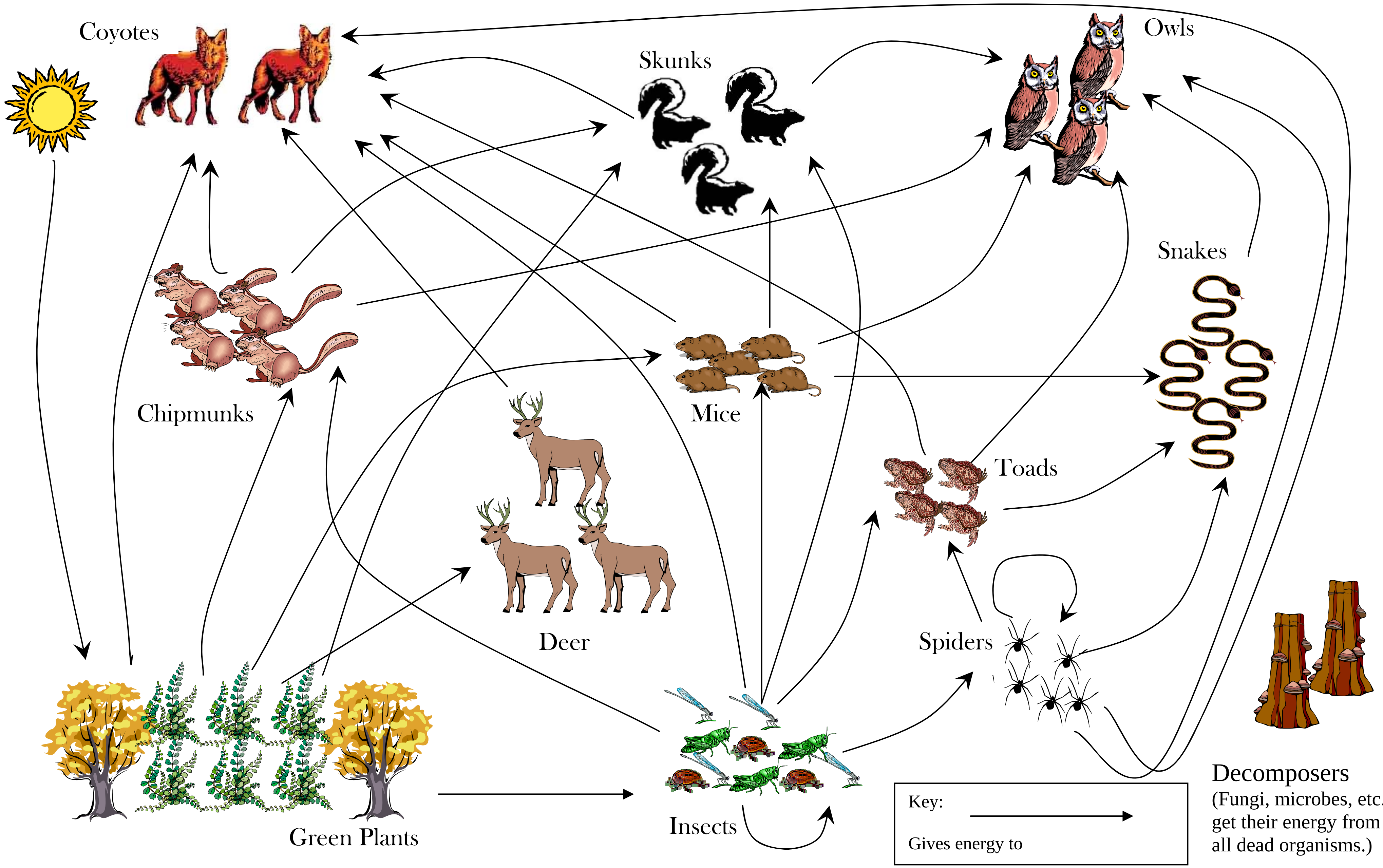
Earthworms eat:
Dead things (plants, insects and animals)

A FOREST FOOD WEB

How is this food web different from food webs that you typically see?

This food web on the following page emphasizes ***populations*** by illustrating more than one of each type of organism. Most food webs depict one organism to represent the population. However, this may exacerbate a difficulty that students already have. Students tend to focus on the fate of individual animals rather than populations.[5] So when looking at a food web diagram, they are unlikely to realize that the one animal represented really stands for a whole population of animals. This food web attempts to make it clear that the interactions are between whole populations.

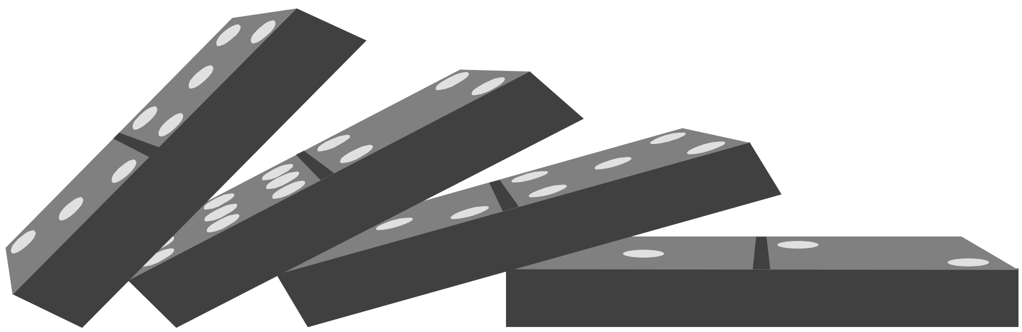
A Forest Food Web



What is Domino Causality?

If you have ever played a game of dominoes, then you are familiar with the patterns that they create. One domino causes the next domino or set of dominoes to fall down. Those dominoes, in turn, cause other dominoes to fall, and so on.

Dominoes are interesting to think about in terms of cause and effect. This is because when dominoes fall, the falling is both an effect (of the domino that fell into it) and a cause (of the fall of the next domino). This is true for all of the dominoes except the last one (which is just an effect.)



When we think about cause and effect, we often think that things are just causes or just effects. In simple linear causality, one thing directly makes another thing happen and the effects end there. But it is VERY common for effects to become causes of new events. For instance, imagine that school is let out early because of snow. This affects the students who get to go home early. That in turn affects parents who may need to leave work early to care for them. That may affect people who were planning to meet with the parents and so on. The effects branch out in many directions. We call this "domino causality."

Domino causality happens in science, too. For example, think about food webs. If the green plants die out, it indirectly affects the entire food web.

Questions to Think About

1. How is Domino Causality different from Simple Linear (or Direct) Causality?
2. What examples of Domino Causality can you think of?

Food Web Connections Game
Teacher Preparation

Materials

- 64 Food Web Cards (including consumer, producer and decomposer cards)
- 20 Interact! Cards

Background

Students often have difficulty understanding the extended domino-like connections within a food web. Students think about the way in which one organism affects another directly without thinking about how events on one level can indirectly affect organisms on another level. They also tend to think about the connections in an ecosystem in a linear fashion, or a straight line, and therefore are more likely to envision a food chain. This game aims to reinforce the notion that organisms within an ecosystem are related in complex ways. This game also encourages players to think about the important role of producers and how organisms at the lower levels affect higher order consumers.

Goal

The goal of the *Food Web Connections Game* is to create a food web with at least five levels (decomposers, producers, and three levels of consumers) and the greatest number of connections.

Getting Started

- Create the playing pieces:
    1) Copy or print out the Food Web Connections Cards. Make 2 copies of page 44, and 3 copies each of pages 45 and 46 (a total of 64 cards) for each set of students.
    2) Copy or print out the Interact! Cards. Make 2 copies each of the Interact! Cards on pages 47, 48, 49, and 50 (a total of 40 cards) for each set of students. Cut cards and laminate if possible.
- Break your students up into groups of 4, or have 4 students work on this game as a separate activity.
- Each group needs one set of Food Web cards and one set of the Interact! cards.
- Have your students find a space on the floor or a round table where they can place many cards.

Playing the Game

See *Food Web Connections Game Directions* on page 41 for instructions on how to play the game.

Strategy Questions

1. Is it important to have producers in your web? Why?
2. If you had a choice between choosing a card to place on a level where you already have many cards and a level where you only have one card, which should you choose? Why?
3. Is it better to extend your web to higher levels or make sure that you have enough cards at lower levels to support the ones above it? Why?

Follow-Up Questions

1. Do you think the food web members needed producers (plants) to be in the game? Why? Is this true of a real ecosystem?
2. Do you think the game could be played without decomposers? Why? Would that work in a real ecosystem?
3. Can you think of a way that mice and plants are connected in a food web? What about earthworms and owls?

Food Web Connections Game Directions

Goal

The goal of the *Food Web Connections Game* is to create a food web with at least five levels and the greatest number of connections.

Getting Started

- Play the game in groups of four.
- Each player should draw six cards from the food web pile. The remaining food web cards should be mixed in with the Interact! Cards to create a draw pile.
- Make a place for the “discard” pile.
- Arrange your cards into a web of up to five levels starting from the bottom and working your way up. At the bottom, put any decomposers in your hand (molds, fungi, sow bugs, earthworms, mushrooms). They are at the bottom because they recycle nutrients needed by plants to grow. Above the decomposers, on the second level, put any producers (green plants) in your hand (grasses, strawberry plants, poison ivy, oak trees, white pines and pine cones, milkweed). They make their own food using energy from the sun. The next three levels are organized by who eats whom. On the third level, above the green plants, put any primary consumers—those consumers that directly eat green plants (moths, ants, caterpillars, crickets, beetles). In the fourth row, put any secondary consumers—organisms (shrews, mice, toads, bats) that eat primary consumers. Above them in the fifth row, put any tertiary consumers—organisms (bats, owls, skunks, snakes, foxes) that eat secondary consumers. Use the box below as a guide.

Level 5 Tertiary Consumers	Bats, owls, skunks, snakes, foxes Eat ↓
Level 4 Secondary Consumers	Shrews, mice, toads, bats Eat ↓
Level 3 Primary Consumers	Moths, ants, caterpillars, crickets, beetles Eat ↓
Level 2 Producers	Grasses, strawberry plants, poison ivy, oak trees, white pines and pine cones, milkweed. Make food using energy from the sun
Level 1 Decomposers	Molds, fungi, sow bugs, earthworms, mushrooms Recycle nutrients that benefit plants

- If any of the Food Web cards that you draw do not have a connection to another part of your food web, put them into the discard pile. For example, if you have an owl card but no mouse or shrew (something the owl can eat) the owl must be put back into the draw pile because it has no place in that web.
- If you don't draw a producer card (plants) at the beginning, there can be no food web, so you lose all your cards. You still draw one card from the pile on each turn. Once you draw a producer, you can start building your food web. Until then, you must return your cards to the discard pile. (*Can you guess why this is part of the game?*)

Playing the Game

1. The player with the lowest number of food web members goes first. If there are two players with the lowest number of cards, the player whose birthday will be coming up next starts. Then the person on their right goes and so on.
2. Each player in turn draws a card from the mixed pile. If you draw a Food Web card, find a place to attach that card to your food web. If there is no place to attach it (something it really eats), then return it to the pile. Plants are automatically connected (because they make their own food from the sun.) If you draw an Interact! Card, follow the instructions on the card. When you are finished with the Interact! Card, put it in the discard pile.
3. If you lose your producers (plants) during the game, then you lose your entire food web and have to begin again.
4. If you have only one card left on a level of your web and another player takes it, the levels above it go back into the draw pile.
5. If you do not have decomposers, you can still play. *(How is this like what happens in nature and NOT like what happens in nature?)*
6. Play until all the cards in the mixed pile are gone.
7. At the end of the game, the player with the most levels in their web wins. If there is a tie, the tie is broken by who has the most cards in their web. (*In nature, food webs do not actually have to have many levels to survive.*)

Questions to Think About

1. Is it important to have producers in your web? Why?
2. If you had a choice between choosing a card to place on a level where you already have many cards and a level where you only have one card, which should you choose? Why?
3. Is it better to extend your web to higher levels or make sure that you have enough cards at lower levels to support the ones above it? Why?

Once you have learned the game, try playing with these alternative rules:*

Decomposer Rules:

Instead of placing the decomposers at the base of the pyramid, players will keep all decomposers to the side of their web (aligned on the vertical axis). Since decomposers have the ability to recycle matter, add a rule that reads “Each time you get 3 new decomposers in your pyramid, you may recycle one organism from the discard pile”

Options: This rule could only be for plants since technically they directly benefit from the soil, but could also be played with any organism to make it more fun.

Have the students invent a version of the game that reveals their ecosystems knowledge. For instance, by making the cards more related to the ecosystems and vary the types of interaction cards:

Instead of “take a producer from an opponent's web”, the card would read “Your ecosystem received more sunlight and rainwater than your opponent's, take a producer from their web” or instead of “give a decomposer to an opponent”, “Give a decomposer to the opponent with the greatest amount of discarded organisms.”

Or by introducing alternative cards that emphasize the idea of biodiversity:

“A rich source of bat food source has just moved into your ecosystem, all the opponent's bats migrate to your ecosystem.”

“A lumber yard has just opened within your ecosystem. Put all your trees into the discard pile.”

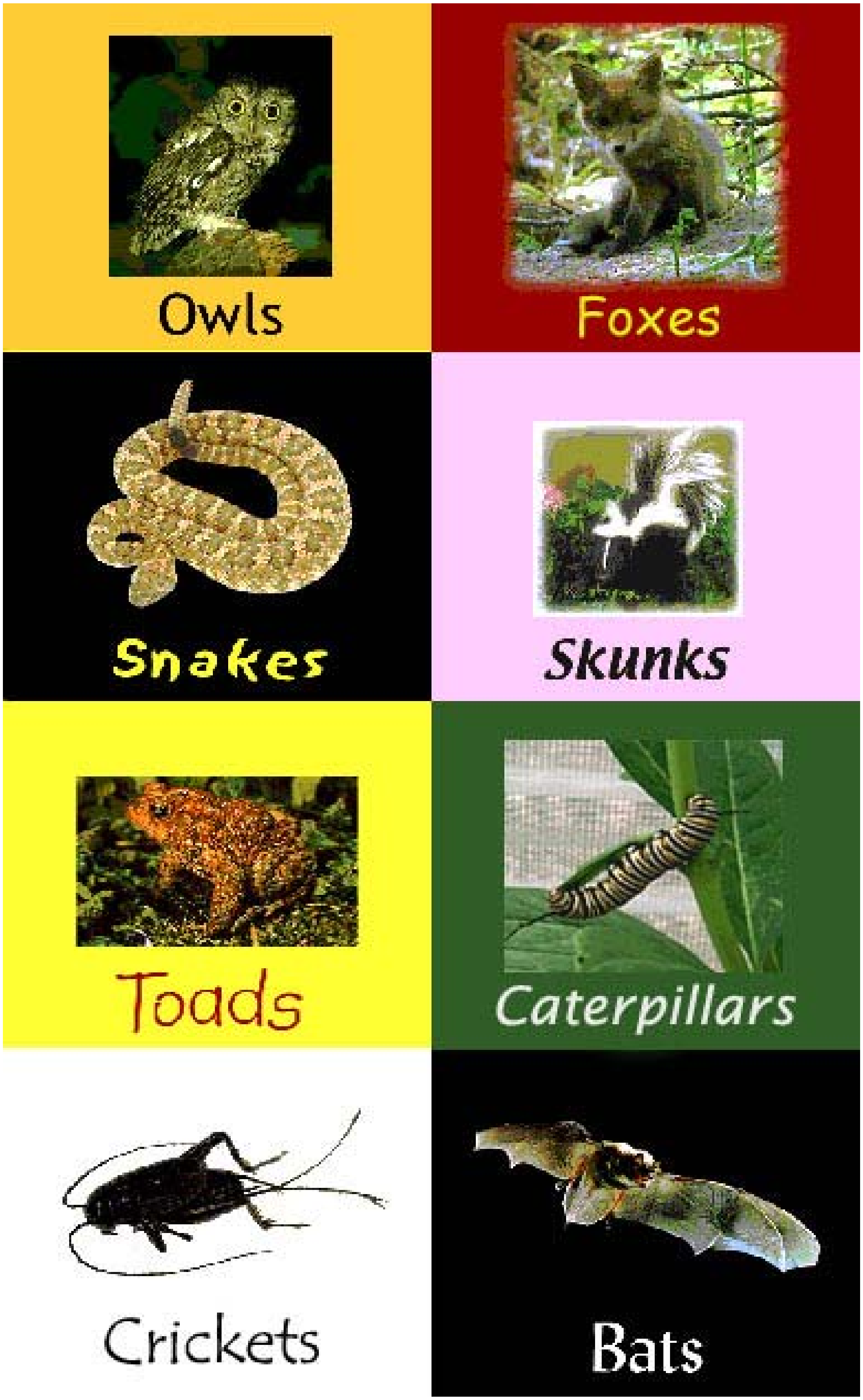
“A blight has spread throughout your ecosystem killing all strawberries, grasses and milkweeds.”

“A rodent disease has just struck your ecosystem killing all shrews, mice and bats.”

Population Dynamics:

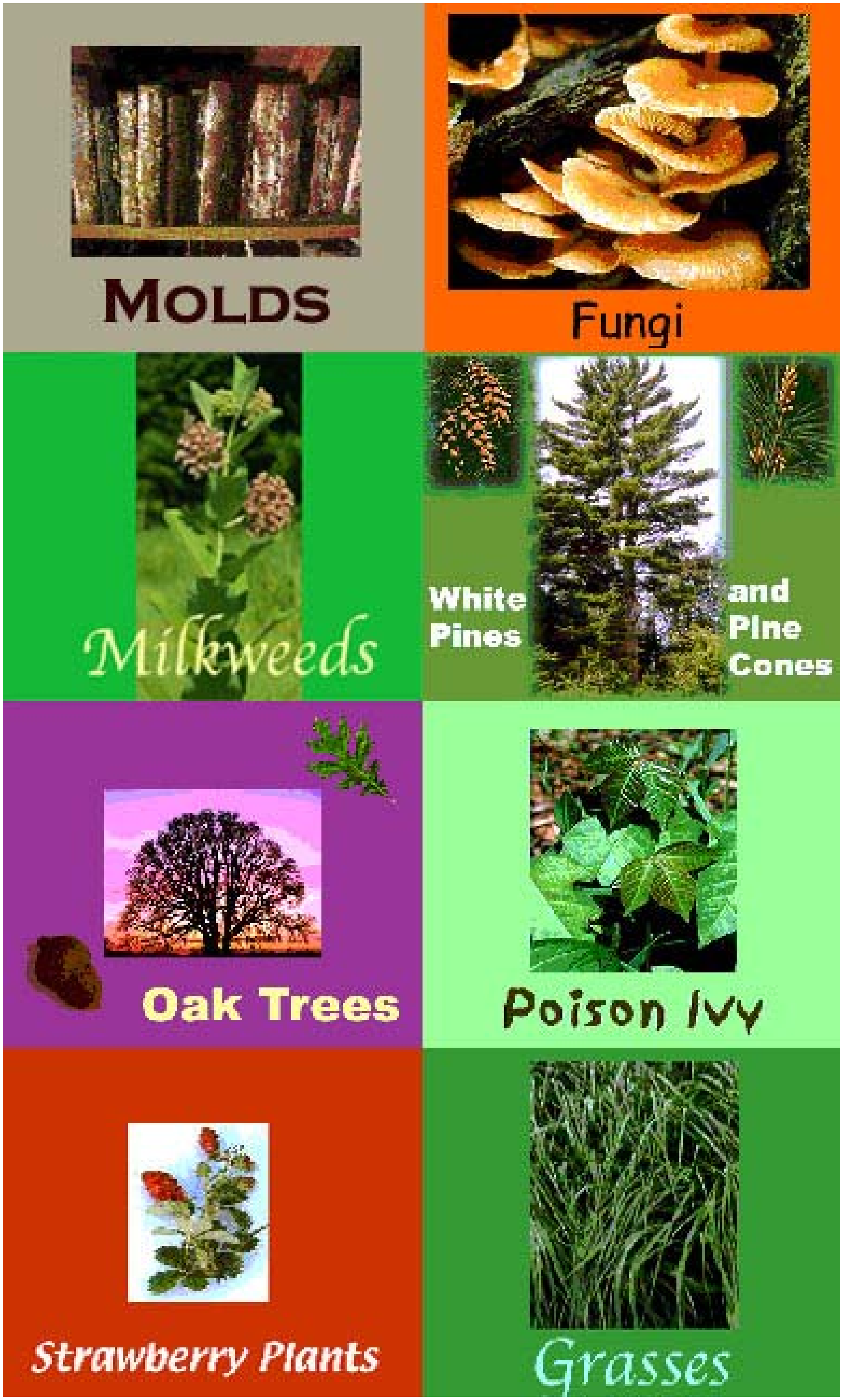
Discuss with the students the problem of having one producer support one snake (through a straight linear chain from producer to tertiary consumer). What game variations could they introduce to consider the idea that most of the energy is lost as you go up trophic levels? For instance, one simple solution would be to rewrite the cards so that instead of a strawberry plant you could have a field of strawberry plants; a hive of moths; a nest of mice; but one owl. What ideas can your students come up with?

*Game alternatives developed by Matthew Shapiro.


Owls
Foxes
Snakes
Skunks
Toads
Caterpillars
Crickets
Bats

Food Web Connection Cards

Food Web Connection Cards



Draw a card from an opponent's web.	Draw a card from an opponent's web.
Draw a card from an opponent's web.	Place a card in an opponent's web.
Draw a card from an opponent's web.	Place a card in an opponent's web.

Food Web Connection Cards

Draw a card from an opponent's web.	Place a card in an opponent's web.
Draw a consumer from an opponent's web.	Draw a consumer from an opponent's web.
Draw a consumer from an opponent's web.	Draw a consumer from an opponent's web.

Draw a producer from an opponent’s web.	Place a producer in an opponent’s web.
Draw a producer from an opponent’s web.	Place a producer in an opponent’s web.

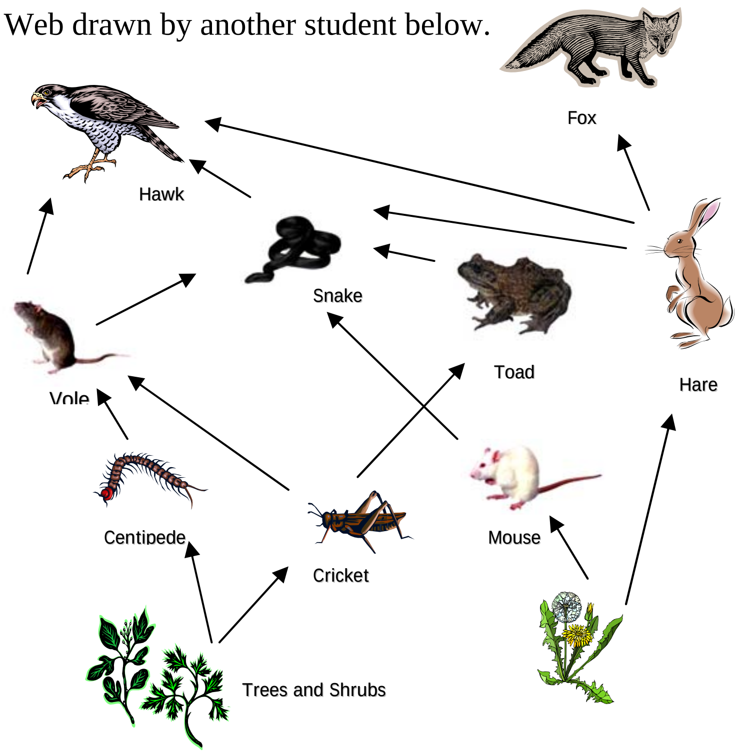
Food Web Connection Cards

Draw a decomposer from an opponent's web.	Draw a decomposer from an opponent's web.
Draw a decomposer from an opponent's web.	Place a decomposer in an opponent's web.

Food Web Critique Activity Sheet

Name ________________________________

Study the Food Web drawn by another student below.



What does this food web diagram do well? List as many things as you can think of:

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What would you change to improve this food web diagram? List as many things as you can think of?

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Where Does the Energy Come From? Activity Sheet

Name______________________________

1. The top of a yogurt container had the following words:
“Some of the energy in this yogurt was generated from the sun.”
Do you agree or disagree? Explain why.

2. Are you solar powered? Tell whether you think you are or are not and explain your reasoning.

Ecosystems Discussion Guide:
Thinking About Predator-Prey Relationships

One issue that may come up as students are discussing ecosystems relationships is the relative size of predators and prey. You may hear things like:

"The larger animals eat smaller animals"
"Smaller animals can't eat things that are bigger than themselves."
"The biggest animals are at the top of the food web (or food chain)."

Consider this an opportunity to introduce some important ecosystems concepts. First, what are some of the underlying concepts that students may have in mind or may be grappling with?:

- It takes more energy to sustain organisms at the highest levels of the food web than at lower levels.
- There is energy loss as we move from producers and first level consumers to higher level consumers. (This is why we sometimes hear that it is good to eat lower on the food chain or food web.)
- It is often the case that larger animals are carnivores or omnivores.

What are some other important understandings that you can invite through the students' questions during your discussion?

- It is often the case that larger animals are carnivores or omnivores. However, this is not always the case. Animals such as deer, cows, or elephants can be baffling to students. These animals have to consume a lot of green plants to have enough energy to survive.
- Decomposers consume dead matter to get energy for their own survival. These include some of the smallest organisms. In this sense, some of the smallest organisms actually consume some of the largest.

What are some questions or probes that you might use in conversation to get students to think about these concepts?:

- Are there any very large animals that do not eat other animals? If so, what are some of them? What do you know about these animals and how they spend much of their time? *[They spend large amounts of time grazing or eating shrubs, bushes etc.]* Why might they spend their time this way? *[They need to meet their energy needs.]*
- Why are we sometimes told to eat low on the food web or food chain? *[Energy is lost at each level. Plants and lower level consumers make the most efficient use of the energy. With each step up the food web, energy is lost in sustaining life at that level.]*
- What happens to the largest animals when they die? Are they eaten for energy? If so, what eats them? *[Students may not yet know that the smallest decomposers eat the largest dead animals. They may think that the animals*

just break down or not realize that decomposers break things down to get energy. They often think of them as doing what they do as a public service to the food web. So you may need to post this question somewhere in your room and come back to it.]

- How have your ideas changed about how bigger things eat smaller things and vice versa?

Ecosystems Discussion Guide:
Thinking About Energy Transfer/Conservation in Food Webs

One issue that may come up as students are discussing ecosystems relationships is the issue of energy transfer and conservation of energy. You may hear things like:

"The energy has to go some place, kind of like a circle, I guess."
"The sun's energy goes to the plants and it never stops."
"After a while the energy disappears when the biggest animal dies."

Consider this an opportunity to get students to differentiate between energy transfer and matter recycling.

- Students who know that energy must be conserved, might reason that it is recycled. Other students may also think this in a less examined way. They might just think that it is recycled because they think it travels with the matter always (which it does to a certain extent.)
- There is no easy way to detect energy loss in the system, so students might not think any is lost along the way.
- Some students won't know about conservation of energy and they might assume that it disappears with the largest animal in the food web. This is close to the scientifically accepted understanding for food webs, but is inaccurate from the perspective of what happens to the energy.

What are some other important understandings that you can invite through the students' questions during your discussion?

- Energy is lost as it is transferred from organism to organism. It is given off as heat energy and is used to fuel an organism's activities.
- Decomposers get energy to sustain their life and activities when they eat dead matter.
- Energy is given off as heat energy when dead matter decomposes.
- Energy does not cycle the way that matter does. Realizing this helps us to recognize our critical link to the sun.

What are some questions or probes that you might use in conversation to get students to think about these concepts?:

- How does the temperature of a compost bin compare to the temperature of the soil a short distance away or of the surrounding air? What do you think is going on?
- Why are we sometimes told to eat low on the food web or food chain? *[Energy is lost at each level. Plants and lower level consumers make the most efficient use of the energy. With each step up the food web, energy is lost in sustaining life at that level.]*
- Why is it so important that we have green plants to convert sunlight into useable food energy? Can we just store up enough energy that we no longer need green plants? Why or why not?

Ecosystems Discussion Guide:
Connectedness vs. Insurance in Food Webs

When students are learning about connectedness in food webs, it is common to over-extend the idea so that they use it absolutely. You may hear things like:

"If anything disappears, the whole thing collapses."
"Everything is connected, so everything depends upon everything."
"If the plants start dying, then everything dies."

In one sense, this is good and it means that they really get the idea of the domino-like connectedness of energy transfer within food webs. Make sure that they solidly get this idea before introducing the idea of insurance. Once they are really clear on that idea, you can back off a little to help them understand that there is some flexibility or "insurance" built into ecosystems. Because kids are growing up in a world of grocery stores when you can get just about any kind of food any time of year, they may not realize that animals in the wild need to eat what is available when it is available. Also, the food webs that they study make the diet sources look definitive and constant. What are some other important understandings that you can invite through the students' questions during your discussion?

- Organisms have some flexibility in their diets. If one food source lessens or dies out, they may be able to eat other food sources.
- Organisms need to be opportunistic in what they eat in order to survive.
- If all the green plants die out, the link to the energy from the sun is lost and then the ecosystem collapses (except in the very rare cases of ecosystems at the geothermal vents.)
- Because organisms have some flexibility, it makes it possible for them to survive variations in their food sources.
- The "insurance" built into the web can make it hard to see when a food web system might be in the early stages of trouble.
- One reason to introduce insurance is that it is part of the larger concept of balance.

What are some questions or probes that you might use in conversation to get students to think about these concepts?:

- What are some of the things that a fox eats? What might a fox do if he couldn't get one or more of those things?
- Do you think that animals eat the same kinds of things all year long or different kinds of things? Why might this be so? *[Berries ripen at certain times of the year and then are gone. Certain animals migrate at certain times and provide food sources. Birds, bugs, etc. lay their eggs at particular times. When a bunch of insects or tadpoles hatch out, there is a wealth of a kind of food for a while.]*

- How might this flexibility in what organisms eat the patterns in the ecosystem? *[The lines in the food web will actually look different at different times. But the food web is less likely to collapse.]*
- How do the food web diagrams that we have been studying make it harder to think about flexibility in what organisms eat?
- What part of the food web is not flexible—meaning that we must have it in order to have life?

Endnotes for Section 1

[1]Leach, J., Driver, R., Scott, P., & Wood-Robinson, C. (1996). Children's ideas about ecology 3: Ideas found in children aged 5-16 about the interdependency of organisms. *International Journal of Science Education, 18*, 19-34.

Senior, R. (1983). Pupils' understanding of some aspects of interdependency at age 15. Unpublished Med thesis, University of Leeds.

[2]Hogan, K. (1994). *Eco-Inquiry: A Guide to Ecological Learning Experiences for the Upper Elementary/Middle Grades.* Dubuque, Iowa: Kendall Hunt.

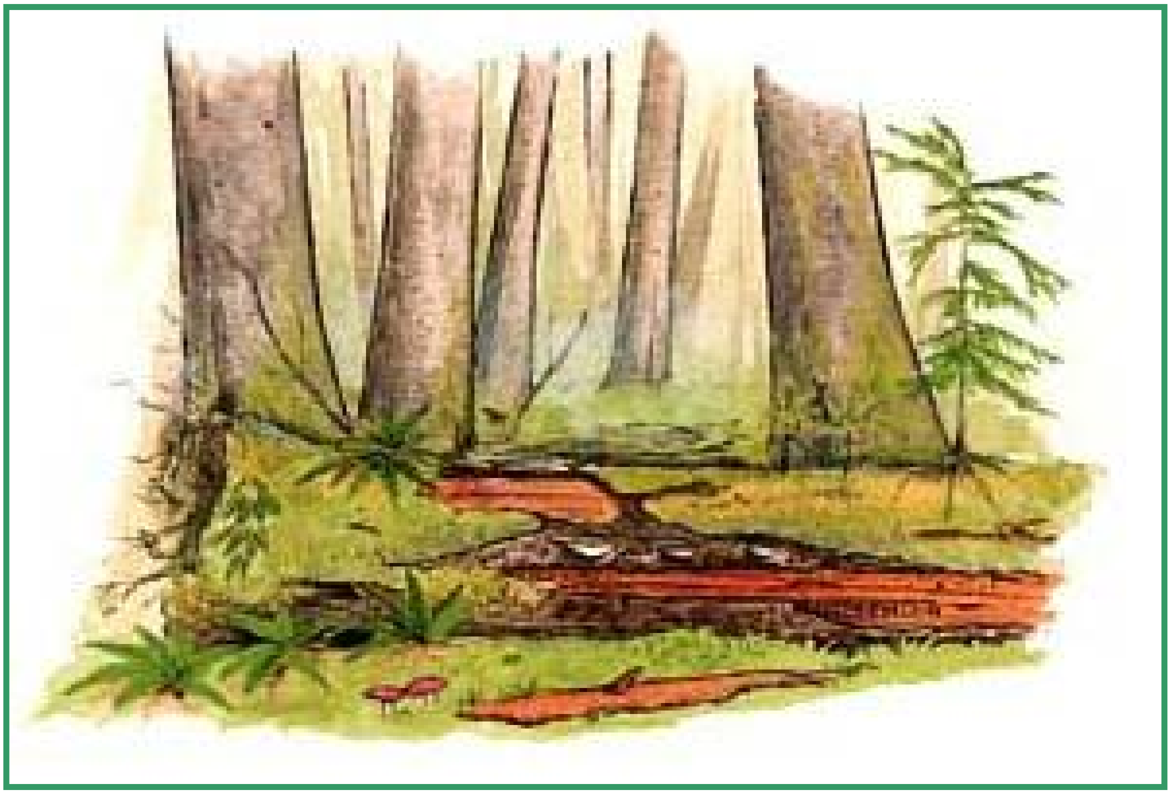
[3]Pickett, S. (1999, March). Everything is connected? EcoNotes Column, *Taconic Newspapers*, pp. A5-6.

[4]Leach, J., Driver, R., Scott, P., & Wood-Robinson, C. (1996).

[5]Leach, J., Driver, R., Scott, P., & Wood-Robinson, C. (1996).

SECTION 2

LEARNING ABOUT DECAY USING CYCLIC CAUSALITY



This section addresses students' tendency to miss cyclic causal relationships. It helps students to realize that the same atoms are continuously recycled between the living and non-living parts of an ecosystem. This "circle of decay" is always happening. A contrast is drawn between matter, which is recycled, and energy, which is not.

Section 2 Table of Contents
Learning About Decay Using Cyclic Causality

Learning About Decay Using Cyclic Causality

The lesson plan in this section offers a choice between two RECAST activities. The first involves exploring a rotting log and helps students to realize that it is becoming a part of the soil. Those without access to a rotting log might prefer the second activity. It involves building a decomposition chamber and observing it over time.

Understanding Goals

Subject Matter

- ❖ When dead matter decomposes it does not disappear, but is recycled through living things and the physical environment. (The atoms are recycled.)
- ❖ When dead matter decomposes it breaks down into its basic elements, some of which are nutrients.
- ❖ The nutrients from dead matter are put back into the surrounding physical environment (soil, water, air) by decomposers.*
- ❖ The nutrients in soil make the soil a good environment for new plants to grow.
- ❖ Nutrients are passed along the food web from plants to animals, from animals to animals, from dead plants and animals to decomposers, and finally back to plants via soil, air and water.
- ❖ The matter cycle (of producers to consumers to decomposers back to producers, and so on) is crucial to the rest of the food web and the ecosystem as a whole.

Causality

- ❖ In cyclic causality, there is no real beginning or ending.
- ❖ There are cycles of decay happening all of the time (simultaneously). Thus there will always be nutrients being made available in the ecosystem.

*This module uses "soil" to stand for the "receiver" of nutrients as they are broken down and returned to the physical environment. However, in other environments, nutrients can be released into water or air, such as in ponds or oceans.

Background Information

Matter Recycling and the Conservation of Matter

Matter is neither created nor destroyed, but it can be changed into new forms. Matter in the non-living world can enter the living world through plants. As matter then moves through a food web, it becomes reorganized and is incorporated into the bodies of the living things that take it in. When something dies and decomposes, matter does not disappear but is broken down and recycled into the ecosystem (though not necessarily the same ecosystem). Decomposition, carried out by decomposers, is the process of breaking down dead matter into basic substances that can then be used again by new living things. The nutrient cycle is the way in which nutrients move between living things and the physical environment. It is the intake of basic substances (like CO_2 and H_2O) from the physical environment by plants, the consumption of food in the form of plants and animals, the release of waste and other by-products of life processes by all organisms, and decomposition of any dead thing by decomposers. It can be challenging for students to grasp the idea of conservation of matter. They do not necessarily believe that matter is conserved and are comfortable with explanations that involve dead material *drying up*, *blowing away*, and *disintegrating till there's nothing left*, for example.

Cyclic Causality and Decay

The activities in this section introduce students to the cyclic causal pattern involved in decay. It can be difficult to talk about cyclic patterns. Typically we break them down into linear patterns to talk about what happens, and so we lose the fundamental circular aspect (which cannot be reduced further). In cyclic causal forms, no single event is the cause of what happens, rather events are both causes (of other events) and effects (of other events). In some curricula, decomposers are introduced as *the end* of a food chain. Decomposers ARE the end of the food chain in terms of being the end point of energy flow. They are NOT the end of a nutrient cycle because the matter can be used again. The activities in this section underscore that the relevant causal pattern is a circle, not a line. Decomposition is always occurring. Students need to realize that there are many things decomposing simultaneously in different states of decay. There are many simultaneous *circles of decay*. Matter is being recycled. Energy is not. New energy enters the system from the sun.

Lesson Plan:
Learning About Decay

There are two alternative RECAST activities in this section. *The Rotting Log* activity has the appeal of getting the concepts across in one lesson and is often very exciting for the students. However, it may be difficult for some teachers to obtain a rotting log or some teachers may not feel comfortable taking apart a rotten log. The *Decomposition Chamber* activity is slower and offers a clearer sense of process. Teachers may of course choose to do both.

RECAST Activity A: Investigating a Rotting Log

By investigating a rotting log, students will notice different stages of decay and begin questioning why they find soil inside a rotting log. The activity can be done as a class activity in small groups or as a group demonstration. Having students discover soil inside the logs for themselves is a powerful learning experience. However, it involves having enough rotting logs to go around, dealing with the mess involved (certainly worth it!), and dealing with whatever students find in the logs. This can include various types of fungi, insects, and spiders.

The Brown Recluse Spider is a poisonous spider that lives in woodpiles. It is unlikely that one would remain inside a log transported to school because they are reclusive; however, it is not impossible. For these reasons, teachers may choose to do a demonstration instead. If you do the activity, encourage the students to see the log as a habitat and make your best effort to return the creatures with the remaining pieces of the log to an appropriate spot outdoors after the activity. If you can't find a rotten log, a pile of rotting leaves and its residents can be a good substitute.

RECAST Activity B: Creating a Decomposition Chamber

By setting up and observing a decomposition chamber, students will notice changes that indicate that decay is occurring over time. This activity can be done as a small group activity or together as a class. Having students observe the process of decay over time and discover the soil that is generated from the breakdown of matter is a wonderful learning opportunity. It takes approximately 6-8 weeks in order for observable changes to occur, therefore it involves planning ahead by the teacher. This activity should take place in two parts: the first part to talk about predictions and to set up the chamber; and the second part to observe, measure and discuss the changes and the causes of them.

Materials

RECAST Activity A: Investigating a Rotting Log

- A piece of log that is beginning to rot
- Some broken bits of a well rotted log
- Rotting log segments (1 per 4 to 5 students or 1for a class demonstration)
- Some soil with obvious bits of decaying material
- Hand lenses
- Plastic tablecloths or newspaper to place on desk tops
- Plastic containers for any critters that might need a temporary home
- Metal spoons (or something to examine the log with; to break apart gently or examine nooks with so as not to use hands)
- Gloves for students pulling log apart
- Observation sheets
- Field guides

RECAST Activity B: Creating a Decomposition Chamber

- Clear plastic two liter soda bottles with the top fourth cut off
- Pieces of cheesecloth or pantyhose
- Rubber bands (2 per bottle)
- Bag of sand
- Bag of garden soil
- Water
- Organic materials in containers: leaves, grass clippings, pine needles, lettuce,
- Other items made from organic materials: newspapers, sticks
- Inorganic materials: plastic wrappers, Styrofoam pieces

Prep Step

RECAST Activity A: Investigating a Rotting Log

- Read the background information.
- Read the lesson plan.
- Find rotting logs and get soil from a forest or wooded area. Plan one log or log segment for approximately every four students.
- Gather newspaper or plastic tablecloths, hand lenses, gloves, plastic spoons and containers.
- Protect tabletops or desktops by covering with newspaper or plastic tablecloths, or work outside.
- If students will be working in groups, break rotting logs into segments so that each group of students has one segment to explore.
- Photocopy the two observation sheets (pp. 73 and 74).

RECAST Activity B: Creating a Decomposition Chamber

- Read the background information.
- Read the lesson plan.
- Gather materials needed for the decomposition chamber.
- Cut bottle tops.
- Cut cheesecloth or pantyhose.
- Measure out soil and sand.
- Gather organic and inorganic matter to add to chamber.
- Read the *Picture of Practice* (p. 77) to familiarize yourself with what to expect from the lesson.
- Photocopy the sheet, *What is Cyclic Causality?* (p. 75) for your students.
- Photocopy the story, *The Cyclic Journey of an Atom* (p. 76) for your students.

Analyze Thinking

Step 1: Gather Students' Ideas and Questions

Ask, "What happens to a tree when it falls in the forest?" Gather students' ideas and questions. Track these on chart paper. Students will typically say things like, *It disappears; It goes into the ground; It disintegrates; It rots; and It turns into little pieces until it is gone*.[1] If students use words like *decay* or *decomposers*, ask them to define the words.

Step 2: Expand Students' Ideas

Ask, "Does whatever happens only happen with trees, or does it happen with other things? What about a piece of fruit, for example?"

Encourage some dissenting ideas by asking, "How many of you think that it completely disappears? If it doesn't disappear, what else might happen to it?" Some students may have compost bins at home and may know that it becomes a part of the soil.

RECAST Thinking

RECAST Activity A: Investigating a Rotting Log

Step 3a: Explain the Activity

Explain to students that they are going to break apart a piece of rotting log and examine what they find. This will help them think about what happens when something decays. Have students think about the following questions as they work:

- What happens to a log as it decays?
- What causes the log to decay?

Note to Teacher: Do the activity in small groups or as a class demonstration. Read the background information to help you decide which is best for your class. Try to have your class work outside for this activity if at all possible. If not, have them work on newspaper or on plastic tablecloths.

Divide students into groups of four. Hand out the two observation sheets. The student who is actually breaking the log apart should be wearing gloves because there might be insects and fungi in the log that shouldn't be handled. If anyone notices a spider, they should NOT touch it. Have students call you over instead.

A Caution about Centipedes and Brown Recluse Spiders

There are a few critters that students should be cautious of when investigating rotten logs. Centipedes and the brown recluse spider are two to look out for. Centipedes are brown-red in color, with long, segmented bodies and numerous pairs of legs. Centipedes make their homes in rotting wood, compost piles and under rocks, among other places in moist and humid outdoor environments. *Brown Recluse Spiders*, or *Fiddlebacks*, pictured above, are indigenous to the southern and Midwestern states, but have been known to migrate to other parts of the country by various means, and may therefore be found in any part of the country. These spiders are often yellowish light brown to dark brown in color and characterized by a dark colored fiddle or violin shaped marking on their head, as well as three pairs of eyes. They often make their home in wood piles or under the loose bark of logs. This spider is typically not aggressive, and usually bites its victim only when disturbed or touched.

Step 4a: Explore the Log

Give the students about 15-20 minutes to explore the log and to record their findings on their observation sheets. Circulate while they are working and help them to think about the kinds of evidence that they are finding in the log to suggest what might be happening to it.

Many students are unaware that the log is turning into a part of the soil. They may try to find explanations for how soil got into the log. Having students notice the soil is the first step towards inviting them to question how it got there and helping them to see that decay is a cyclic process.

Step 5a: Discuss Students' Findings

Regroup for a class discussion. Ask, "How would you describe the log? How is it different from a log that is not as decayed? What are some of the things that you noticed inside the log?" List what students found. Review the list. If the list doesn't include soil, ask, "Did anyone find any soil? Why was soil in the log?" Gather some contrasting ideas.

Step 6a. Compare Logs at Three Points of Decay

Show students: 1) a piece of a log that is beginning to rot; 2) smaller, broken pieces of a log that is further in the process of decay; and 3) some soil.

Ask, "Do you see any ways that these things are related? In what ways are they alike and similar? In what ways are they different?" Explain that the piece of log, the bits of broken down log and the soil were all at one time the same material---wood from a tree. Students are looking at wood at different stages of decay.

Ask: "Have you heard the word "decay" before?" Explain that another word for decay is *rot*. Decay is when dead matter is broken down. When a log begins to decay, it breaks down into its basic parts, which end up as part of the soil and as gases that are given off.

Step 7a: Consider How Decay Happens

Engage students in a conversation to consider how the log is decaying. Ask, "What kinds of creatures did you find and what might they be doing in a rotting log? What did you observe about the creatures? Do you think that the creatures play a role in the log decaying and turning into a part of the soil? How might this be?"

See if anyone thinks that the creatures are eating the log. Ask students to think about what they know about the job of earthworms and other decomposers. Many students think that decay just happens, like something falling apart. They don't think that something actually causes it, so they may need help in making the connection between the decomposers and the decay.

[Continue with Step 8 on p. 69]

RECAST Activity B: Creating a Decomposition Chamber

Step 3b: Explain the Activity

Explain to students that they are going to build a chamber filled with organic and inorganic matter and observe the changes that take place within it over a period of a month or two.

Ask, "Does anyone know what *organic matter* and *inorganic matter* are?" Gather ideas. Explain that organic matter is stuff that is alive or made from substances that are alive. Inorganic matter is matter that is not alive and has never been alive in its current form. Have students consider different types of organic and inorganic matter that could be added to their decomposition chambers.

Step 4b: Make Predictions

Ask, "What will happen over time to organic matter, like fruits and plants, which are placed in the decomposition chambers?" Then ask, "What do you predict will happen to inorganic matter like Styrofoam cups, plastic toys and packaging and so on?" Record their predictions and save them to be reviewed later.

Ask, "How long do you think it will take to observe changes in the bottle? What are you basing your prediction on?"

If students predict that changes will take place, ask, "What will cause the changes that you are predicting?" Many students think that weather, animals or humans are responsible for the decay and breakdown of organic matter. Explain how the decomposition chamber is a "controlled environment" and discuss what this implies for the causes of decay. Encourage some initial conversation on this issue. Section 3 addresses the causes of decay in greater depth.

Step 5b: Creating the Chamber

Follow the instructions on page 80 for building the chamber. This project can be done in groups or together as a class. Circulate while students are working and gather their individual thoughts on what will happen.

Step 6b: Discuss Students' Findings

In six to eight weeks, regroup for a class discussion about what students observed about the decomposition chambers. Review the list of students' predictions for what might happen. Ask:

"What have you noticed about the chambers?" List the changes that students observed.

"What do the measurements on the sides of the containers suggest?" Gather ideas and discuss.

"What do you think happened to the organic matter?" Some of it broke down into smaller particles and some of it was given off in the form of gases. Explain that when the plant matter broke down, some of it became a new part of the soil. This explains why the level of soil seems greater now.

"Are there any differences between what happened to the organic matter and the inorganic matter?" Students should have noticed more change in the organic matter. Discuss the differences.

"Do you think that inorganic matter breaks down or not?" Discuss how time is a factor in decomposition.

Step 7b: Consider How Decay Happens

Ask, "Do you have any ideas about how the organic matter in the decomposition chambers decayed?" Gather some ideas. Many students think that decay just happens, like something falling apart. They don't think that something actually causes it so they may need help in making the connection between the decomposers and the decay.

Explore Causality

Step 8: Contrasting Linear and Cyclic Causality

Ask, “Why do people usually show decomposers at the *end* of the food chain?” Gather ideas. People often show them at the end because they eat or digest the things that die. This makes sense in one respect. They ARE the end of the energy domino discussed in section one. However, decomposers do more than just get energy from the things that they eat, they break the matter in these things down enough to recycle it into its basic substances. They are an important part of the nutrient cycle and so here they are NOT the end. There really is no end to a circle.

Ask, “What is the importance of decomposers in the food web and the ecosystem?” Explain that when organisms die, decomposers recycle the dead matter. Recycling it releases the matter back into the surrounding environment and provides the nutrients that green plants need to live.

Draw a cycle on the board that shows a green plant that dies and is recycled by an earthworm, and the nutrients from this decay contributing to the growth of other green plants. Many students are unaware of non-obvious decomposers, so at this point it is important to stick with an obvious one such as an earthworm.

Explain that the process is circular. This circle is called a cycle. Show how the cycle could also include consumers (mice, for example).

Explain that it takes a long time for the different parts of the cycle to happen, so it may be difficult to see how they are related and think about how they go together. The time delay makes it difficult for students to see the cyclic pattern. This is the focus of Section 4.

Step 9: Show How Cyclic Causality Explains Matter Recycling

Explain that sometimes decomposers, like worms, are called *Nature’s Recyclers*. Ask, “Can anyone explain why that is?”

Write the word *recycling* on the board. Explain that recycling is the way people take waste and turn it into something that can be used again. Ask, “Can anyone give an example?” We recycle paper and aluminum and turn them into things that can be used again.

Explain that in some ways, decay and decomposition are like the recycling that people do. Dead matter is broken down, becomes part of the soil, and contains basic substances that are then available to plants. As a class, read and discuss the story *The Cyclic Journey of an Atom* (p.76).

As a class, read the sheet, *What is Cyclic Causality?* (p. 75). Either individually or as a group, have students draw a cyclic diagram showing matter recycling on the bottom of the page.

Review, Extend, and Apply

Step 10: *Considering What Would Happen Without Decay*

Ask, "What would happen if the cycle were to be broken? What would happen if logs didn't decay? Why is it so important that there is decay? What might the world look like if things didn't decay?" Gather some ideas.

Explain that the forest floor would be covered with dead logs and dead leaves and over years it would pile up so high that it would keep new things from growing. In addition, the dead matter and waste would pile up so high that it would eventually cover plants living on the ground and even the tops of trees. Earth would be covered with waste. Decomposers keep this from happening by breaking down dead matter and putting important nutrients into the soil, which helps keep things growing.[2]

Ask, "What would happen if dead logs all disappeared instead of being recycled? What might the consequences be?" Gather some ideas.

Step back and compare the two forms of causality introduced so far—domino causality and cyclic causality. Consider why they are important in ecosystems. Domino causality helps us to see that all the organisms in the ecosystem get their energy from the sun, through the crucial link of green plants. It also helps us to see that the energy is "lost" to the ecosystem throughout the process (and by the end of the domino effect). We can refer to this process as the "energy domino." Cyclic causality helps us to see that matter is not lost—it is continually recycled. We can refer to this process as the "matter circle."

Reinforcement Activities

Cycles of Nature Game (p. 81) – The aim of this card game is to show how energy travels through the food web and how matter is recycled into nutrients that support the growth of plants. It stresses the roles of producers and decomposers. Students try to make as many matter cycles as they can.

Nutrient Cycles Game (p. 84) – This game helps students understand that nutrients flow through ecosystems in cyclic patterns during the process of decay. This game also supports the understanding that matter is neither created nor destroyed during the decay process.

The Puzzle of the Rotting Log Video[3] – This is a film about the lifespan of a tree. While students are watching, they should recall the different kinds of organisms that they saw in their logs and compare them to the ones shown in the film. They should also think about what might happen if there were no decomposers. This video is appropriate for elementary classes.

The Forest Log[4] – Read *The Forest Log* by James R. Newton. Ask students what they think is meant by the term, "nurse log" and why it is important to the forest community. After the first paragraph on page 2, ask students to predict the kinds of changes that may happen to the log and the ways in which other living things may use it. Discuss the processes of decay that are described and ask students to explain why and how these are occurring. Again discuss what the term "nurse log" means and how it helps nurture new trees and provides living things with the resources they need to live. The book is currently out of print but can often be found in library collections.

Death is Natural[5] – Read *The Travels of Atoms* in *Death is Natural* by L. Pringle, a book that discusses how death in the plant and animal kingdoms is natural, why it is necessary and how it can be thought of positively. With students, create a map of how and where the atom of the rabbit travels in the ecosystem. The book is currently out of print but can often be found in library collections.

The Atom Tracker – A module in the Scheele Pond EcoMUVE developed at the Harvard Graduate School of Education by Chris Dede, Tina Grotzer, Shari Metcalf, and Amy Kamarainen allows students to follow the path of an atom through a virtual world. Information can be found at www.ecomuve.org.

Resources for Section 2

Observations Sheets (RECAST Activity A)
- Things I noticed about the rotting log were
- Drawing what I see in the rotting log

What is Cyclic Causality? Sheet

The Cyclic Journey of an Atom Story

Picture of Practice (RECAST Activity B)

Building a Decomposition Chamber (RECAST Activity B)

Cycles of Nature Game
- Teacher Preparation
- Directions
- Cards

Nutrient Cycles Game
- Teacher Preparation
- Directions
- Cards

Endnotes for Section 2

Name: ____________________

Things I noticed about the rotting log were...

As you explore the log, write down the things that you notice about it and describe what you see. Record as many observations as you can.

1. ____________________

____

2. ____________________

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3. ____________________

____

4. ____________________

____

5. ____________________

____

6. ____________________

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Name: ____

Drawing what I see in the rotting log

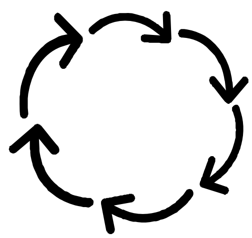
Draw a picture of what you observe in the rotting log. You may use the space below to do more than one drawing. Be sure to label your drawings.

What is Cyclic Causality?

Cyclic causality means that events are connected in a circle. One event makes a second event happen but the second event then makes the first event happen again (which then makes the second event happen again and so on).

In a cyclic cause and effect story:

- There is no real beginning or ending (once it gets going).
- A cause can also be an effect and vice versa.
- If you break the story into a line, it loses important parts of the story.



Cyclic causality happens in science and in everyday life. For instance, if you say something that hurts your friend’s feelings, then she might not be nice to you, so you get mad and aren't nice to her, so then she is not nice to you, and so on. It becomes a cyclic cause and effect story.

Decomposition is part of a cyclic causal story. In the space below, draw a cyclic causal story that shows how decomposers break down dead matter into smaller bits of matter and nutrients that can then help green plants to grow. Your drawing should show a circle for matter recycling and an arrow coming in from the side to show that plants need energy from the sun. Be sure to use arrows to show what makes what happen. Then check your diagram to make sure it shows cyclic causality.

The Cyclic Journey of an Atom

Three children are playing in a meadow. They come across a dead pheasant in the grass. They wonder why the pheasant died and what will happen to it now. They agree to check in the coming days.

The next time they look for the pheasant, they can't find it at first. Then they see it a few feet away. What they don't know is that a red fox found it, dragged it to a comfortable spot, and fed on it. The children flip the pheasant over with a stick and notice little insects and larvae on the other side. The fox, insects, and larvae have been using the pheasant's body for food.

The children can't see the very tiny organisms called microbes that are also eating the pheasant. Microbes are decomposers. Decomposers break down dead plants and animals and recycle the material they were made of back into the ecosystem. Bacteria, fungi and other microbes are helping the pheasant's body to break down into little parts that can be used again by other forms of life. Some of the microbes were in the pheasant before it died. Others came from the ground and the air.

Everything on Earth is made of elements. All living things have elements in common, such as carbon, hydrogen, nitrogen, and oxygen. Elements are made of atoms. An atom is one of the tiniest things on Earth. Each element has one specific type of atom, for instance, carbon is made of carbon atoms. Atoms can form into groups called molecules. The microbes decomposing the pheasant are breaking apart the molecules into the atoms. When the molecules are broken down into atoms, energy is released. This energy is food for the microbes, the fox, the insects, and the larvae.

After a few months pass, the children go to look at the pheasant again. All they can find are bits of feather and bone. They think that it is disappearing. But the pheasant's body isn't really disappearing. Some of the atoms are now in the fox, the insects, and the larvae. Some atoms broken down by the microbes went into the ground and into the air. The atoms that went into the ground went into the root of a blueberry bush near the pheasant and then up into its leaves. From there, the atoms grouped into a sugar molecule in the blueberries growing on the bush. A pheasant came by and ate some of the blueberries so now atoms from the dead pheasant are in another living pheasant.

The children's mother picked the blueberries and put them in pancakes that the children ate for breakfast. So now, some of the atoms from the pheasant are in the children. This might surprise the children. They would be more surprised to know that the atoms in their bodies could have been part of a dinosaur once or even a meteorite! The atoms on Earth have been around for billions of years. All the atoms on Earth get recycled and become part of something else. It's sort of like atoms are borrowed--to be used during our lifetimes. They go back into the ecosystem upon death. Death is natural and necessary for healthy ecosystems. It is one of life's many cycles where organisms die but the atoms that they were made of continue on as part of the living and non-living environment.

This story is based on a concept from <u>Death is Natural</u> by L. Pringle.

Picture of Practice

Realizing that Decomposing Matter Doesn't Disappear
A 5th Grade Science Lesson

The following picture of practice looks in on two lessons as students explore the idea that matter is conserved during the decomposition process. By observing decomposing plants turning into part of the soil, students understand that matter does not disappear. In the first lesson, students set up an experiment and make predictions about what will happen. In the second lesson, students consider the outcome of their experiment.

Setting up the Experiment: Collecting Initial Thoughts and Predictions:

- Mr. Wahl: We've been talking about decomposition, but today we're going to think about what happens to all the stuff that decomposes. What do you think happens to leaves, twigs, Styrofoam cups, and everything that you might find on the ground or in the trash? Scientists call all this stuff "matter." Does anyone have any idea what happens to it?
- Judy: Well, I think things like logs and leaves turn to rot.
- Mr. Wahl: What do you mean by "turn to rot," Judy?
- Judy: Well, the stuff gets all dirty. Sometimes it kinda smells.
- Mr. Wahl: Is there anything you noticed about the size of the logs or leaves as they rot?
- Judy: Oh yeah, it breaks up into pieces.
- Billy: I think the stuff gets eaten by worms.
- Eli: And bugs, too! I see all sorts of bugs eating garbage and leaves. So I guess the leaves and stuff end up in the bugs' stomach.
- Mr. Wahl: Interesting. Does anyone else have any other ideas?
- Dan: Well after a while it just disappears.
- Jo-Jo: Yeah, I think the stuff turns into nothing.
- Mr. Wahl: Can you think of a way that we might be able to find out whether or not the stuff disappears over time?
- Billy: We could watch it to see what happens.

At this point, Mr. Wahl does not confirm or disprove students' ideas. The discussion is kept as open as possible, with ideas flowing freely.

- Mr. Wahl: You came up with lots of interesting ideas about what happens to matter, or stuff, during decomposition. Over the next few weeks, we'll make careful observations of the materials in our decomposition chambers. Right now, let's talk about what we should put in our decomposition chambers. What kinds of things would you put in it?
- Billy: leaves, pieces of wood, maybe some dirt
- Mr. Wahl: Those sound like good things to put in. Why did you choose those items, Billy?
- Billy: Well, that's the kind of stuff I see rotting in the forest.
- Mr. Wahl: OK. Are there any other ideas about what to put in our chambers?
- Suzi: Maybe some dead insects or a dead mouse or something like that *(Some of her classmates respond with "ugh" sounds.)*

Picture of Practice

Continued from previous page

- Mr. Wahl: Good thinking, Suzi, dead insects and animals also decompose. For this activity though, we'll just use dead plants.

The class continues to brainstorm a list of all sorts of organic materials.

- Mr. Wahl: Alright, we have lots of ideas of organic materials we can add. Does anyone have any ideas of some inorganic things they might put in their decomposition chamber?
- Janis: What's "organic matter" and "inorganic matter"?
- Mr. Wahl: Good question, Janis. Organic matter is stuff made from living things. It includes things such as grass clippings, coffee grounds, newspaper strips, pine needles, pieces of lettuce, leaves, or other forms of organic matter. Inorganic matter is stuff made from non-living things, like Styrofoam cups or plastic wrappers.
- Tyrone: Wait, did you say "newspaper" was "organic"?
- Mr. Wahl: Another good question. Does anyone know where newspapers come from?
- Class: Trees!
- Mr. Wahl: Great, and are trees living or non-living things?
- Class: Living!
- Mr. Wahl: Yes. Now, are there any other questions?
- Judy: Yeah, how do we know what stuff to put in there?
- Mr. Wahl: Well, that's really up to you and your partner to choose what you want in your decomposition chamber. Remember, we are looking to see what happens to all kinds of stuff over time.
- Eli: If we all put in different materials, won't different things happen?

A discussion ensues about what sorts of difference students might notice with the organic versus inorganic matter. The students decide it will be useful to have different groups use different materials to compare possible differences.

Reflecting on Observations:

A month or two later, students discuss their predictions about what might happen to what they observed happening to the matter over time. Mr. Wahl stresses that everyone's contributions help the class to better understand what's going on.

- Mr. Wahl: Are there any volunteers to share what they have observed in their chamber? Tell the class what you put in your chamber and any changes you noticed over time.
- Noah: We put soil and leaves and twigs in. We also put in a plastic dinosaur that Joey found.
- Mr. Wahl: And what did you observe over time?
- Noah: We noticed that the leaves got broken up, but the dinosaur didn't.
- Mr. Wahl: OK. Did you notice any overall changes to the different layers in your chamber?

Picture of Practice

Continued from previous page

- Noah: Yeah, the layer with the leaves and grass clippings and stuff is a lot smaller than it used to be. And I think it looks like the layer with the soil got bigger. But the plastic dinosaur looks pretty much the same.
- Mr. Wahl: Very interesting. Did anyone else notice anything similar? Anything different?
- Julie: We also noticed that the leaves broke apart the most. It kinda looks like they're becoming big, chunky pieces of soil.
- Mr. Wahl: Did you notice anything about the amount of soil in your chamber?
- Julie: Yeah, I guess its kinda like Noah said, it looks like there's more soil now.
- Dan: But there isn't as much stuff as before, look how much lower it got. I think that the little pieces break down to invisible pieces. It just sort of disappears.
- Julie: Maybe some things break down and go into the ground, and some things just disappear.
- Mr. Wahl: That's one idea. Can anyone think of another possible explanation?
- Rebekah: Well, if the pieces got smaller they would fit together like puzzle pieces so it would look like it takes less space even if the amount of stuff is the same.

Mr. Wahl has the students create models to illustrate Rebekah's idea. They present a variety of examples by cutting up Styrofoam, weighing out small and large steel balls to show that the same mass can fit in different amounts of space, and so on.

- Mr. Wahl: So what do these comparison suggest?
- Olivia: That the amount of stuff could stay the same even if it looks like less.
- Mr. Wahl: But we noticed that the plant matter did break down. Where do you think it went?
- Tyrone: Well, it looks like it just became soil. That would explain why our layer of dirt looks a little bigger now.
- Eli: So the stuff doesn't disappear, it just turns to dirt.
- Mr. Wahl: Alright, so what about the plastic dinosaur? Why didn't it become part of the soil?
- Janis: Well, because it's made from stuff that is not alive.
- Mr. Wahl: So do you think that all inorganic things cannot break down into soil?
- Janis: No.
- Mr. Wahl: Why not?
- Janis: Because I saw a really old chunk of a Styrofoam cup once that looked like it was rotting. If you wait a long time it might turn into soil.
- Mr. Wahl: Good observation, Janis. Can anyone think of any other examples of inorganic matter breaking down into soil?
- Olivia: Rocks break down into smaller pieces.

The class discusses other examples of the decomposition of inorganic matter. Students seem to understand the idea that all matter, organic and inorganic, eventually does not disappear, but rather, breaks down into parts of the soil or whatever surrounding environment it is in.

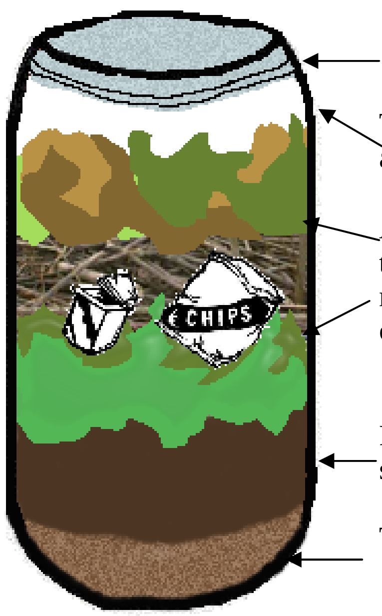
Building a Decomposition Chamber

Materials

- Clear plastic 2 liter soda bottles with the top fourth cut off
- Piece of cheesecloth or pantyhose (1 large piece per bottle)
- Rubber bands (2 per bottle)
- Sand (1 cup per bottle)
- Garden soil (Do NOT use sterilized soil!) (2-3 cups per bottle)
- Water (1 cup per bottle)
- Organic materials in containers: leaves, grass clippings, pine needles, lettuce,
- Other items made from organic materials: newspapers, sticks
- Inorganic materials: plastic wrappers, Styrofoam pieces (Do NOT use packing peanuts made from corn starch which may dissolve in water).

Procedure

Place a cup of sand at the bottom of the container. On top of the sand, place about two cups of garden soil, followed by one cup of organic or inorganic material. Add one cup of water. Finally, cover the top of the bottle with pantyhose or cheesecloth cut large enough to fully cover the opening and secure it with a rubber band.



Cycles of Nature Game
Teacher Preparation

Materials

- Game cards
- Game board

Background

Matter and energy travel together through a food web. Energy is burned along the way, with most of it eventually being transformed into heat, which is not useful to sustain life. Matter, however, is reorganized as it is taken in and incorporated into the bodies of living things. Matter is not “lost” like energy—it gets passed around.

Goal

To win, players try to make the most matter cycles. (Even though they are making matter cycles, when they include producers and consumers, these are energy and matter links. Food is matter and carries energy.) A cycle can have just two cards (a producer and a decomposer) or it can have more (consumers that get energy and matter from the things that you connect them to.) However, players only get one point per cycle.

Getting Started

- Copy or print out game cards. Use the cards from the *Food Web Connections Game* (pp. 44-46). Photocopy one copy each of pages 44 and 46. Photocopy two copies of page 45 for each group of students. Cut and laminate if possible.

  Note: If you already copied the cards for the Food Web Connections Game, you can use those sets; however, you should remove some of the decomposers and producers from the pile. You may also wish to hand out the chart showing levels of consumers, producers, and decomposers from page 41.

- Copy or print out the game board and laminate if possible.

Playing the Game

See the *Cycles of Nature Directions* on the following page for rules and strategy for playing the game.

Follow-up Questions

1. Why can you make a cycle that has only a producer and a decomposer? How is this like a real ecosystem?

2. Why do you think the game board shows different colors for the cycle above the ground and below the ground?

Cycles of Nature Game
Directions

Goal

To win, you try to make the most matter cycles. (Even though you are making matter cycles, remember that the matter and the energy go together as "food.") A cycle can have just two cards (a producer and a decomposer) or it can have more (consumers that get energy and matter from the things that you connect them to.) However, you only get one point per cycle.

Rules for the Game

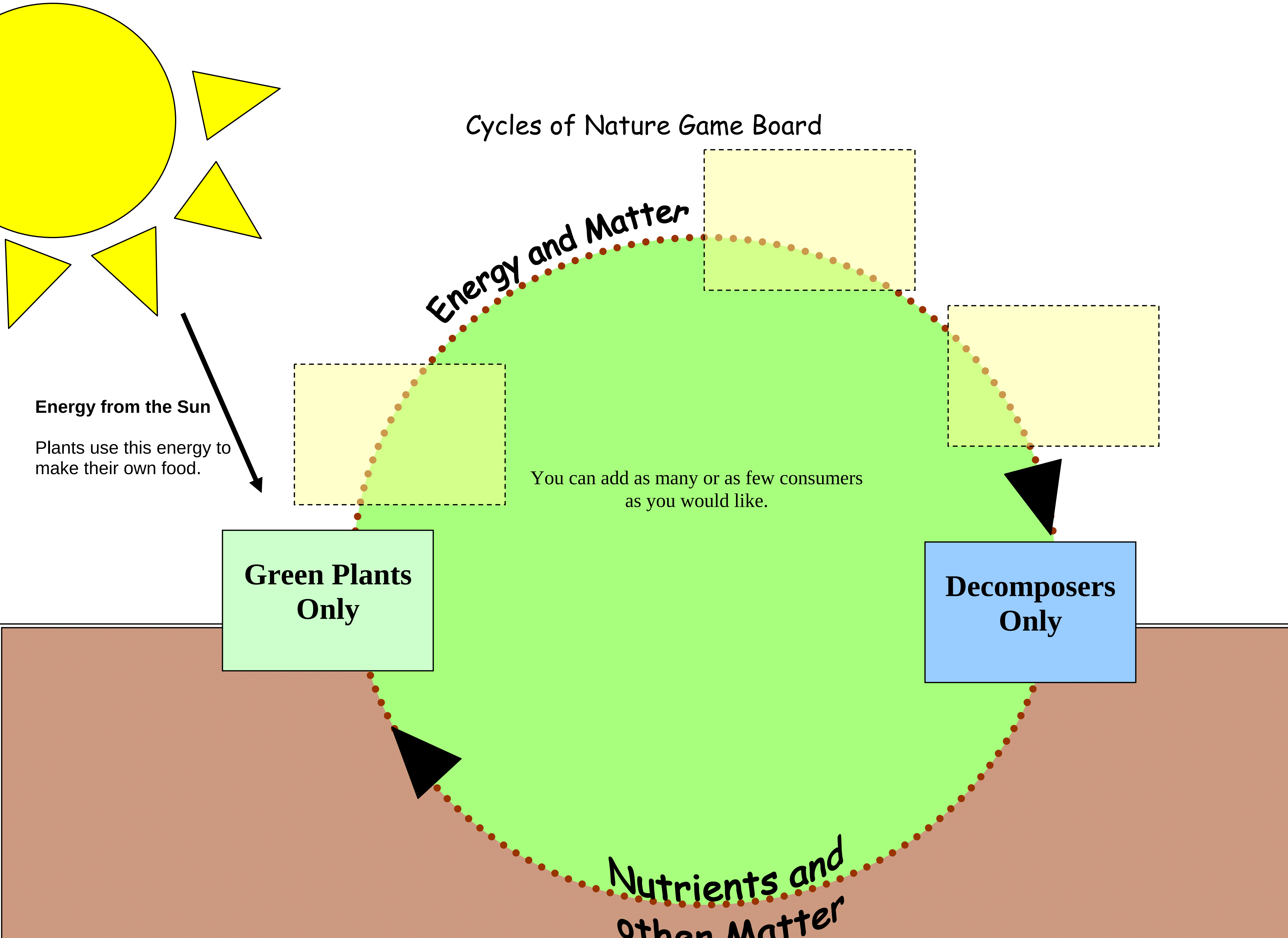
1. Play in groups of four to five students. Each player gets five cards. Put the extra cards in a "pick-up pile."
2. On your turn, ask another player if he or she has a specific card that you want. If not, take a card from the pile.
3. If you have less than five cards at any time, take ones from the pick-up pile.
4. When you get a cycle, set it out in a circle on the game board to show the other players. (The spaces are just to show you where to put them. The cards are a little larger than the spaces.) Then take as many new cards as you need to have five total. When you make your next cycle, stack the old one next to the game board and put the new one on the board.

Strategy

You want to construct cycles that are long, if possible, to clear your hand of consumers so you can get more cards. (This is because you NEED a producer and a decomposer to make a cycle.) However, if you wait a long time to make a cycle, someone may ask for your plant or decomposer. You need balance waiting too long with getting consumers out of your hand. Also, think carefully about how you use particular cards. For example, you could use an earthworm to get a toad out of your pile. But if you do, you will have lost a valuable decomposer. If you aren't sure what something eats, look it up. There are a few consumers in the game that also can act as decomposers because they scavenge (look for) and eat dead matter.

Follow-up Questions

1. Why can you make a cycle that has only a producer and a decomposer? How is this like a real ecosystem?
2. Why do you think the game board shows different colors for the cycle above the ground and below the ground?



Cycles of Nature Game Board
Energy and Matter
Energy from the Sun
Plants use this energy to make their own food.
You can add as many or as few consumers as you would like.
Green Plants Only
Decomposers Only
Nutrients and other Matter

Nutrient Cycles Game
Teacher Preparation

Materials

- Playing pieces for 4-6 players
- Small Post-it notes for students to write their names on to mark starting point
- Game board
- 54 playing cards
- Encounter Cards sheet to be photocopied and put on back of playing cards
- Timer (a clock will work fine)

Background

Many students have a difficult time understanding how nutrients are cycled through an ecosystem. Ecosystem interactions are not obvious and students find it hard to grasp the underlying processes. Even if students understand how nutrients move in the process of decay, or how animals and plants get nutrients from their food, they have trouble understanding that all of these processes help to explain how nutrients flow on the scale of an ecosystem. This game aims to reinforce the idea that these interactions do not occur in a linear pattern, but that nutrients flow through ecosystems in cyclic patterns. Also, this game supports the understanding that matter is neither created nor destroyed in this process.

Goal

This game helps students think about how nutrients move through an ecosystem. As players, students represent the atoms of nutrients that move through a particular ecosystem. The goal of the game is to keep moving, therefore, whoever moves the most number of spaces (arrows) in a given amount of time wins the game. NOTE: Make sure your students realize that atoms of nutrients do not have goals and that there is no particular value to a nutrient in moving through the nutrient cycle quickly. The purpose of the goal in the game is to underscore the cyclic nature of nutrient recycling.

Getting Started

- Assemble the game board by taping the two halves together. You can also download the full-sized version of the game board from our website at http://pzweb.harvard.edu/ucp/curriculum/ecosystems/ . To print out the full-sized game board, you will need access to large-scale printers, which are available at many copy centers.
- Print the Encounter Cards with the images on one side, then feed those sheets through the printer again to print the backsides of the cards (the side labeled "Encounter Card"). The images and the "Encounter Card" rectangles are the same size and should line up when you print them. Cut to make individual cards.
- Play the game with groups of 4-6 students.

Playing the Game

See *Nutrient Cycles Game Directions* on page 91 for instruction on playing the game.

Questions for Students to Think About as They Play

1. Why do players move many spaces in some encounters and only one in others?
2. Why do players lose turns in other encounters?
3. Why is the path of nutrients shown with two yellow arrows in connected circles? What does that tell you about how atoms move through ecosystems?

Follow-up Questions

1. Why was there no official start point or end point in this game?

   There is no official starting point to this game because in a circle, there is no start or finish. Letting students choose where they want to begin helps to show that matter is neither created nor destroyed. Rather, nutrients cycle through an ecosystem as part of a non-reducible cycle.

2. Why is the path of nutrients shown with two yellow arrows in connected circles? If nutrients are transferred by interactions between two specific things, why aren't the lines drawn back and forth between two animals or plants on the board? What does that tell you about how atoms move through ecosystems?

   The pattern on the game board aims to reinforce the idea that nutrients do not flow in a linear pattern. An atom of carbon may flow from plant to insect to bird, or it may flow from bear to human to soil. The overall circular pattern aims to show that there is no one-way path that nutrients take in cycling in an ecosystem.

3. What were some of the encounters that made you lose a turn? What do they tell you about how nutrients move in an ecosystem?

   Logging and harvesting of foodstuffs (in the game, mushrooms) can cause ecosystems to lose nutrients. In the case of logging, carbon stored inside woody and leaf material is lost when it is taken to the lumber mill, or to someone's home via a new table. When the vegetative cover that helped regulate nutrient cycling is removed, nutrients, especially nitrate, may also be washed away into the local watershed. In this way, large-scale deforestation can cause leaching.

   Because matter cannot be created or destroyed, however, students may argue that nutrients are never completely "lost." Assure them that this is a good point, but nutrients can be transferred out of a particular ecosystem. Because ecosystems may be fragile, even slight changes in nutrient cycling may have *large impacts on the overall function of the ecosystem.*

4. Can ecosystems "lose" nutrients? If so, where do they go? If not, where do they go?

   This question allows students to create their own model of nutrient cycling and apply what they've learned about how ecosystems function. Students' models should show that there is no starting point or ending point involved in nutrient cycling. After nutrients are broken down, they become available to organisms from non-living sources: soil, water, and air. In this way, they continue cycling throughout the ecosystem.

   Students' models may look very similar to the pattern depicted on the game board, or they may be different. Students do not necessarily need to draw a perfect circle as shown on the game board. The key understanding that students' models should reflect is that there is no start point and no end point in the path of nutrient cycling.

5. The game focused on moving through the cycle as many times as possible. This was to help make the game fun for the players. What are some instances when the recycling process might take a long time? What are some instances when it might happen quickly? How might slow or fast recycling impact the ecosystem? Ultimately, does the speed matter? Why or why not?

   The speed of nutrient recycling varies a great deal depending on what type of matter it is part of. Nutrients may stay "locked" in unusable forms for many thousands of years, such as in rock. In other cases, however, nutrients may cycle relatively quickly, such as in the decomposition of leaf litter on a forest floor. Speed of recycling is also a characteristic of the ecosystem. In a balanced ecosystem, the speed of recycling keeps pace with the demand.

6. We've learned about the importance of decomposers, but what happens to the nutrients after they get broken down into soil?

   Once nutrients are broken down into soil, they may be absorbed through roots of plants, taken in by organisms in the soil, or leached into nearby watersheds via runoff. Nutrients then pass through the food chain as plants, are then eaten by herbivores, and then are eaten by omnivores or carnivores, etc. When organisms die, the nutrients are returned to the soil and the cycle begins again.

7. Can you draw your own path to show how nutrients flow in an ecosystem?

   Students should come up with their own models for thinking about how nutrients pass through an ecosystem. By creating a scenario that depicts a nutrient cycle, students think about the variables involved in the process of nutrient cycling.

Nutrient Cycles Game
Card Explanations

Bacteria

"These tiny bacteria helped you, a nutrient, move from the soil to the roots of a plant. Move ahead 2 spaces."

This card helps students to think on a microscopic level about how nutrients are assimilated by plants from the soil. Nitrogen is an important example. Nitrogen as it exists in the air – nitrogen gas (N_2) – is un-useable in the living world. The forms that *are* useable are nitrate (NO_3) and ammonia (NH_3). Nitrogen-fixing bacteria that live in the soil and in the roots of certain plants (e.g., legumes) take in nitrogen gas molecules (N_2) and transfer the nitrogen into ammonia molecules (NH_3). Nitrifying bacteria take in ammonia (NH_3) and transfer the nitrogen into nitrate molecules (NO_3). Nitrogen in these forms can then enter and be used by plants.

Because it is an essential function to help move nutrients through terrestrial ecosystems, the player-nutrients move two spaces.

"Microbes help you decompose. Move ahead 2 spaces."

This card also helps students think about how nutrients transfer on a microscopic level. Microbes include a diverse range of microscopic organisms, primarily from the Eubacteria and Archaea (bacteria and bacteria-like organisms) and Protists (mostly single-celled plant-like, animal-like, and fungus-like organisms). They play an essential role in decomposition by helping release nutrients.

Students get to move two spaces because microbes are ubiquitous and play a vital role in nutrient cycling.

Plants

"Sunshine! Through photosynthesis, these plants make their own nutrients. Move ahead 3 spaces."

"As a nutrient, you help these plants grow. Move ahead 3 spaces."

"April Showers! Along with carbon dioxide and sunlight, the rain helps these plants make sugar and oxygen. Eventually, these nutrients will be cycled through the ecosystem. Move ahead 3 spaces."

These cards help students to understand that plants play an important role in supplying ecosystems with nutrients. Plants are called *autotrophs*, which means "self-feeder." They create some of their own nutrients through photosynthesis. By using carbon dioxide, water, and light energy, they form sugar, oxygen and water ($6CO_2 + 12\ H_2O + \text{Light energy} \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$). The sugar acts as a primary source of matter and energy for the plant. Two primary ways in which plants provide nutrients to the ecosystem are by being consumed or through decomposition.

With this series of plant cards, students move three spaces to emphasize the important role that plants as primary producers to fuel nutrient cycling.

Animals

- ***Large mammals***

“This big bear ate the berries you were in for breakfast. Move ahead 1 space.”

“This deer ate the leaf you were in. Move ahead 1 space.”

“Once you were a nutrient inside this little prairie dog. Now, you are stored inside a wolf’s belly. Move ahead 2 spaces.”

These cards help students think about one primary way that nutrients are passed through an ecosystem: consumption by herbivores, carnivores, and omnivores. When a bear, an omnivore, eats a berry, the berries' sugar, which contains carbon and other nutrients in the berry are passed to the bear. Similarly, when a deer, an herbivore, eats a leaf, the carbon and other nutrients inside the leaf are transferred to the deer.

These are both instances of primary consumption. Thus, they are worth only one space. When a wolf, a carnivore, eats a prairie dog, however, it is considered secondary consumption. Therefore, in the game, the player moves ahead 2 spaces, because more matter has been transferred between the prey and its predator.

"Children playing help leaves decompose. As a nutrient, the leaf you are in is one step closer to becoming part of the soil."

This card helps students understand that humans and other animals can help decomposition through mechanical processes such as playing in a leaf pile, walking through a forest, or by other physical means. Of all the processes that help nutrients cycle through decomposition, human impact is relatively small, compared to fungi or bacteria. Therefore, the card is only worth one space.

"This bear ate a lot of berries. He passed along what was left over, providing extra nutrients to the ecosystem. Move ahead 4 spaces."

“You were excreted by this deer. Move ahead 4 space.”

These cards help students think about the effect of nutrients as they are digested and processed by animals and passed from the body as solid or liquid wastes. These wastes are loaded with nutrients that animals didn't use for growth and maintenance. Because animal wastes are nutrient-rich, this card is worth 4 spaces.

NOTE: Elimination is the process of passing solid wastes. Excretion is the process of passing liquid (nitrogenous) wastes.

- ***Worms***

  "When this worm digested organic matter, it was broken up into the soil and nutrients were released. You became free to move around the ecosystem. Move ahead 1 space."

  This card helps students to think about how the process of decomposition helps break up organic matter. When things decompose, nutrients are released. Because worms are so ubiquitous in rich soil, the encounter is worth two spaces.

- ***Insects***

  "You took flight with this butterfly. Move ahead 1 space."

  "As a tiny nutrient inside some pollen, you catch a free ride on these bees' antennae! Move ahead 1 space."

  "This guy chewed you up and spat you out. Move ahead 2 spaces."

  These cards help students to consider the role of insects in nutrient cycling. The card depicting the bee and the butterfly help students consider other physical ways that nutrients flow in an ecosystem: through bits of organic material stuck to animal carriers. Also, beetles and other insects play an important role in decomposition. In these ways, as well as by eating and generating wastes, insects help to facilitate nutrient cycling.

  The number of spaces students move varies because the ways in which insects contribute to nutrient cycling varies. They play a large role in decomposition, but the movement of nutrients, which stick to the outside of their bodies, is relatively small.

Fungi

"You move from the soil to the inside of these fungi. Move ahead 1 space."

This card helps students to understand that fungi play a vital role in decomposition. Fungi are classified in their own kingdom. They acquire their nutrients by absorbing small organic molecules from their surroundings. Along with bacteria, fungi are the primary decomposers in ecosystems. Without fungi and bacteria, carbon, nitrogen, and other nutrients would remain unavailable for new generations of life.

Natural Disturbance

"Wildfire! Nutrients released during a small, natural fire. Move ahead 5 spaces."

This card helps students understand that wildfire is a natural part of the process of nutrient cycling in an ecosystem. Although large fires, such as the catastrophic 1988 fires in Yellowstone, can be so intense that nutrients may be lost, smaller fires actually help release nutrients. In cool temperate areas, decay is slow and logs, leaves, and needles pile up on the forest floor. Fire reduces this material to mineral-rich ash. Nutrients are released and recycled during this process. Fire also creates openings in the forest. Sunlight penetrates these gaps, warming the soil and stimulating new growth from seeds and roots.

Removal of Nutrients

"This mushroom was harvested and sent to the supermarket. Instead of decomposing on the forest floor, you'll be preserved in the mushroom, inside a cool grocery store. Lose a turn."

"Your forest was logged. As a nutrient inside a log, you were taken to a lumber mill instead of decomposing on the forest floor. Lose a turn."

This helps students think about what happens when natural resources are taken from an ecosystem. At the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire, ecologists clear cut 15.6 acres of forest to test the effect of logging on nutrient cycling. They found that when plants are not available to regulate the flow of nutrients (and are removed with their nutrient stored) nutrients are lost from the ecosystem.

Although the biomass of fungi harvested by humans is far less than the biomass of trees, the same things happen on a smaller scale. That is, since fungi play an essential role in decomposition, when they are taken from an ecosystem, those nutrients that would otherwise be released are kept in unusable forms for the rest of the ecosystem.

Nutrient Cycles Game
Directions

Goal

This game helps us think about how nutrients move through an ecosystem. As players, you are atoms of nutrients that move through a particular ecosystem. The goal as a nutrient atom in the ecosystem is to keep moving. Therefore, whoever moves the most number of spaces (arrows) in a given amount of time wins the game. There is no real rush, however. You should take time to talk with your group about where you are and what is happening to your atom at each turn. The group must make a decision about whether or not you move, according to the type of Encounter Card you draw and your location on the board.

Getting Started

- Place your piece on any yellow arrow on the board. You decide where to start.
- Write your name on a small Post-it note and mark your starting spot with it.
- Find a fair way to decide who goes first, then take turns in a clockwise pattern.

Playing the Game

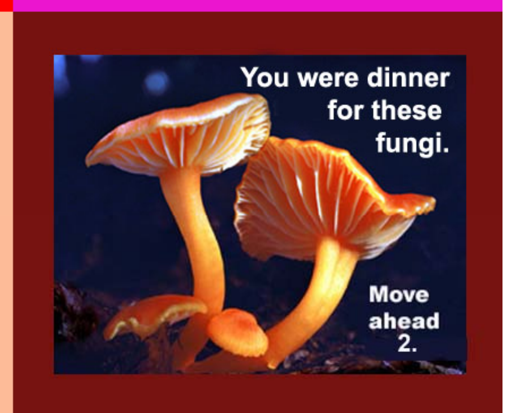
1. Draw Encounter Cards from the pile on the game board. These Encounter Cards will tell you what type of organism you, the atom, are in at a particular moment. The cards also give you instructions on how to move.
2. You can only move if you are in a location on the board where that interaction might actually occur. For example, if you draw a card that says that an owl ate you, but your piece is located underground, you cannot move.
3. Discuss as a group whether or not the interaction is likely to occur, depending on where you are located on the board.
4. Discuss with the group what you think is happening to you, the atom, during each of these Encounters.
5. After twenty minutes or so, the teacher will say, "Time is up." After the game, the class will discuss it and the questions below.

Questions to Think About

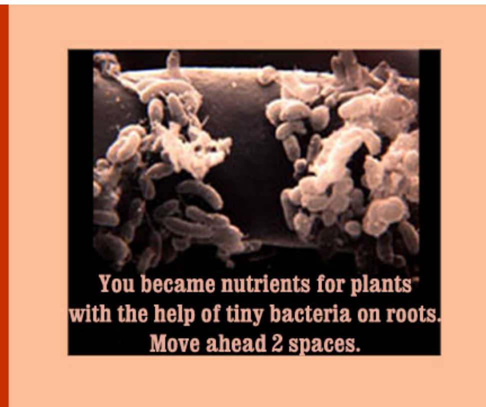
1. Why do you move many spaces in some encounters and only one in others?
2. Why do you lose turns in some encounters?
3. Why is the path of nutrients shown with two yellow arrows in connected circles? What does that tell you about how atoms move through ecosystems?
4. Was it difficult to remember that you were an atom at times? Which game pieces had wording that made it most difficult? Compare for instance, “The Big-Eyed Owl spies you” to “You become part of the soil.”

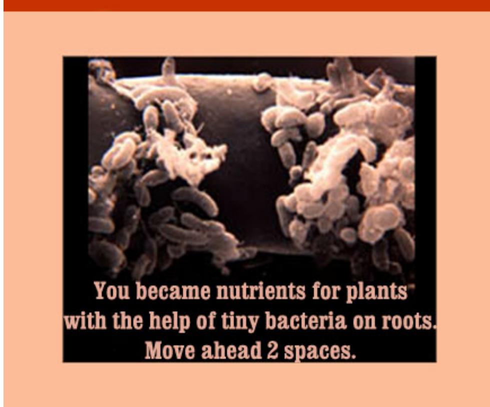
**This game was created by Sarah Mittlefehldt.*

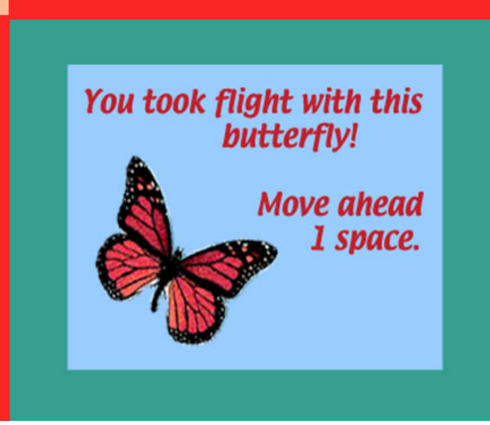
Nutrient Cycles Game Cards



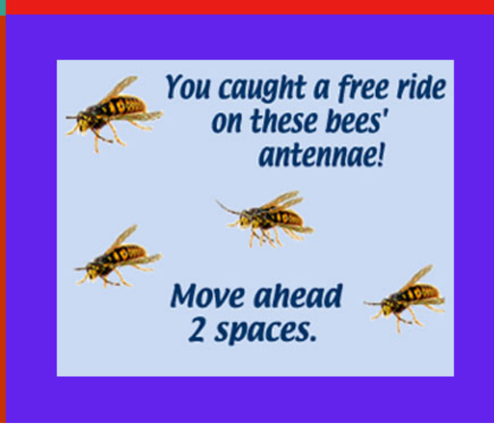
Nutrient Cycles Game Cards







Nutrient Cycles Game Cards



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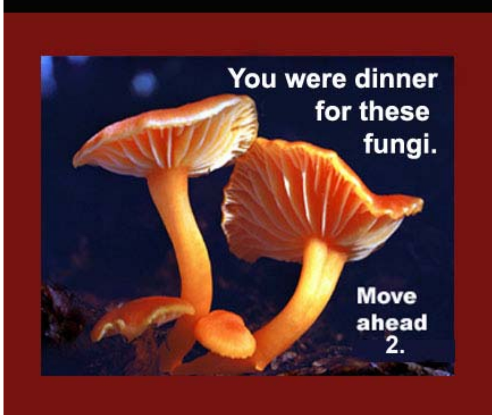

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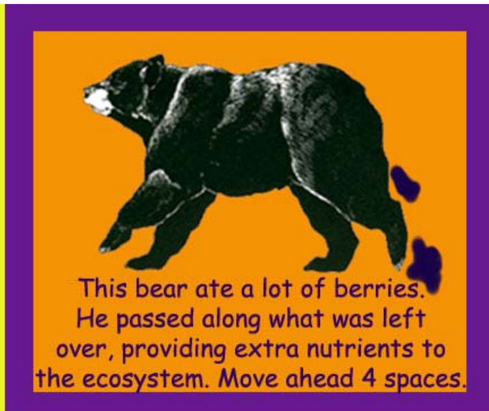

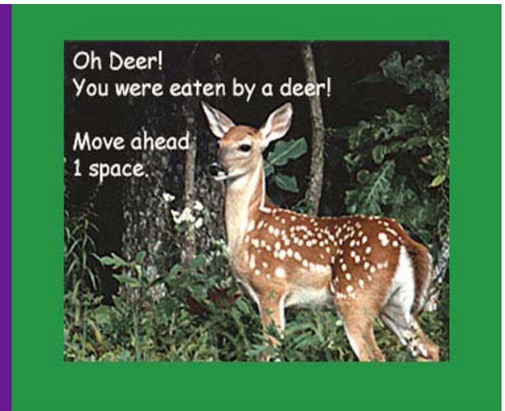

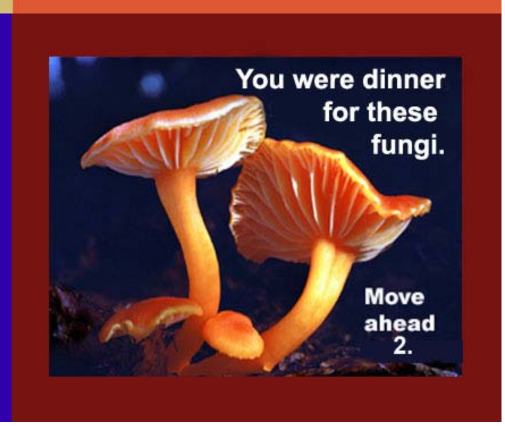

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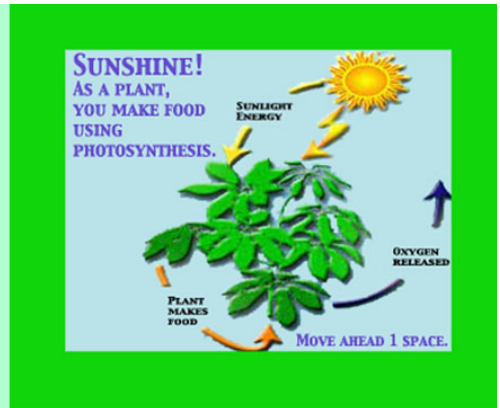
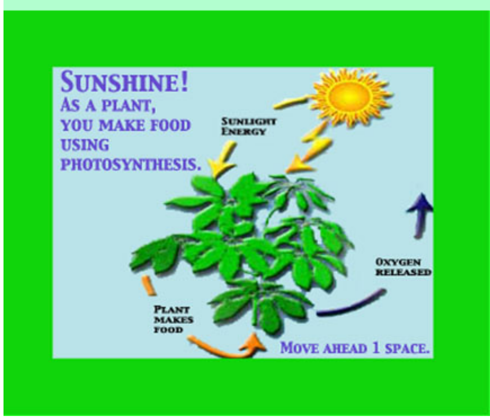
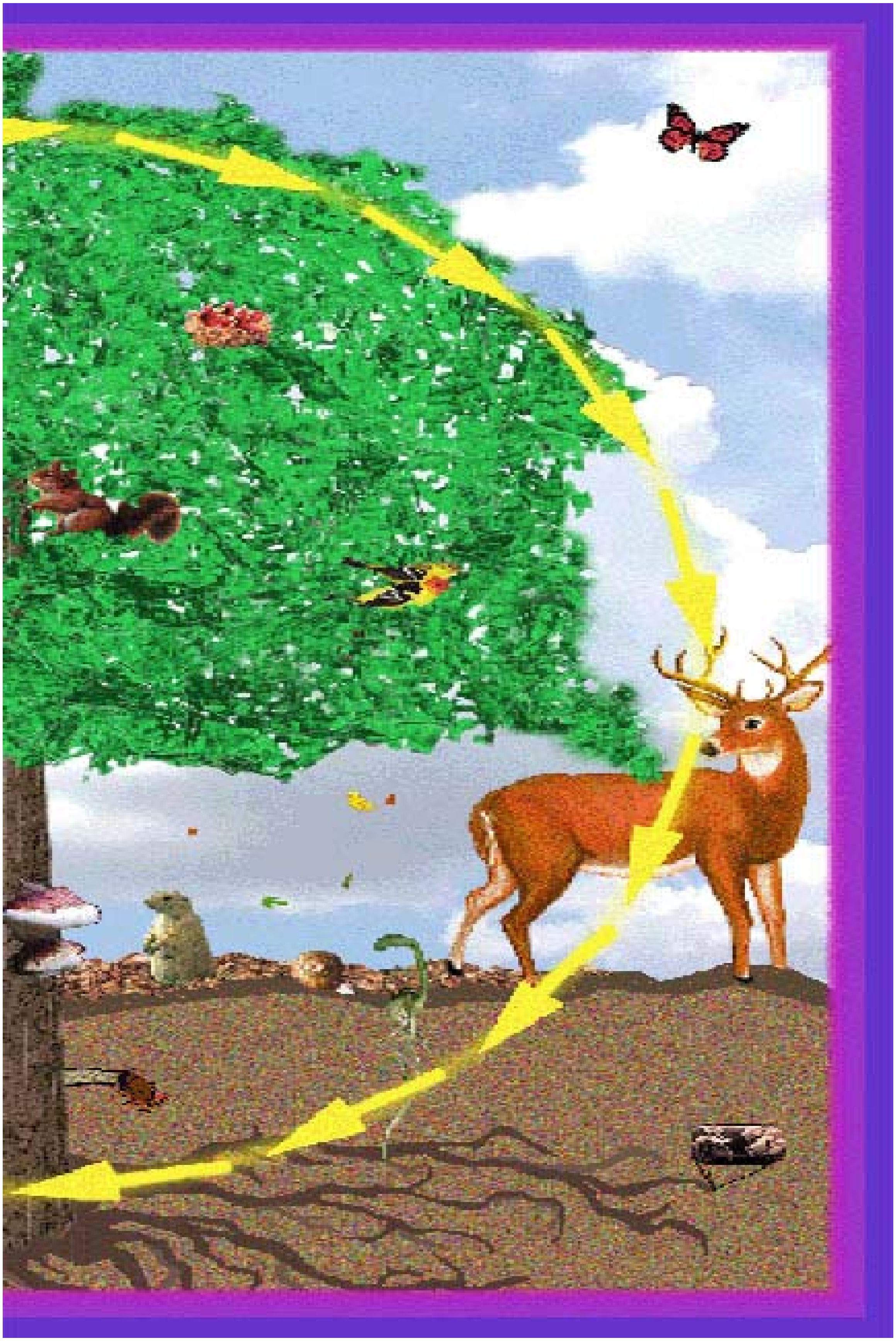




Nutrient Cycles Game Cards
(Photocopy and put on the back of the playing cards.)

ENCOUNTER CARDS	ENCOUNTER CARDS	ENCOUNTER CARDS
ENCOUNTER CARDS	ENCOUNTER CARDS	ENCOUNTER CARDS
ENCOUNTER CARDS	ENCOUNTER CARDS	ENCOUNTER CARDS

Nutrient Cycles Game Board



Endnotes for Section 2

[1]Grotzer, T.A. & Bell-Basca B. (2000, April). Helping Students to Grasp the Underlying Causal Structures when Learning About Ecosystems: How Does it Impact Understanding? Paper presented at the annual conference of the National Association for Research in Science Teaching, New Orleans, LA.

Hogan, K. (1994). *Eco-Inquiry: A Guide to Ecological Learning Experiences for the Upper Elementary/Middle Grades*. Dubuque, Iowa: Kendall Hunt.

[2]This discussion is adapted from Hogan, K. (1994). *Eco-Inquiry: A Guide to Ecological Learning Experiences for the Upper Elementary/Middle Grades*. Dubuque, Iowa: Kendall Hunt.

[3]*The Puzzle of the Rotting Log Video*, produced by MBG Learning Network, a joint venture of the Missouri Botanical Garden and The Evergreen Project Inc. Video can be purchased on-line at: <http://www.ajschools.com/mall/videos/>

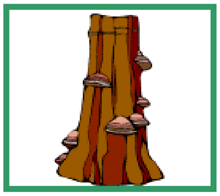
[4]*The Forest Log*, written by James R. Newton, 1980, New York: Thomas Y. Crowell Co. This book is out of print, however it may be found in public libraries. Many on-line book sellers list out-of-print and used books.

[5]*Death is Natural*, written by L. Pringle, 1977, New York: Four Winds Press; 1991, New York: Morrow Junior books. This book is out of print, however it may be found in public libraries. Many on-line book sellers list out-of-print and used books.

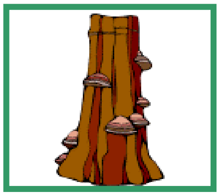
SECTION 3

Thinking About Obvious and Non-Obvious Causes of Decomposition

This section addresses students' tendency to consider only the most obvious causes of an effect. It helps students to see that non-obvious microbes are the primary decomposers, that things don't "fall apart" on their own, and that detritivores that we can see, such as earthworms and sow bugs, are responsible for only a small percentage of decomposition.



Section 3 Table of Contents
Thinking About Obvious and Non-Obvious Causes of Decomposition



Thinking About Obvious and Non-Obvious Causes of Decomposition

This section compares a compost tank with worms to one without to help students realize that the decomposers we can see, such as earthworms and sow bugs, are responsible for only a small percentage of decomposition. Microbes are the primary decomposers.

Understanding Goals

Subject Matter

- “Decomposers” are organisms that cause things to decay by eating (or digesting) organic matter.
- Some decomposers, such as earthworms, are more obvious than others, such as microbes.
- Some decomposers are microbes—tiny organisms that are typically too small to see with just your eyes.
- Microbes do most of work of decomposition.

Causality

- There are obvious and non-obvious causes for decay.
- When causes are not obvious, it can make it harder to see causal patterns, such as the cyclic causal pattern involved in decay.

Background Information

Microbes Do Most of the Recycling

Living things called “decomposers” break down organic matter by digesting it. Some decomposers that we can see are worms, mites, and sow bugs. Other decomposers are microbes, tiny organisms such as fungi and bacteria. They are not easily visible. Whereas larger decomposer organisms that children are familiar with are responsible for some of the physical breakdown of organic matter, microbes are the primary agents that recycle dead matter into its basic elements.

Typically, children identify physical factors as the cause of things like branches or fallen fruit, for instance, breaking down. Their explanations may include people or animals stepping on the thing to make it break apart, or rain and wind as the cause for materials breaking down and disappearing. They may also say that earthworms or bugs eating branches or fallen fruit cause decay. Sometimes children will simply say that over time things just disappear into the soil

Microbes Are Everywhere

Microbes are all around in the physical environment, feeding on and breaking down dead matter. Fungi and bacteria are two common microbes. Individual bacteria are too small to see with the naked eye, as are some fungi. Some fungi can be seen if there are large enough numbers of them growing near each other. Mold seen on and in rotten food is a type of fungus. The white fuzz is called hyphae. Hyphae are threadlike strands of the fungus that take in food. On the hyphae, there are "spores," which look like colored powder, and which the fungi use to reproduce.

Matter Recycling

Decomposition recycles dead matter by reducing it to its basic substances, which are then released into the physical environment and may become part of living things once again. A nutrient cycle is the flow of nutrients from living things to the physical environment and back again. In a nutrient cycle, nutrients are passed along from plants to animals, from animals to animals, from dead plants and animals to decomposers, and finally from decomposers back to plants via the physical environment (i.e. soil, air and water).

Microbes Are Not Obvious, But The Result of Their Actions Is Obvious

It is common to focus only on obvious causes of events unless there is some evidence to suggest that the obvious causes one can detect do not completely explain what is going on. The activities in this section help students notice the role of non-obvious, or in this case microscopic, decomposers. It does this by comparing two tanks of decomposing matter and revealing that even the one without the obvious decomposers is decaying. This encourages many students to believe that there could be microscopic decomposers at work.

Dead Matter Doesn't Just Fall Apart

There is still a remaining challenge to understanding decomposition. Children (from infancy) typically believe that you can't have a causeless effect. If something is changing, then something must be causing it, right? However, in the case of decomposition, many students believe that things just break down on their own, similar to how a toy can break into parts. They draw an analogy to objects falling apart rather than being acted upon by tiny decomposers at work. This section attempts to address this by having students observe the growth of mold in a reinforcement activity and to discuss what happens when food is "preserved."

Microbes "Eat" or Digest Dead Matter

This section often refers to microbes eating or digesting food. Students may think of eating in a very active sense, the way that they pick up a piece of food and eat it. It may not seem to them that the microbes are eating. Also, it can be hard for them to think of something as small and undifferentiated as a microbe being alive and doing things like digesting food, growing, etc.[1] It is a good idea to address this with students. Explain that microbes digest food. They secrete digestive chemicals outside their bodies that break down the food, and then they absorb it. This is really the same as the way animals eat food, even though it might seem more passive.

Notes to the Teacher

Timing: The activities in this section require at least two sessions, separated by six to eight weeks (and longer if possible.) They involve setting up two worm tanks and observing what happens in them over time. The initial lesson should occur near the beginning of your unit to give enough time for observable changes to take place.

Detritivores vs. Decomposers: Here is a technical point to consider introducing to your students. Most scientists refer to the larger decomposers that you can see as "detritivores," and call bacteria and fungi "decomposers." To simplify matters, both are referred to as "decomposers" in this module. However, older students could certainly learn to make this distinction.

The Difficulty of Demonstrating Conservation of Matter: This lesson focuses on noticing that a tank of compost without worms undergoes changes (the particles become smaller and the level in the tank goes down) and that tiny microbes are responsible for those changes. Students are asked to make observations. You may be tempted to also try to teach a secondary concept—that the amount of actual matter is conserved. This is difficult to illustrate for a number of reasons. There are a lot of other variables that influence the outcome, such as the exactness of the scales, differences in the weight of the actual worm tanks, differences in how much the tanks are watered or differences in rates of evaporation depending upon where they are put. However, even if you could control all of those variables perfectly, you would still not be able to show that matter is conserved. This is because gases are a product of decomposition. If you include the gases and the matter in the tank, then the matter is conserved, but there is no straightforward way to show this (because the tanks allow gas exchange with the atmosphere.)

If you want to discuss the idea of gas exchange, engage the students in a discussion about how we need air, more specifically oxygen (O_2), to live. We exhale carbon dioxide (CO_2). Worms as animals need oxygen and exhale carbon dioxide. Microbes also need oxygen and exhale carbon dioxide. This helps to explain the loss of matter from the tanks. It also underscores the importance of plants because they need carbon dioxide and give off oxygen. (They also need oxygen and release carbon dioxide as they "burn" their own food energy after making it.) One issue that will come up is that it is cognitively difficult for students to view gases as matter. Therefore, they may have a hard time relating the explanation to the loss of matter from both tanks.

Lesson Activity: Comparing Worm and Worm-free Compost Tanks

Materials

- Two identical tanks (High and narrow will give the best results.)
- Soil (There should be enough for 2-3 inches in the bottom of each tank. Be sure to NOT use sterilized potting soil.)
- Composted leaves and/or other organic matter (There should be enough for 2-3 inches in the bottom of each tank.)
- Slightly shredded or composted leaves (There should be enough for 3-4 inches in the bottom of each tank.)
- 12-15 worms (for a tank approximately 12”x14”x4”. Adjust up or down depending upon tank size.)
- Observation journals
- Measuring Cup

Prep Step

- Read through the background information.
- Read over the lesson plan.
- Purchase worms or dig some up in a garden.
- Gather tanks, soil, compost mixture, and leaves for compost tanks.
- Prepare observation journals for each student by either stapling together several sheets of paper or by using small composition books.
- Photocopy observation graph sheets (pp.122 and 123).

Analyze Thinking

Step 1: Gather Students’ Ideas and Questions

Explain that the activities in this lesson will help us find out more about how decay happens. Review students’ ideas about decay. Some common ideas that students hold include: *Decay is when something just breaks up and disappears; Physical factors such as animals, wind and rain spread it out into the dirt and make it decay; There are creatures that break it down and make it decay*. Explain that more than one of these things could be responsible for decay.

Ask, “Now that we have learned more about decay, would anyone like to change their ideas?” Gather ideas.

Worms in the Classroom

Acquiring Worms

Worms can be acquired by digging them up in the garden, buying them at a bait store, or ordering them from an educational supplier. If you plan to dig them up, look in a rich soil area such as a garden, under rocks or logs, or on the lawn after a heavy rain. Going out at night with a flashlight after a heavy rain is also a good way to find them. Buying them at a bait shop is fairly straightforward. Most large biology and educational supply companies sell worm 'packages.' Here are a few places to try:

- Carolina Biological: http://www.carolina.com, 1-800-334-5551
- Nasco: http://www.enasco.com/prod/Home?seqid=1, 1-800-558-9595
- Insect Lore: http://www.insectlore.com/, 1-800-LIVEBUG
- Aquatic Eco-Systems, Inc.: http://www.aquaticeco.com/, 1-407-886-3939

Caring for Worms

To care for your worms, keep them in a large tank or bucket filled with rich soil. Adding things like sawdust, compost, dead leaves, manure, or peat will improve the quality of your soil. Water the tank enough to keep it damp, but not wet. Keep it in the coolest part of the classroom; worms are happiest between 10 and 15° C (50 and 60° F). Typically the worms need to be fed occasionally with small amounts of organic matter such as grass clippings, fruit peels, or dried leaves. (However, in the worm tank experiment, include the organic matter from the outset so that you won't have to add to the matter during the experiment.) Planting grass seeds in the soil is a good way to keep an eye on moisture in the tank: the amount of water needed to keep the grass healthy will also keep the worms happy.[2]

RECAST Thinking

Step 2: Make Predictions as a Group Comparing Worm and Worm-free Compost Tanks

Explain that a worm compost tank is a tank filled with compost and worms. Ask: “What do you think happens to the organic matter in a worm compost tank?” Record the students’ predictions.

Have students take a few moments to think about what would happen <u>without</u> these decomposers. Then ask: “What do you think would happen if there were no worms to eat the dead plants and things (in a worm-free tank)?” Track students’ predictions on the board or on chart paper. Ask students to justify their predictions with reasons.

If students did the decomposition chamber in the last section, ask them to consider what happened in considering what might happen here. How is the decomposition chamber similar to and different from the worm and worm-free tanks?

Step 3: Explain the Activity

Explain to your students that in order to know if their predictions are correct, they can gather some evidence by creating a test. Ask: "What might you do to test out your predictions about what would happen if there were no decomposers?" Collect ideas.

Step 4: Set up the Tanks

- Show students two tanks identical tanks.
- Measure out the same amount of soil for each tank.
- Spread it in the bottom of each tank.
- Do the same with the compost mixture, and then with the shredded leaves. (As you add each layer, try not to disturb the layer below it, so it replicates the layers that might be found on the forest floor.)
- Make sure that there are no worms in the compost and make sure the students agree with you.
- Sprinkle each tank with the same amount of water.
- To one of the tanks, add 12-15 worms. Label it "Worm Tank."
- Label the other tank "Worm-free Tank."
- Leave the top of the tanks open. A piece of screen could be stretched across each tank.

Step 5: Discuss the Design of the Comparison

Ask, "Why should there be both a worm-free compost tank and a worm compost tank?" Discuss the importance of being able to compare what happens in the two tanks.

Ask, "What kinds of things should be equal between the two tanks in our test?" Students saw you put the same amount of soil, compost, and leaves in both tanks. Some may realize that other things such as light, water, heat, etc. will matter. Make sure students realize that by making everything the same (controlling for the other variables) except the worms, you can see the effect of the worms.

Ask, "What would you look for as evidence to support or contradict your predictions?" Generate a list of things to look for. (For instance, measuring the height of the stuff in the tank, noting what it looks like, etc.) Over the next few weeks, continue to revise the list as students realize new types of evidence.

Step 6: Make Predictions as Individuals Comparing Worm and Worm-free Compost Tanks

Ask students to write down their individual predictions in their journals (or on paper if they don't keep journals.) Have them answer the following questions:

- What will happen to the leaves and soil in the worm compost tank versus those in the worm-free compost tank?

- Why do you think this will happen? (Give reasons for your predictions, including information you already know about decay.)
- What evidence will you look for to tell you what is happening?
- What other questions do you have? (List things that you want to find out more about.)

Step 7: Arrange for Care of the Tanks

Create a schedule for observing the compost tanks and for periodically watering them. (Each tank should receive exactly the same amount of water. Don't over-water as it will drown the worms.) Keep the tanks out of direct sunlight. Put them in the coolest, darkest location in the classroom.

Assign students to make observations every few days, including the kinds of observations they have identified as providing evidence for their predictions. (These might include measuring how high the pile is in addition to visible changes and smells.)

Ask students to independently observe the compost tanks and to record their observations in their journals using the guidelines generated in class and any others they added in their journal for what makes good evidence.

Note to the Teacher: In approximately 6-8 weeks, have a follow-up lesson where students discuss what they saw and learned from the activity.

Step 8: Revisit the Worm Tanks

Come back to this lesson after approximately six weeks have passed. (The photos on p. 121 illustrate the types of change that you should see over time in the worm and worm-free tanks.)

Discuss the observations and measurements that students made over time. Invite students to share. Compare their observations and measurements of the two tanks. Typically students notice that the worm tank appears to have increased in volume and then to have decreased. The worm-free tank typically decreases slowly. The initial increase in the worm tank is due to the burrows that the worms build, which push the organic matter aside.

Ask, "How can you explain the differences? What do you think is going on?" Gather ideas.

Students' Predictions for the Worm and Worm-free Tanks

What do you predict will happen in the Worm and Worm-free Tanks?

1. After a few days the leaves in the worm tank will disappear. Worms will eat them.
2. The worm tank will weigh less.
3. The leaves in the worm tank will get smaller and some will turn to soil.
4. In the worm tank, leaves that have been bitten by decomposers will break down.
5. Nothing will happen in the worm free-tank.
6. The leaves will go down in the worm tank and the leaves will stay the same in the worm-free tank.
7. Stuff will fall apart in both tanks.
8. The worms will eat all the leaves and need more food.

Step 9: Consider the Results in Each Tank

First, consider the worm tank. Ask: "Why does it look like there is less in the tank than there was?" Help students to realize that the worms are digesting and decreasing the space that the compost takes up because they are making the pieces smaller.

Ask, "Is the stuff in the tank actually disappearing?" Gather ideas. Explain that the matter is not actually disappearing, but it takes up less space because the tiny particles fit more closely together than big particles. (There are a couple of ways to show this idea. See the related box on page 115.) It also looks like less because gases are a product of decomposition. So some of what the decomposers eat goes into the air. This isn't the same as disappearing. You just can't see it.

Next consider the worm-free tank. Gather ideas. Some students will think that the compost just falls apart on its own, others may think that there are worms that we didn't catch, others might mention little tiny bugs or microbes. Explain that there are tiny organisms called microbes that are breaking down the dead matter. They are so small that you cannot see individual organisms, but when they grow as a group, you can see them. They do MOST of the decomposing—not worms and other decomposers that you can see.

Ask, "How many of you have ever seen mold or fungi growing on food? Explain that these are microbes. They digest what they are growing on and break it down into little particles that green plants and other organisms need to grow.

Note to Teacher: Some students will not be easily convinced that things don't just fall apart on their own. You could address this though the bread mold activities on pages 124 and 126.

Explore Causality

Step 10: Contrast Obvious and Non-Obvious Causes

Ask, "Why do you think it was hard to know that the microbes were making the leaves and compost decompose?" Gather ideas. Explain to students that when they are looking for the cause of something, it is a natural tendency to look for an explanation that they can see (or hear, smell, etc.). If they can't find an obvious cause, then they might look for something that is not so obvious. In the case of decomposition, they can see worms and sow bugs, etc., so they may assume that these creatures are making decomposition happen. They might not think to check if something else is ALSO responsible for decomposition. Matter recycling is a BIG job and there would have to be a lot of worms, etc. to do all that decomposing. It turns out that there are millions of microbes at work and that they do MOST of the decomposing.

Review, Extend, Apply

Step 11: Review the Understanding Goals

Discuss the Understanding Goals with students to be sure that they understand them.

Step 12: Apply the Concepts More Broadly

Say, “Consider how we preserve foods. What makes it possible to “preserve” them? If things did just fall apart on their own, how is it possible that heating or sterilizing make them last longer? What does sterilization actually do?” (It destroys the microbes responsible for decay.) Discuss students’ ideas.

Ask, “What about pressure-treated lumber that contains chemicals to make it last longer? What is going on there?” (The chemicals kill the microbes that would digest the wood and break it down to recycle it.)

If nothing has disappeared, how come it looks like there is less stuff in the tanks?

It can be hard for students to reconcile the idea that matter is NOT disappearing when it looks like there is less in the tanks than there was before. How can this be so? It has to do with the size of the particles and how they are arranged. There are a couple of ways to show this to students. You could show this idea by taking balls or marbles of different sizes (but the same material) and showing how if you weigh out equal amounts of bigger and smaller marbles, so that you have the same amount of stuff, the smaller marbles pack into a smaller amount of space.) Another possibility is to demonstrate the difference by chopping something up finely, as with the apples in the picture.

Ask students, "How come there appears to be less apple in the blender once it has been chopped up?" What is happening is that the particles have less space between them, so they are closer together and look like there is less apple. Show your students the first image of the apple slices. Ask if they think that the apple is taking up as little space as possible. Could the pieces be re-arranged so that they are closer together? Ask them to point out any place where the apple pieces are not touching and where they think there is space between the slices.

Next, show them the second image of the chopped up apple. Ask them if they think this apple takes up the same, more, or less space. Ask them to explain why it would or would not take up less space. Explain that it is the same apple. Ask them to imagine that the apple slices are particles in the worm tanks from the day the tanks were put together. Imagine that each slice is a dirt molecule. There is room between these particles. Over time, as the worms move around and the gases escape, the particles get closer and closer together and the height of the material in the tank goes down and it appears that there is a lot less of the matter than there was on the first day. It's like the apple: in the first image there is a lot of space in between the slices. Once the apples were chopped up into smaller pieces, the particles fit closer together, so it appears that there is less apple even though the amount hasn't changed.

Reinforcement Activities

Earthworms: Nature's Soil Builders Video[3] – This film will help students understand the role of earthworms as decomposers in the ecosystem and the processes by which they improve soil.

Collecting Evidence for Non-Obvious Decomposers: Growing Microbes on Bread (p. 124) – This activity helps students understand that microbes are so tiny that you can't see them, but you can witness their effects. It is a particularly useful support activity for students who are unconvinced that microbes exist.

Learning About Preservatives: Bakery Bread Versus Store Bought Bread (p.126) – This activity will help children learn about the role of preservatives in food and how they act to slow down decomposition. Students will compare what happens over time to slices of store-bought bread containing preservatives to fresh bread from a bakery, which contains no preservatives.

The Good, The Bad and The Ugly: The Many Sides of Bacteria (p.127) – This activity aims to help students recognize that bacteria have many good functions, such as helping to recycle nutrients for plants, helping to make cheese and yogurt, and helping humans digest food, but that bacteria also have some not-so-good functions, such as causing illnesses.

RESOURCES FOR SECTION 3

Picture of Practice

Time-Lapse Photos of Worm and Worm-Free Tanks

Worm and Worm-Free Tank Observation sheets

Collecting Evidence for Non-Obvious Decomposers: Growing Microbes on Bread (Reinforcement Activity)

Learning about Preservatives: Bakery Bread Versus Store-Bought Bread (Reinforcement Activity)

The Good, The Bad, and The Ugly: The Many Sides of Bacteria (Reinforcement Activity)

Endnotes for Section 3

PICTURE OF PRACTICE

Discovering Non-obvious Causes of Decay: A 5th Grade Lesson on the Role of Microbe Decomposers in the Ecosystem

The following picture of practice describes a lesson in which students discuss the possible causes of decomposition when there are no visible or obvious decomposers present. Through discussion with their teacher, students discover that sometimes the causes of things are difficult to detect because they are invisible and/or take time to have a noticeable effect. Here we look in on a portion of the conversation early in the unit and then a little later in the unit, after students have had a chance to discuss their worm tank experiments.

- Mr. Miller: Let's review a little from yesterday, can anyone remind us of what decomposition is?
- Hannah: It's when something breaks down dead matter and turns it to soil.
- Mr. Miller: Okay, and we've talked about several types of decomposers. Can anyone name some of them?
- Jake: Earthworms.
- Becca: Sow bugs.
- Emily: Mushrooms.
- Carlos: Fungi.
- Mr. Miller: Now I want you to think about what would happen if something died and there were no earthworms, sow bugs, mushrooms, or fungi to break it down. What do you think would happen?
- Becca: Uh, nothing. It would just be there.
- Mr. Miller: It would just stay there? Okay. What are some other ideas?
- Jake: It would turn to soil.
- Mr. Miller: And can you say how that would happen?
- Carlos: Maybe the heat would turn it to soil.
- Sarah: Or maybe the rain would wash it away. Or wind.
- Mr. Miller: Okay, what are some other ideas?
- Ian: Maybe it would just fall apart on its own, you know, because it's so old.
- Katie: I don't think it could just fall apart on its own. I think nothing would happen, that if there aren't any worms and things, it just stays the same.
- Mr. Miller: Okay, today, we are going to set up an experiment to help us think about this question. We'll compare what happens to dead plant matter when there are worms and when there are no worms. We'll set up two tanks to compare what happens. In each of the tanks we'll put the same amount of dirt, some grass and some shredded leaf matter from outside. Then, in one of the tanks we'll put some earthworms and in the other tank we won't. We'll watch these two tanks carefully for several weeks, making observations of what's going on in each of the tanks every couple of days. What do you think will happen in each tank? Take a minute to think about what you think will happen in these two tanks.

Picture of Practice

Continued from previous page

Mr. Miller records the students' predictions on a piece of chart paper, which he saves to revisit later.

- Jacob: I think the leaves in the worm tank will get smaller and smaller. The worms will eat them.
- Emily: I think the tank with the worms will have more soil than the tank with no worms.
- Mr. Miller: Okay. And what about the worm free tank?
- Becca: I don't think anything will happen in there.
- Carlos: Yeah, in the worm tank the leaves will go down, but in the worm-free tank they will stay the same.
- Mr. Miller: Okay, and how will we be able to know that? What can we do to test some of these predictions?
- Jacob: We could see how high the stuff is in the tanks.
- Mr. Miller: Okay, we could measure it. Can anyone think of some ways that we could measure the two tanks?
- Ian: We could use a ruler to measure how tall the stuff is.
- Mr. Miller: Okay. Now, in order to have a fair test, we will need to mark the height of the matter in both tanks and to be sure that we put the same amount of stuff in each. That way we will know that if there is a difference later on, it's because of what happened and not because we put more dirt in one than in the other.

Mr. Miller goes on to explain how the class will care for the worms and observe the changes occurring in the tanks over the next 6 to 8 weeks. After this time has passed, Mr. Miller and the class gather to discuss what they have observed in the worm and worm-free tanks.

- Mr. Miller: Boys and girls, today I'd like to talk about what we have been observing in the worm and worm-free tanks. Would anyone like to share some observations with us?
- Ian: The stuff in the worm tank got higher at first and there were lots of worm trails, but then it got lower. There was less stuff after a while.
- Emily: Yeah, the stuff was disappearing.
- Mr. Miller: Do you think that it was actually disappearing, or was something else happening to it? Can it just disappear? What do we know that could help explain what happened?
- Jacob: The worms were eating the leaf matter.
- Mr. Miller: That's right. The worms were eating the leaf matter and breaking it down into smaller particles. When things are smaller, they can fit into less space. *He demonstrates by taking a couple of leaves and crunching them up so there is no air between them.* Also, some of the stuff turns into gases as the worms digest it. Therefore, there seems to be less matter in the worm tank over time. Let's talk about the worm-free tank. What happened there?
- Becca: The stuff went down over time.
- Mr. Miller: How would you explain this change? Any ideas?
- Becca: I think the stuff just broke apart as it got old.
- Ian: Maybe there were some worms in there that we didn't see.

Picture of Practice

Continued from previous page

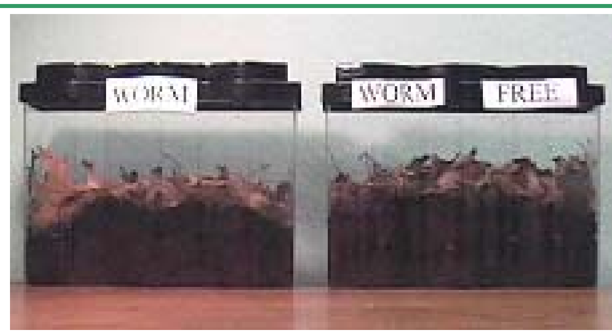
- Carlos: Or maybe there were some other tiny bugs in there.
- Sarah: There could be some other stuff in there like bacteria that maybe we don't see.
- Mr. Miller: That's an interesting idea, Sarah. Let's talk a little bit about that. Bacteria, and something else called mold, are what we call microbes. Microbes are tiny living things that you can't see without a really good microscope. But, although we can't see microbes, we can see their effects.
- Emily: But I've seen mold before. It grew on some bread we had at home.
- Jacob: There was mold on our pumpkin from last Halloween. We left it out on our steps and after it rained and it was out there a long time, it had mold stuff all over it.
- Mr. Miller: That's right, when there's enough mold all together, you actually can see it. Did you notice what happened to the pumpkin after the mold had been growing on it?
- Jacob: Yeah, it just sort of got all mushy and stuff.
- Mr. Miller: Yeah, as it grows, mold can be seen spreading like a type of fuzz on things like bread or old fruits and vegetables. Bacteria do the same kinds of thing, but because it is so small you can't really see it like you can mold. Do you think this could explain what caused the change in the worm-free tank?

Some students nod in agreement, other shake their heads and still others seem unsure one way or another.

- Mr. Miller: Well, some of you seem unconvinced that this is what's happening in the worm-free tanks. Sometimes when you can't see something, it makes it difficult to know what is going on. For example, because we can't see microbes, it makes it hard to understand the job they do in the ecosystem. Let's start an activity to help us find out more about microbes.

Mr. Miller then sets children up for collecting evidence of non-obvious decomposers using bread samples for growing mold. (This activity can be found under Reinforcement Activities, following the worm tanks experiment).

Time-Lapse Photos of Worm and Worm-Free Tanks

Time	Worm Tank	Worm-free Tank
Week 1		
Week 4		
Week 8		
Week 12		

Name: ______________________________________

Worm and Worm-Free Tank Observation Sheet

To graph the changes that you observe in the worm and worm-free tanks:

- Measure the height of matter in each tank in centimeters. This measurement should be the same for both tanks. From the total measurement, subtract 10. Use this number (total matter - 10) to start numbering from the bottom and go up. Use 1 cm intervals until you get to the measurement of matter that is now in the tank. So for instance, if you have 30 cm of matter in your tank, start numbering your graph at the bottom with 20 (30 – 10). Your markings should read: 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30.

- Together with your class, create a regular schedule for observing the tanks; for example, every 7 days. Write the dates that you plan to check the tanks in order in the columns along the "Day" axis for both graphs.

- Each day that you make an observation:

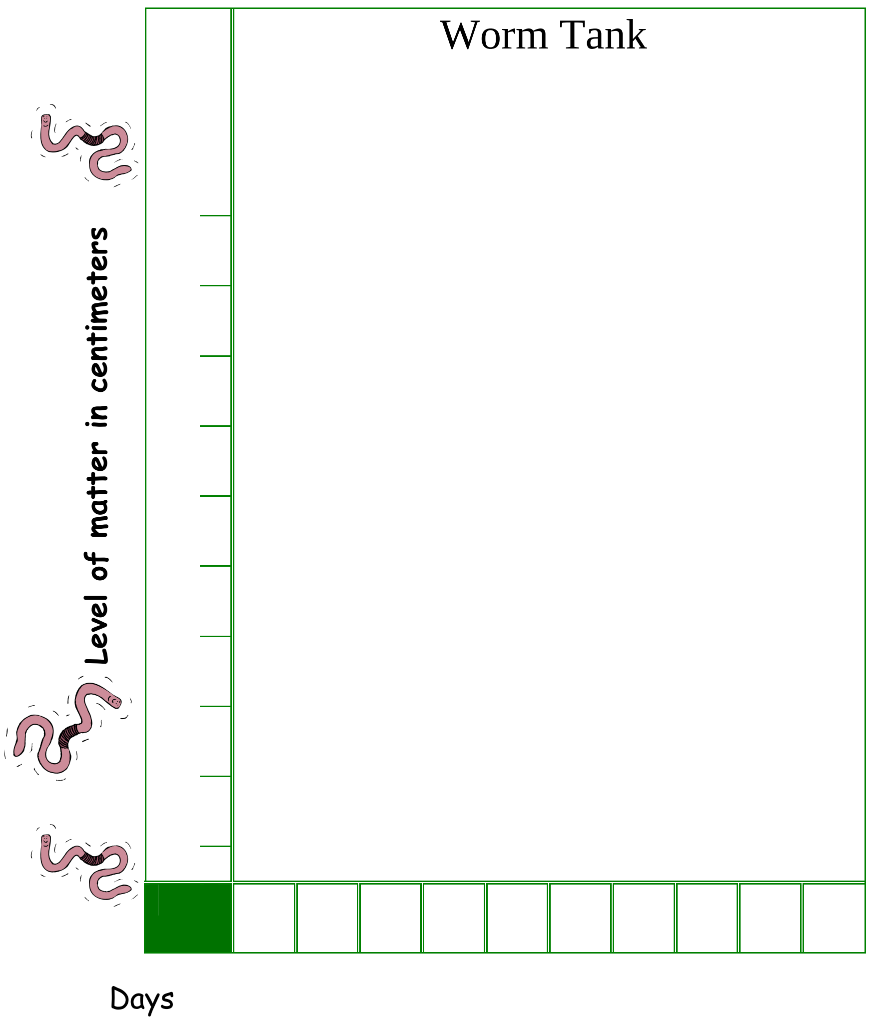
  1. Find the column for that day.

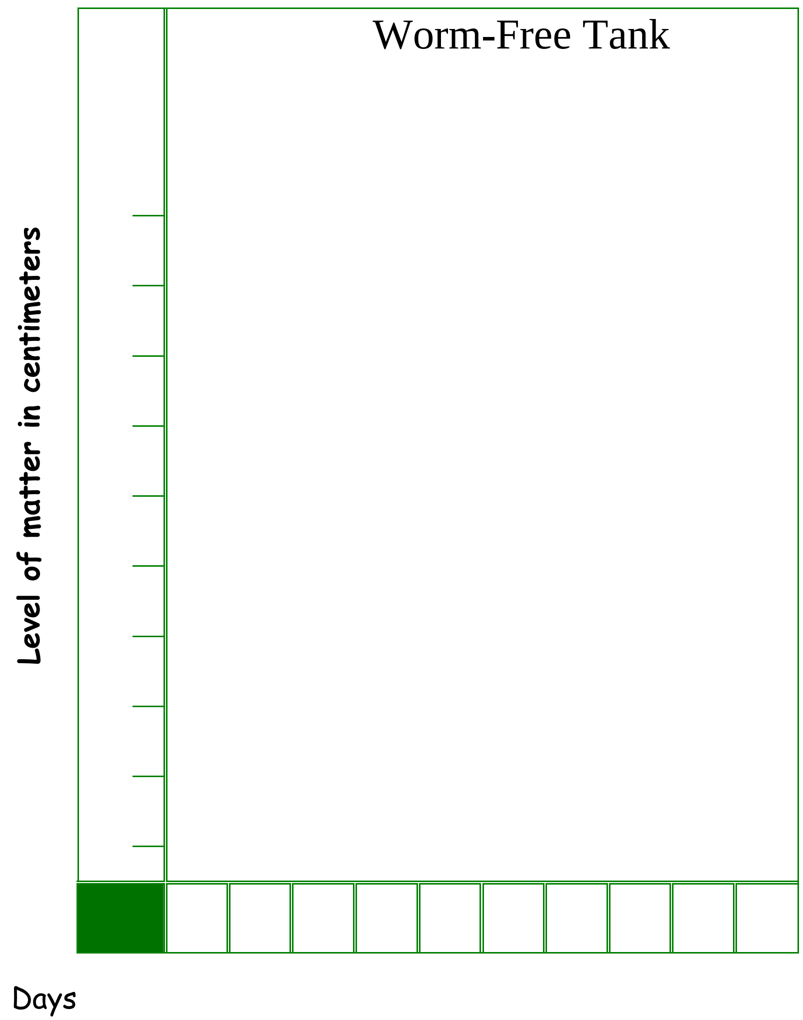
  2. Measure the matter in the worm tank from the bottom of the tank to the top of the matter. Record the height by making a mark at the corresponding level in the graph above the date.

  3. Repeat steps 1 and 2 for the worm-free tank.

4. At the end of the experiment, connect the markings you made to create a graph of the level of matter in each tank.

Observation sheet





Collecting Evidence for Non-Obvious Decomposers: Growing Microbes on Bread

(Reinforcement Activity)

A Caution about Mold

Because some children may be allergic to molds, it is important to use re-sealable plastic bags to hold the moldy bread, and to remind students to keep the bags sealed at all times. While keeping the moldy bread in plastic bags is generally a safe practice for this experiment, you may suggest that children with allergies wear dust masks to minimize exposure to any possible airborne allergens from the specimens. If you have any students with severe mold allergies, you may need to substitute a different activity.

This activity helps students understand that microbes are so tiny that you can't see them, but you can witness their effects. It is a particularly useful support activity for students who are unconvinced that microbes exist.

Have students take a piece of bread and rub it somewhere in their school. (The cafeteria floor, the banister in the stairwell, and the jungle gym on the playground are good choices). The bread you use should not contain preservatives in order to see results in a short period of time (bread from a bakery is likely to contain little or no preservatives). After rubbing the bread somewhere, students should seal the bread in a plastic re-sealable bag and then wash their hands. Direct them to put a piece of masking tape on the outside of the bag and write their name on it, as well as the date and the place where they got their sample. The bags should be pinned up (on the very top edge of the bag so as not to puncture the sealed part) in a place that does not receive direct sunlight. A hallway is an excellent choice as long as the bags are pinned up high enough so that students unfamiliar with the project will not open them. Tell the students not to open them.

After a few weeks, ask students to observe their bread samples (through the bag, they should not open it) carefully with hand lenses and describe what they see. Ask how their observations of the bread are similar to their observations of the logs. How are the processes similar? Explain that they are observing decomposition that is being caused by tiny organisms, some of which are not visible with a bare eye, and that these things are called "microbes." Students may be familiar with bacteria or germs. Explain that bacteria and fungus are two types of microbes. Mold is a type of fungus that they may have seen on their bread samples, or on old fruit or old leftovers. Remind students that some types of bacteria and fungi are harmless, like the kinds of fungi that we eat. Other types are dangerous and may cause people to become sick. For that reason we will not touch the fungi and bacteria on the bread and will keep the bags sealed. The mold they are looking at is feeding, and the fuzz they see are called “hyphae.” These hyphae are actually threads or roots that are attached to the bread and are the way that molds absorb their food. These strands digest the food.

Where did the microbes come from and why didn’t you see them there? Students should realize that their microbes came from the places where they rubbed the bread. They weren’t seen there because microbes are hard to see unless there are many of them growing together, as is the case with the bread. This requires the right conditions. Microbe decomposers are everywhere, but they need the right conditions to grow. Ask students what they think those conditions are. They need food to live and grow, like any other organism. Other conditions, such as dampness, dark, and warmth encourage microbes to grow.

Learning about Preservatives: Bakery Bread Versus Store Bought Bread
(Reinforcement Activity)

By comparing slices of store-bought bread containing preservatives to bread from a bakery that contains no preservatives, children learn about the role of preservatives in food and how they act to slow down decomposition

Ask students if they have heard of preservatives and if they know what preservatives do in food. Explain that some food is prepared without preservatives, such as bread from a bakery or bread made at home. Tell students that in order to see how preservatives work, they will be testing out the differences between bread with and without preservatives. Discuss the importance of treating both kinds of bread the same in this experiment.

Ask students to make predictions about what will happen to both kinds of bread when moistened and sealed in a bag. Record their predictions. Proceed with the experiment by giving each student or each group of students a slice of store bought bread and bakery bread. Be sure to check the ingredients of the store bought bread to make certain that it contains preservatives. Likewise, inquire about the ingredients of the bakery bread to be certain that it does not contain preservatives. Using a water dropper, have the students dot both pieces of bread with 10 drops of water, reminding students to be careful to drop the same amount of water on each slice of bread. Seal each slice of bread in its own plastic resealable bag. Direct them to put a piece of masking tape on the outside of the bag and write their name on it, and to label each bag as “preservatives” or “no preservatives” accordingly. In order to help students not to mix up the breads, hand out one type of bread at a time and go through all the steps with that bread first. Once it is sealed and labeled, proceed with the other type of bread. The bags should be pinned up (on the very top edge of the bag so as not to puncture the sealed part) or taped up in a place that does not receive direct sunlight. A hallway is an excellent choice as long as the bags are pinned up high enough so that students unfamiliar with the project will not open them. Tell the students not to open them.

Every few days, have students observe their bread samples (through the bag, they should not open it) carefully with hand lenses and describe what they see. They should record their observations in a journal, by describing what they see and/or drawing pictures. Ask students to think about how what is happening to the two slices of bread is similar and how it is different, and to think about the role of the preservatives in what is happening. After approximately 2-3 weeks (or whenever there is sufficient mold growth on the bread), review the students’ predictions and observations, and discuss the effect of preservatives and no preservatives on the bread samples. Students should understand how preservatives relate to decomposition and how they slow down the rate of microbe growth. Ask students to think about why people put preservatives in food, particularly food that is made and shipped to stores where it sits on a shelf waiting to be bought. Ask them to consider the pros and cons of adding preservatives.

The Good, The Bad And The Ugly: The Many Sides of Bacteria
(Reinforcement Activity)

Most students think of germs, microbes, and bacteria as bad and harmful. They generally have no idea of the beneficial aspects of microbes.[4] This activity aims to help students recognize that bacteria have many good functions, such as helping to recycle nutrients for plants, helping to make cheese and yogurt, and helping humans digest food, but that bacteria also have some not-so-good functions, such as causing illnesses. After learning about how bacteria are microscopic, living things that act as decomposers, ask your students to think about what they know about living things and what they need to survive. Ask them to think about some of the needs of bacteria. Tell the students that like other living things, bacteria need food, water (or moisture) and a suitable environment in which to thrive. A suitable condition for bacterial growth is typically a moist, warm and dark environment. Explain to students that bacteria cause illnesses such as Strep Throat, tooth decay and food poisoning. Knowing what they do about bacteria growth, have your students brainstorm about ways that people can prevent bad bacteria from causing illness.

Next, discuss the ways in which bacteria are helpful, reviewing their role in decomposition of waste and recycling of nutrients, and introducing students to the idea that bacteria exist in some foods and in the stomachs of humans and many animals. It is bacteria that break down the sugars and make acids that give yogurt its tangy flavor. Many cheeses are made using bacteria. Bacteria also live in the stomachs of humans, cows, and other animals, where they help to break down food that the stomachs cannot digest on their own. Intestinal bacteria also provide many animals with essential vitamins.

Endnotes for Section 3

[1]Driver, R., Squires, A., Rushworth, P. & Wood-Robinson, V. (1994). Making sense of secondary science: Support materials for teachers. London: Routledge.

[2]Hampton, C. H.; Hampton, C. D., & Kramer, D. (1996). *Classroom creature culture: Algae to anoles: A collection from the columns of 'science and children'*, National Science Teachers Association, Washington, D.C.

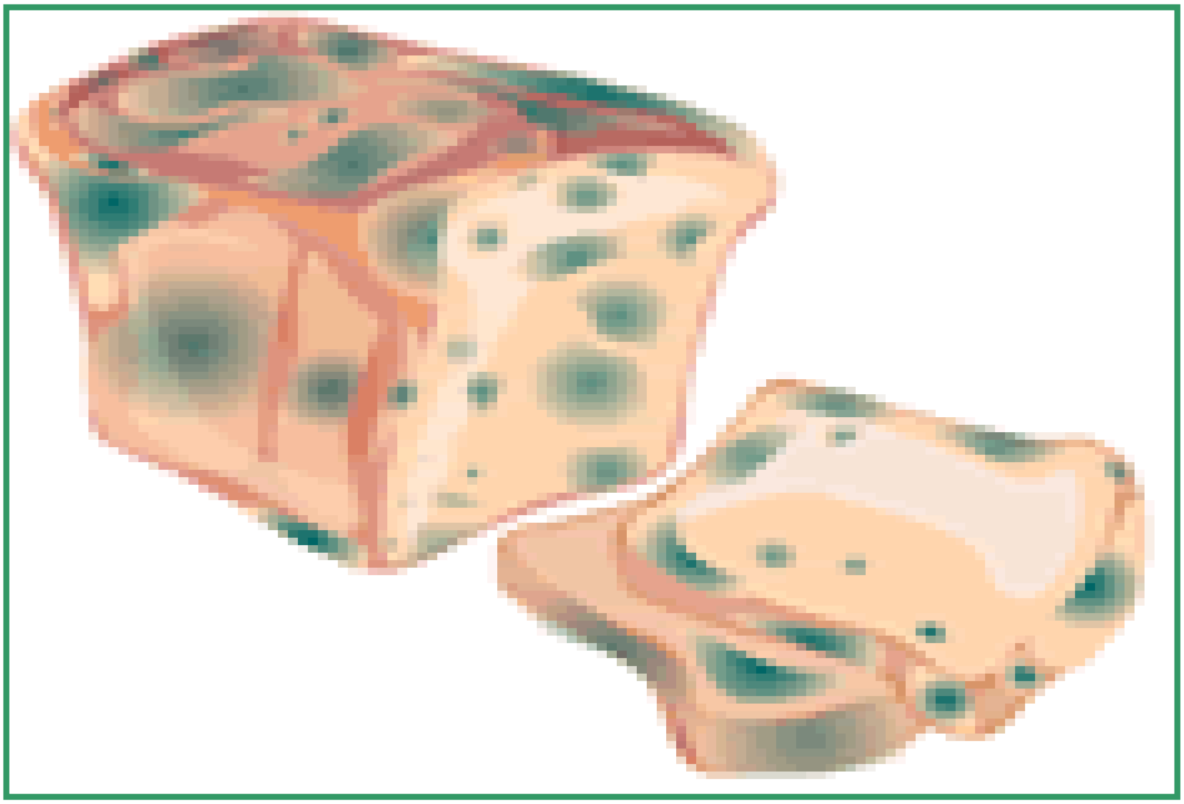
Knott, R. C., Hosoume, K., & Bergman, L. (1989). *Earthworms: Teacher's Guide: LHS GEMS: Great explorations in mathematics and science*. Regents of the University of California, Lawrence Hall of Science, University of California at Berkeley, CA.

[3]Earthworms: Nature's Soil Builders Produced by Stanton Films. Video may be purchase from Stanton Films, PO Box 2148, Redondo Beach, CA 90278.

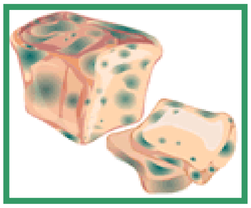
[4]Driver, R., Squires, A., Rushworth, P. & Wood-Robinson, V. (1994). Making sense of secondary science: Support materials for teachers. London: Routledge.

SECTION 4

Decay Takes Time: Detecting Causal Relationships Despite Temporal Delays



This section addresses students' tendency to miss effects that involve time delays. It helps students to realize that decay occurs even if we aren't likely to notice it on a regular basis because we don't typically observe what happens to matter over a long time span.



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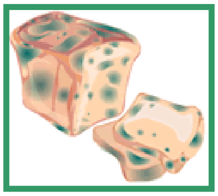
Decay Takes Time: Detecting Causal Relationships Despite Temporal Delays



Decay Takes Time: Detecting Causal Relationships Despite Temporal Delays

This section uses time- lapse video to help students realize that decay occurs even if we aren't likely to notice it on a regular basis because we don't typically observe over a long time span.

Understanding Goals

Subject Matter

- ❖ Decomposition or decay is a process that happens over time.
- ❖ Variables such as temperature and moisture affect rate of decay.

Causality

- ❖ It can be hard to detect the cause of something when there is a time delay between the cause and noticeable effects.
- ❖ It can be hard to see certain events as connected in systems when it takes a long time for the effects to become noticeable, or when there is a time delay between causes and effects.
- ❖ Decay is characterized by cyclic causality. It is hard to see the cyclic pattern because of time delays and causes that you can't see.

Background Information

Time Delays Make it Difficult to Detect Causal Patterns

Many events in ecosystems do not have immediate effects or immediately noticeable effects. For instance, the effects of microbes take a long time to become observable because they are cumulative or aggregate. (This is similar to other processes like erosion by natural events or the effects of acid rain). Therefore it is easy to assume that nothing is happening, when in fact, effects are accumulating which will eventually become quite dramatic. The time delay makes it difficult to recognize the effects of the decay process.

Exponential growth patterns are another type of causal pattern that can be difficult to notice at first. In exponential growth, the size of the population typically keeps doubling (in natural systems). The effects are hard to see at first. Eventually, there are startling effects. Imagine there is one duckweed plant on a pond, and next there are two, then four, then eight and so on. Suddenly, the pond will dramatically go from being half covered to fully covered. The time delay between the start of the process and noticeable effects makes it hard to foresee the outcome or to understand the process that led to it. Initially small effects (new plants) cause new effects (more plants) and ultimately result in a startling change. An invader species such as Purple Loose-strife, a plant with bright purple flowers seen in late summer in many New England wetlands, when introduced to a swamp would at first grow alongside native species such as Eupatorium. However, the Loose-strife growth would be exponential, as each new plant begets numerous new plants. All of a sudden, the continued doubling of the Loose-strife would be enough to make it impossible for the Eupatorium to live.

Time-Lapses Illuminate the Cyclic Pattern of Decay

The activity in this lesson engages students in thinking about the nature of time delays and how such delays can make it difficult to see the underlying causal interaction pattern. Time-lapse video is introduced as a means to help students clearly see the cyclic nature of decay despite the time delay.[1] Linking the concepts in this lesson to those of the lesson on non-obvious decomposers helps students to see that slow accumulation of effects is the result of many microbes doing their work, and will eventually result in a discernible change.

Lesson Plan:
Using Time-Lapse Video to Reveal The Cycle of Decay

Materials

- Time-lapse video, available from: http://pzweb.harvard.edu/ucp/curriculum/ecosystems/.

Prep Step

- Read the background information.
- Read the lesson plan.
- Either download the video or arrange to show them to students on-line.
- Set up a method for viewing the time-lapse clips.

Note to the Teacher: The time-lapse video above is brief (about a minute long). You can find many additional time-lapse videos on line that are longer and show decay across a wider array of organisms. Make sure to preview them first!

Analyze Thinking

Step 1: Gather Students' Ideas and Questions

Many people don't realize that organic matter is recycled. Ask: "What are some of the reasons that it is hard to realize that matter is recycled?" Collect ideas. If no one introduces the issue of time, bring it up.

Ask, "How long do you think it takes for something to decay? …a few days? …a week?" Explain that it takes time for decay to occur. Just how quickly depends on the conditions for decay. Think about how quickly things "spoil" in the summer. What about it the winter? Gather students' thoughts about differences in how long in takes for something to decay in summer versus winter. Explain that the process of decay can happen so slowly and gradually that sometimes people may not notice that it is happening—that a fallen log, for example, is rotting and actually turns into a part of the soil that can be used by plants to grow.

RECAST Thinking

Step 2: Explain the Time-Lapse Decay Activity

Tell your students that you are going to see some film footage that shows decay happening over time. The films have been accelerated to show decay happening at a much faster pace than normal.

Step 3: View the Time-Lapse Videos

Show the first few moments of the film. Stop the film. Ask, "What do you predict will happen to the fruit that looks normal and ripe?" Gather ideas.

Tell your students to watch carefully to what happens to the fruit. Discuss what is occurring and how it happens. Make sure the students realize that eventually the decaying fruit turns into part of the soil. Explain these videos were captured over time and that normally decay happens slowly and gradually so the process is sometimes not noticeable until the object is visibly moldy or rotten. However, microbes are all around, all the time, feeding on dead matter and doing their job, which is decomposing matter and recycling it.

Explore Causality

Step 4: Time Delays Make it Hard to See Causal Patterns

Explain to your students that it can be hard to detect the cause of something when there is, or appears to be, a long time delay between cause and effect. Not noticing effects because of time delays is especially a problem when considering how we interact with our environment. Offer a few examples:

- In Florida, lots of water was used to irrigate and grow sugar cane. It lowered the water table and then suddenly, sink holes started appearing, and the fresh water became brackish. This means that it mixed with salt water. This water is "toxic" to sugar cane.
- Nitrogen used to be an ingredient in detergents. However, when the detergent in untreated waste water gets into natural bodies of water, this nitrogen, which is also a fertilizer, accumulates and causes algal blooms, which throw the ecosystem out of balance and cause fish to die.
- DDT is a chemical that in small quantities does not appear to hurt anything. However, when amounts of it build up in the environment, its damaging effects become clear. When birds eat enough bugs poisoned with DDT, the shells of their eggs become too thin and baby birds die, lowering the size of some bird populations. After this was discovered, DDT was banned.

Ask students if they can think of any additional examples. Collect students' ideas and discuss.

Step 5: Show How Time Delays Affect Our Ability to Think About Decay

Explain that time delays also make it harder to realize that decay is going on. It is harder to understand the cyclic pattern because of time delays and causes that can't be seen. It can be hard to imagine that a piece of fruit or a bunch of leaves can become part of the soil. Have students think back to their own ideas before this unit. Ask them the following questions:

- Did you realize that decay is cyclic? What did you think?
- Did you realize that decay is going on all of the time?
- Did you realize how important decay is to an ecosystem?

Students can answer these questions on paper or in their journals.

Explain that cycles of decay are happening all the time. Even though it takes a long time, matter is always being broken down. Usually we only see different points in the process but cannot observe the process over time. By speeding up the decay, it is easier to see the portion of the decay cycle that goes from dead matter to soil. The results of the decay process help green plants grow.

Review, Extend, and Apply

Step 6: Review the Understanding Goals

Discuss the Understanding Goals with students to be sure that they understand them.

Step7: Extend the Concept

Ask: "What would happen if things decayed very quickly? How would things be different? Think about the tropics where things decay much more quickly as an example." Gather students' ideas.

Why would organisms decay faster in places like the tropics than in places like New England? Tropical rainforests are moist and very warm, two conditions that support decay and decomposition. In New England, the weather can be very cold and dry. This slows decomposition. Think about your bathroom when you take a shower. The hot, moist conditions are perfect for mold to grow. It's the same way in rainforests. Here's a comparison to illustrate their difference: A leaf on the rainforest floor takes about six weeks to decompose, but a leaf in a New England pine forest takes about SEVEN years!

Reinforcement Activities

Varying Rates of Decay in Decomposition Chambers**—**Have the students experiment with different conditions to vary the rates of decay in different decomposition chambers. They can systematically change one variable between different chambers (keeping everything else the same) to see how that one variable affects the rate of decay.

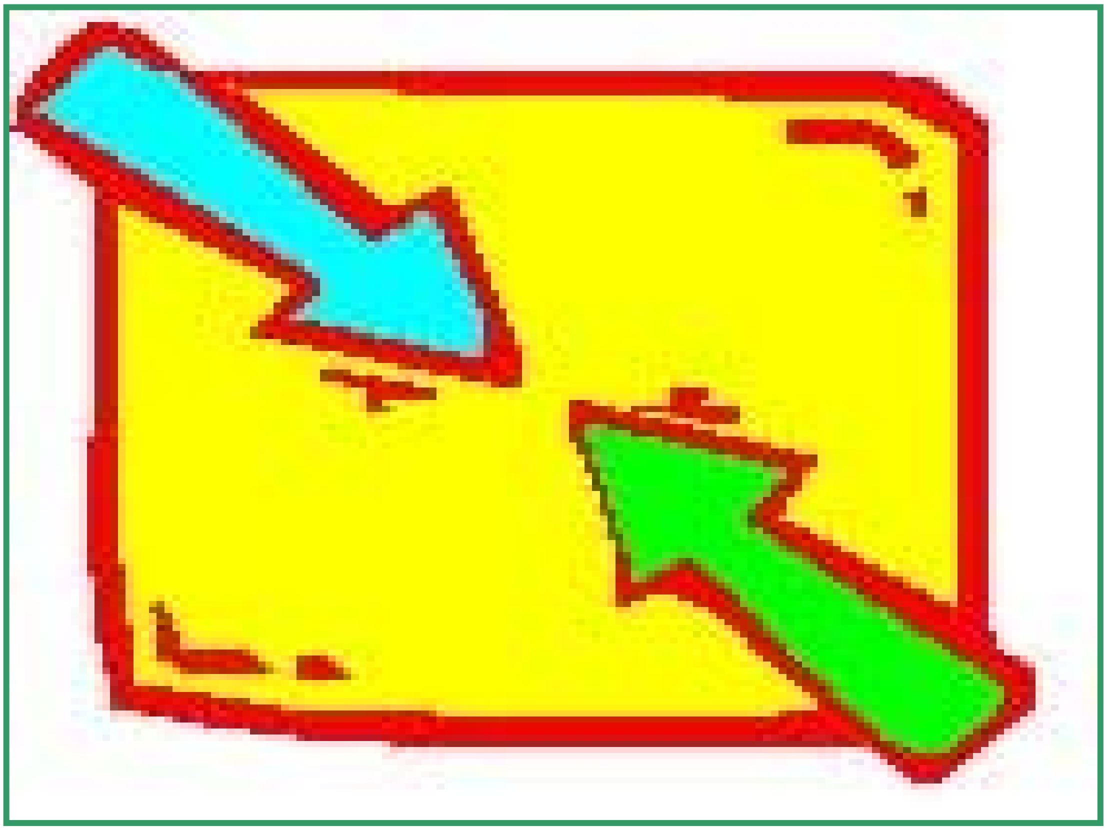
Endnotes for Section 4

Note: *There are no resources for Section 4*

[1]Leach, J., Konicek, R., & Shapiro, B., (1992, April). *The ideas used by British and North American school children to interpret the phenomenon of decay: A cross-cultural study*. Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, CA.

SECTION 5

Understanding Two-Way Causality in Ecosystems



This section addresses students' tendency to notice effects in one direction only. It helps students understand that two-way or mutual causal relationships describe many interdependencies in the ecosystem.

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Understanding Two-Way Causality in Ecosystems

Section 5 Understanding Two-Way Causality in Ecosystems

This section uses stories and computer simulations to help students realize that two-way (or mutual) causality plays a role in ecosystem dynamics.

Understanding Goals

Subject Matter

- Symbiosis is the interaction of two species that are in direct contact and typically affect each other—an instance of two-way causality.
- Mutualism is a form of symbiosis where two organisms mutually affect each other in beneficial ways.
- Parasitism is a form of symbiosis where one organism lives off another organism, usually to the detriment of the organism being lived off of.
- While the process of energy flow in an ecosystem is one-way, effects can be two-way with two populations mutually affecting each other.
- In a food web, some organisms (prey) provide food for other organisms (predators). The predators help to keep the prey population in balance. This is a type of two-way causal relationship.

Causality

- What appears to be a one-way causal relationship can be a two-way relationship.
- Two-way causal relationships mean that both organisms are affected in some way. The outcomes may be on different levels (population versus individual) or may be beneficial to one species and detrimental to the other, beneficial to both, or detrimental to both.

Background Information

Note to Teacher: The lessons in this section span at least two days. The first day introduces the idea of symbiosis, mutual or two-way causality, and the idea that the fates of populations are linked. The second day engages the students in thinking about two-way causality between populations and population dynamics. Students model relationships in a program called Star Logo to consider what happens as populations shift and change.

Two-Way Relationships in Ecosystems

There are many ways in which relationships in an ecosystem are two-way or mutual. This means that two organisms affect each other in some way. While domino models are helpful for conceptualizing the one-way process of energy flow, a different type of model is needed to address relationships where there are mutual effects.

In two-way or mutual causal models, each organism acts as both a cause and an effect. For instance, when a bee pollinates a flower, the bee and the flower are affected. The bee gets the nectar it needs for food energy and the flower gets pollen that the bee picks up from other flowers. The pollen enables the flower to reproduce. Each organism has an effect on the other, so each acts as both a cause and an effect. There are different types of mutually causal relationships in ecosystems (See below.)

Mutualism

One of the easiest types of two-way relationships to understand is a *symbiotic relationship* that involves *mutualism*. These are instances where two organisms are interdependent in a way that benefits both organisms.[1] For instance, ants known as Attini live in tropical regions in North, South and Central America (although some are found as far up the Atlantic coast as Long Island). These ants cultivate fungus gardens by chewing up leaf cuttings into a pulp and dropping bits of fungus onto this pulp, which is then deposited around the base of gardens. The ants eat the fungi and the fungi thrive in the garden that the ants create for it. The fungi that are cultivated by these ants are not found anywhere else and without the ants, would be overtaken by other types of fungi and bacteria.

Another example of mutualism is the relationship between the ox pecker bird and large animals, such as antelopes and zebras. The bird lands on the antelopes and zebras, where it feeds on the ticks and parasites that live on these animals. The antelopes and zebras benefit from the pest control that the ox pecker provides, while the ox pecker gets a meal. The ox pecker may also warn the antelope or zebra of an impending predator by flying upward and sounding a warning call.

Many Different Organisms Have Mutual Relationships

Mutual symbiotic relationships are found between plants and animals, animals and animals, and plants and plants. Lots of plants have symbiotic relationships with either bacteria or fungi that are found in soil. The bacteria and/or fungi incorporate themselves into the roots of the plants, helping the plants to thrive while the plants provide the bacteria/fungi with a food source. Lichen is actually made up of two different types of organisms, fungus and algae, and together these two organisms are able to thrive in conditions where neither could survive on its own.

As humans, we have symbiotic relationships with other organisms that are mutually beneficial. Bacteria live inside the intestines of humans and other animals such as cows. These bacteria help in the process of digestion as humans and other animals are not always capable of digesting all that they consume. The bacteria do this by digesting the food that is not broken down by the human's or other animal's digestive system. The animal's intestines provide food for the bacteria that in turn help the animal by finishing the job of digestion. (In humans, the bacteria "consume" the products of digestion and produce vitamins as a by-product. So they help more than by just digesting. Cows, on the other hand, are aided much more in digestion.)

Mutual Relationships can be Essential for Survival

Some mutual symbiotic relationships are so interdependent that one population cannot exist without the other. Not only is the two-way relationship beneficial, in these cases it is essential for the populations to survive. On the other hand, some mutually causal relationships happen infrequently, once a year or once every few years.

Parasitism

Another two-way symbiotic relationship is that of parasitism. In this case, one species benefits and the other is harmed in some way. For instance, fleas and ticks consume blood from their host animals and receive, in turn, matter and energy. They benefit, however, the host animal is typically weakened as an effect of the parasites.

Two-Way Causality in Food Web Relationships

One of the more difficult types of two-way relationships to understand involves food-web relationships where one type of organism (prey) provides food (or energy) for another (predator), and at the same time the predators help to keep the prey population in balance. For instance, rabbits provide energy for foxes and foxes cull the rabbit population of its weakest members so that the strongest rabbits reproduce, improving the population. This may not be best for the individual, but for the population of rabbits as a whole, it is beneficial.

What makes this so difficult to grasp? The two populations mutually affect each other; however, the effects are positive at the population level for the prey, but negative at the individual level. For the predator, the effects are positive at the individual and population level. This pattern is difficult to understand because:

- On the level of individual organisms, the effects are not parallel. As with parasitism, the effects are beneficial to one organism and detrimental to the other. So while there are two-way effects, the effects are not the same in substance or in quality of outcome.
- It juxtaposes reasoning about populations and reasoning about individuals. Many students have a hard time reasoning about populations at all,[2] and here is an instance where what is good for the population is bad for the individual. This can be confusing to students.*

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*Further, when reasoning about evolution, scientists reason at the level of the individual's "aims"—that each organism is seeking to maximize its ability to reproduce. These individual aims give rise to population effects. Reasoning from the "aims" of individual animals, there aren't good reasons in terms of evolution to be eaten. So the actuality—that both populations ultimately benefit—is difficult to arrive at when reasoning from an individual's point of view. Note that the word "aims" is in quotation marks because scientists don't conceptualize it as intentional—that the organisms do it on purpose—just that this is how they are genetically programmed to behave.

Students typically miss the two-way connections in an ecosystem. It is a common tendency to reason in a unidirectional, linear way. Students need to see that the fates of populations as a whole are linked together in many different ways. This is why it is important to introduce two-way causality. Understanding it is a building block for other ecosystem concepts, such as the dynamics of balance and flux as explored in the next sections.

The fates of populations are linked

There are many interdependencies within ecosystems. Events that affect one population typically have ripple effects—affecting other populations. When the size of one population becomes too large or too small for its niche (or role) in the ecosystem, it is out of balance and may throw others out of balance too. The simulations in Section 5 revealed some of the patterns of boom (when a population size is too big[1]) and bust (when a population size is too small) that can occur.

Modeling Predator-Prey Relationships

This lesson uses a computer simulation called StarLogo.[3] StarLogo is a program created by researchers at the MIT Media Lab to show what happens at a population level when individuals act according to a given set of rules. The resulting outcome is not usually one that can be predicted from the individual interactions, so it can be quite surprising.

StarLogo models the predator-prey relationships differently than what most teachers are familiar with. Models of predation are typically based on classical models, such as the Lotka-Volterra model (as is the case with the Lynx-Hare Cycles model in Section 6). It specifies interactions between predator and prey populations through differential equations that describe the rate of change of different variables over time. These classical models aim to predict at a different level than the modeling approach in the StarLogo program. StarLogo describes the behavior of individuals rather than populations. Therefore the outcomes with the StarLogo program often parallel, but sometimes diverge, from the classical models. Wilensky and Reisman[4] have explored this issue in depth and give examples of explorations that students have engaged in when exploring the relationship between their StarLogo models (or embodied approaches as they call them) and classical models. They offer at least one instance where a student discovered that the Lotka-Volterra model gave a mistaken prediction and that Gause had previously discovered the discrepancy in 1934! As Wilensky and Reisman point out, classical tools allow one to make aggregate level assumptions; however, models focused on the individual level require assumptions to be coded at the individual level, and then one waits to see what the aggregate level consequences are.

It is also important to point out to your students that all models are just that—an approximation of what we think is happening in reality. However, all models are built on assumptions about how things work and these assumptions can be challenged. There are ways in which the Star Logo Models do a good job modeling what really happens and ways in which they don't. For instance, in the rabbits and foxes simulation, the relationship of rabbits to their food sources is not modeled (there is no grass!) Also, the model does not predict well what would happen at the extremes. Building a good model depends upon having deep knowledge of the ecological principles that apply—the more we know, the better we can model what is happening.

Note to Teacher: You will notice that when there are no consumers for grass (in Simulation #1) and for rabbits (in Simulation #2), the population increases to a certain point and then the program stops running. Discuss with students what happens when a population reaches the limits of what the environment can support. Can it continue to grow beyond that point? What do they think?

LESSON PLAN: EXPLORING INSTANCES OF TWO-WAY CAUSALITY IN ECOSYSTEMS

Materials

- *Symbiosis* sheet
- StarLogo Simulations 1 and 2
- *What is Two-way Causality*? sheet
- *Student Guide Sheet* for StarLogo

Prep Step

- Read the background information.
- Review the lesson plan.
- Follow this link for getting a copy of StarLogo on-line. http://www.media.mit.edu/starlogo/ .
- Access Simulation #1 and Simulation #2 from our website at: http://pzweb.harvard.edu/ucp/curriculum/ecosystems/ .
- Photocopy the sheet, *Symbiosis* (p.143).
- Photocopy the sheet, *What is Two-Way Causality?* (p. 169).
- Photocopy the *Student Guide Sheet* for StarLogo (p. 161) if you plan on having students work in small groups.

Note to Teacher: Depending upon what type of computers you are using and what version of Star Logo you have downloaded, you may need more or less time to get the simulations running and to trouble shoot any difficulties.

LESSON PLAN: PART I

Analyze Thinking

Step 1: Review Domino Causality and Define Two-Way Causality

Remind students about domino causality from the first section. Ask them to think back to what they learned. In domino causality, the effects are uni-directional. So for instance, in the process of energy transfer, the green plants give energy to the insects but the insects do not give energy to the green plants. Then put a diagram on the board that looks like this:

Tell your students that this diagram shows a different type of causality. It is called two-way or mutual causality. Ask: "Can you think of any examples where organisms help each other?" Gather students' ideas and list them on the board. Some students may not be aware of any two-way relationships, while others may not be sure that they actually exist.

RECAST Thinking

Step 2: Introduce the Set of Stories about Symbiotic Relationships

Hand out the sheet called *Symbiosis* (p.155). Read and discuss each story about symbiotic relationships. After each story, ask:

- How do the organisms help each other?
- How is each organism a cause and an effect?

Note to the Teacher: The stories are in an order that most students will find is easiest to hardest. For example, it is easier to think of two animals helping each other than of two plants helping each other. Finally, most students don't think about organisms living inside us, so they might find this the most startling.

After you have read all of the stories about mutual symbiotic relationships, ask:

- What similarities and differences did you find between the stories?
- What did you find most interesting? …startling?
- Does any of this change the way you think about ecosystems? If so, how?

Step 3: Introduce the Set of Stories on Parasitic Symbiotic Relationships

Next read and discuss each story about parasitic symbiotic relationships. Your students are probably familiar with some parasitic relationships, such as ticks on their dogs, etc. After you have read all of the stories, ask:

- What similarities and differences did you find between the stories?
- What did you find most interesting? …startling?
- Does any of this change the way you think about ecosystems? If so, how?

Step 4: Analyze Current Thinking

If in the list generated in step 1, students came up with two-way causal relationships where prey provides food for predators and predators keep the size of the prey population small enough, then draw students' attention to those examples. Otherwise say,

- "We have said that some animals cause there to be energy for other animals and so in that sense they help those animals, for instance the mice give energy to the owls. Are there any ways that the owls might also help the mice? Can you think of any other relationships in nature where the entire population of one species benefits from a relationship they have with another population?"

Collect students' ideas.

Some students will deny the possibility of any benefits. Others may give indirect benefits such as they eat things that eat mice or they eat things that eat the things mice eat. Still others may realize that when reasoning about a population, the owls can help to keep the size of the mouse population at a level that the environment can sustain.

Some of my students think predators are bad. They portray them as big, mean, and evil. What is going on?

We typically think about animate behavior as intentional. Young students may see predators' behavior as intentional and bad. This makes it hard to reason about ecosystems because the patterns play out at the population level in a non-intentional way. Research suggests that reasoning about intentionality in this way is a natural part of the progression towards biologically based understandings.[5] Children's intuitive biological understandings emerge from their reasoning about goals and intentions, psychological constructs, more than from pure biological reasoning. Reasoning about the ecosystem relationships in terms of energy needs and energy flow may help students move towards a more biologically based understanding.

Explain to students that they have talked a lot about ecosystems and what happens to populations of animals in ecosystems. Split them into small groups for discussion and ask:

- Do you think a population always has the same number of animals in it, or can it change?
- If you think it changes, how does it change? Yearly? Monthly? Once in a great while? What might cause changes at these intervals?
- Are there ever any patterns to how populations change? If so, how would you describe the patterns? If so, what are some things that make it hard or easy to see the patterns?
- Do you think that change in an ecosystem helps or hurts? Why?
- Can we use words like "good" or "bad" to describe changes in population size?

These questions will be revisited in the next part of Section 5 and in sections 6 and 7. Let the students know this and do not worry about bringing their ideas to closure now.

LESSON PLAN: PART II

Step 5: Introduce and Explore StarLogo Simulation #1: Grass and Rabbits

The simulation in this step and in step 7 can be done as a class demonstration or in small groups in a computer lab. In this section's resources, you will find: 1) *General Instructions: StarLogo* sheets with information on how to run the StarLogo simulation; 2) a *Student Guide Sheet*, which can be handed out to students to guide their small group exploration; and 3) a *Teacher Guide Sheet*, which can be used to walk you through the simulation as a class demonstration.

Either pass out the *Student Guide Sheet* or walk the class through the simulation using the *Teacher Guide Sheet*. Plan at least 30 minutes for this part of the lesson.

Step 6: Discuss the Role of Two-way Causality in the Grass and Rabbits Simulation

Collect students' ideas by asking the following questions:

- Are there ways that the grass helps the rabbits? [As the rabbits eat the grass, they are able to reproduce. They need the energy they get from the grass to stay alive.]
- Are there any ways that the rabbits might also help the grass? [They might fertilize it. They help to spread the plant seeds.]
- Are the fates of the grass and the rabbits linked in any way?
- The simulation is a model. What does it mean to be a model of something?
- Are models right? Does it make sense to talk about them as right or wrong? *(Help your students to realize that models are designed to simulate or be similar to something else, usually something in real life. They fit in some ways and not in others. You can also disagree with some of the assumptions in a model. In this case, the assumptions are programmed into the model.)*

Step 7: Introduce and Explore StarLogo Simulation #2: Rabbits and Foxes

Either pass out the *Student Guide Sheet* or walk the class through the simulation using the *Teacher Guide Sheet*. Plan at least 30 minutes for this part of the lesson.

Step 8: Discuss the Role of Two-way Causality in the Rabbits and Foxes Simulation

Collect students' ideas by asking the following questions:

- What are some things that will help keep the size of the rabbit population under control?" [Predators such as foxes, wolves, and so forth.]
- What does the simulation tell you about whether predators can ever be helpful to the populations that they prey upon?

Discuss the difference between helping an individual versus helping a population. Explain that it doesn't really help the individual rabbit to be eaten, but it does help the population of rabbits. Usually it is the weakest or slowest rabbits that get caught, so the rabbits that survive to have baby rabbits are the ones who are strongest and fastest. That makes the rabbit population stronger and faster overall. If predators never ate any rabbits, the size of their population would keep growing and growing and they wouldn't have enough food to eat, and they would starve to death.

Discuss the simulation as a model:

- What are some things that the model tried to show?
- What are some things that the model leaves out?
- Are there assumptions the model appears to make that you disagree with?

Explore Causality

Step 9: Review Two-Way Causality Explanation

Hand out the sheet, *What is Two-Way Causality*? (p. 169). Read it as a group and discuss.

Review, Extend, and Apply

Step 10: Connect Two-Way Causality to the Interactions in the Simulations

Further the discussion of two-way causality in ecosystems by having students compare what the two simulations show.

Ask: "What do the two different simulations (depicting two different levels of relationships) show about two-way relationships in ecosystems?" Be sure that the following points come up:

- When something is eaten in the food web, there can be two-way effects. The process of energy flow is only one-way, like dominoes, but the nature of the interactions is two-way.
- Many populations affect each other.
- What seems bad on an individual level can be good on a population level.

Ask: "How are the two levels depicted in the two simulations similar?" Be sure that the following points come up:

- Both have a population that is getting eaten.
- Both show how the fates of populations are linked.
- Both show two-way effects.

Ask: "How are the two levels depicted in the two simulations different?" Be sure that the following points come up:

- Unlike animals, when grass or other plants are eaten, their seeds are often redistributed and can germinate. Being eaten actually benefits the individual plants. (This fits with how scientists think about the individual level. Students might not think that the grass would "like" being eaten but if what the grass "cares" about is making sure that it spreads its seeds, being eaten is a good thing.) When an individual rabbit is eaten, it can help the rabbit population stay in balance, but the individual rabbit does not benefit.
- When rabbits eat grass, the grass doesn't benefit in terms of population control. Grass doesn't crowd itself out. However, like a forest, the more trees there are, the less light, water, and nutrients there are for new trees to grow (and in the case of grass, being eaten can stimulate growth, too).
- When foxes eat rabbits, it is harder to see foxes as helpful to the cute little rabbits, than it is to see rabbits as helpful to the grass plants. It is also harder to see rabbits as "mean" for eating the grass.

Step 11: Review the Understanding Goals

Review the Understanding Goals for this section. As a class, consider why it is important to understand how populations interact and how their fates are linked. This is the focus of Sections 6 and 7.

My students tend to say things like, "It would be bad for the mouse if an owl ate it because it would die." How can I get them to think about it as an ecosystem?

It is common for students to reason about individuals instead of populations. This type of reasoning is especially common for younger students, but can be seen at all ages.[6] Even adults have difficulty thinking about population versus individual effects. We often try to apply consequences at the population level to individuals, on topics from inheritance to the lottery.

It is hard to move from reasoning about individuals to reasoning about populations because outcomes can be at the same time bad for an individual (being eaten, for instance) and good for the population. Children often reason from their experience; however, it doesn't help to put yourself in the place of a certain animal when you need to think about an effect on the whole population. Thinking about populations involves thinking about percentages and probabilities rather than finite amounts and certain outcomes. Instead of thinking about what definitely happened to one animal, students need to think about what could happen to a percentage of a population of animals.

Noticing that your students are reasoning this way is an important first step in helping them learn to think in terms of populations. Listen for references to *the mouse, it, him,* or *her*. Responses such as, *No, I can't think of any way that the owl helps the rabbit because he would be dead* or *The wolf ate the rabbit so then he would have to eat the squirrel next* suggest students are reasoning about individuals.

One approach to dealing with this is to address the issue head on. Explain to the students that you noticed how they are talking about the animals and that you'd like to compare two different ways to think about ecosystems. One way is how they are thinking about this problem and the other is how scientists think about it. On the board, show a food web branch (as on page 20.) Explain that many of them are thinking about one animal in each place. Then explain that scientists use one animal to stand for all of the animals in the food web. So in a certain habitat, there might be 200 rabbits and 9 owls, not just one of each. Next lead them though a comparison of what each situation means. Let's compare how it is different to think about one rabbit and one owl compared to 200 rabbits and 9 owls. If there were one rabbit and one owl and the owl ate the rabbit, it would be bad for that rabbit. However, if there were 9 owls and 200 rabbits and an owl ate a rabbit, what might that mean for the other rabbits? Gather student ideas. (Students may say things such as: *They might be frightened*; *They might have more food*; *They might have more space*; or *They might learn to stay away from owls if they saw another rabbit eaten*.) You might need to encourage the realization that they would have more food and more space by asking what happens if that rabbit isn't there to eat green plants or take up space.

Reinforcement Activities

Two-Way Web of Life Game – Follow the directions for the basic *Web of Life* game described in Section 1, *Understanding the Connectedness of Ecosystems*. This time, explain that instead of thinking about the transfer of energy, or who eats whom, we're interested in all the different ways that organisms in an ecosystem are connected and rely on each other. Have students give examples of ways that organisms rely on each other in ways other than for food. Some examples may include: *The plants need the earthworms to make rich soil for them; The rabbits need the owls to keep the size of their population small, otherwise there will be too many of them and not enough plants to eat and they'll starve*.

This idea in particular, of the prey organisms needing the predator organisms as much as the predators need the prey, may not be intuitive for students and may need to be discussed further. Once students have a grasp on the concept, explain the goal of the game: to reverse all the 'connections' that were made during the first round of the *Web of Life*; that is, to show that the connections between organisms are also mutual, two-way connections.

Resources for Section 5

Symbiosis sheet

Mutually Beneficial Symbiotic Relationships

Parasitic Symbiotic Relationships

StarLogo Simulations 1 and 2 Accompanying Materials

General Instructions: StarLogo Simulations

Student Guide Sheet

Teacher Guide Sheet

What is Two-Way Causality? sheet

Endnotes for Section 5

Symbiosis

Mutually Beneficial Symbiotic Relationships

Animal-animal relationships

The Egyptian Plover bird and the crocodile. You might think that if a bird landed in the mouth of a crocodile, the crocodile would eat it. Well, not the Egyptian Plover bird. Egyptian Plovers and crocodiles have a unique symbiotic relationship. Because crocodiles can't use dental floss, they get food stuck in their teeth. All that food rots their teeth and probably causes them some pain. When a crocodile feels the need for a good tooth cleaning it will sit with its mouth wide open. The Egyptian Plover bird recognizes this invitation, and if one is nearby it will fly into the mouth of the crocodile, eat the food stuck in its teeth, and fly away. The plover gets a meal and the crocodile gets a valuable tooth cleaning: they both benefit.

Animal-plant relationships

Bees and flowers. You are all probably familiar with the idea that bees and flowers have some kind of relationship. A bee goes from flower to flower gathering nectar. While it is doing this, some of the flower's pollen ends up sticking to the bee's hairy body and legs. When it goes to the next flower, some of that pollen rubs off of the bee and gets into the flower. The flower needs pollen to reproduce, but since flowers can't move to get it themselves, the bees get it for them. Without bees, some flowers would have no way of getting the pollen they need to reproduce. Without flowers, bees wouldn't get the nectar they need to eat.

Plant–plant relationships

Lichen. The first time you see lichen, you may be surprised that it is alive! It can be flat and not very obvious; it almost looks like a discoloration on a rock. Lichen is special because it can live in places where other organisms cannot. Lichen is a partnership or symbiotic relationship between two different species. Fungi and algae combine to create lichen, because together they can live in places where alone, as just algae or fungi, they could not survive. Their relationship is mutually beneficial—both species benefit from their relationship.

Human-bacteria relationships

Your intestine and bacteria. You might wonder how you can have your very own symbiotic relationship going on right now and not know it. It's because it happens in your intestine where you can't see it. When you eat food, very little of it gets digested in your stomach. It travels through your intestine where bacteria further digest the partly digested food. The bacteria also produce vitamins. Your food gets digested, you get vitamins, and the bacteria get a meal. You have your very own partnership, without which, your body would not be as healthy!

Parasitic Symbiotic Relationships

Tapeworms

Tapeworms are long, flat parasites that live in the intestines of pigs, cows, and even humans. A tapeworm gets into its host by laying its eggs in the host's food source. The host eats this food, and the eggs develop and grow into tapeworms, which attach themselves to the intestines of their host. Tapeworms feed off the food that the host eats, and sometimes a tapeworm has been known to live in a human for ten years without being detected! The tapeworm has a safe, warm home and a constant food source, but the host does not benefit from the relationship. In some rare cases, the tapeworm can make the host sick or even cause death.

Ticks

Ticks are pinhead-sized arachnids that form parasitic relationships with birds, reptiles, animals, and sometimes humans. Ticks attach to their host's skin and feed off its blood. In this way it gets both food and a home. Ticks can consume enough food to grow 200 to 600 times their original body weight. In this relationship, the tick gets the benefits of a warm home and food, while the host gains nothing. The tick may even give the host a disease, which could weaken or kill it.

Mistletoe

Mistletoe is a plant that people hang above doorways at Christmas-time. Before it gets picked and hung inside it grows by living off of other plants. Mistletoe grows on woody plants, taking nutrients and moisture from them. It also "strangles" it—reducing the nutrients that the plant can take in. Mistletoe is considered a parasitic plant, because the mistletoe gets all the benefits, while the woody plant or tree has to support itself as well as the mistletoe.

StarLogo Simulations:
General Instructions

What is StarLogo?

StarLogo is a computer program designed to create models of systems. It simulates what happens at a population level when individual organisms interact in certain ways.

In the two simulations provided, you and your students will be manipulating the rules and interactions between individuals and observing ecosystem relationships. These explorations can be done as a whole class demonstration or in small groups.

Simulation #1 focuses on rabbits and grass. In this simulation, the rabbits eat grass and reproduce. The grass decreases where it is eaten, but grows in new areas. Simulation #2 focuses on foxes and rabbits. In this simulation, the foxes eat the rabbits and reproduce. You can change certain aspects of these relationships and observe what happens. The aim of these simulations (and the step-by-step instructions on the guide sheets that follow) is to show students how these populations impact each other and to prepare them for the next sections on balance and flux.

The Student Guide sheet is designed for students working in small groups. It guides students to explore specific aspects of the simulations, step-by-step. It asks them to manipulate different variables and to try to predict what will occur. Students experiment with the first simulation and discuss it as a class before moving on to the second simulation. The Teacher Guide sheet explains how to walk through the simulations as a demonstration.

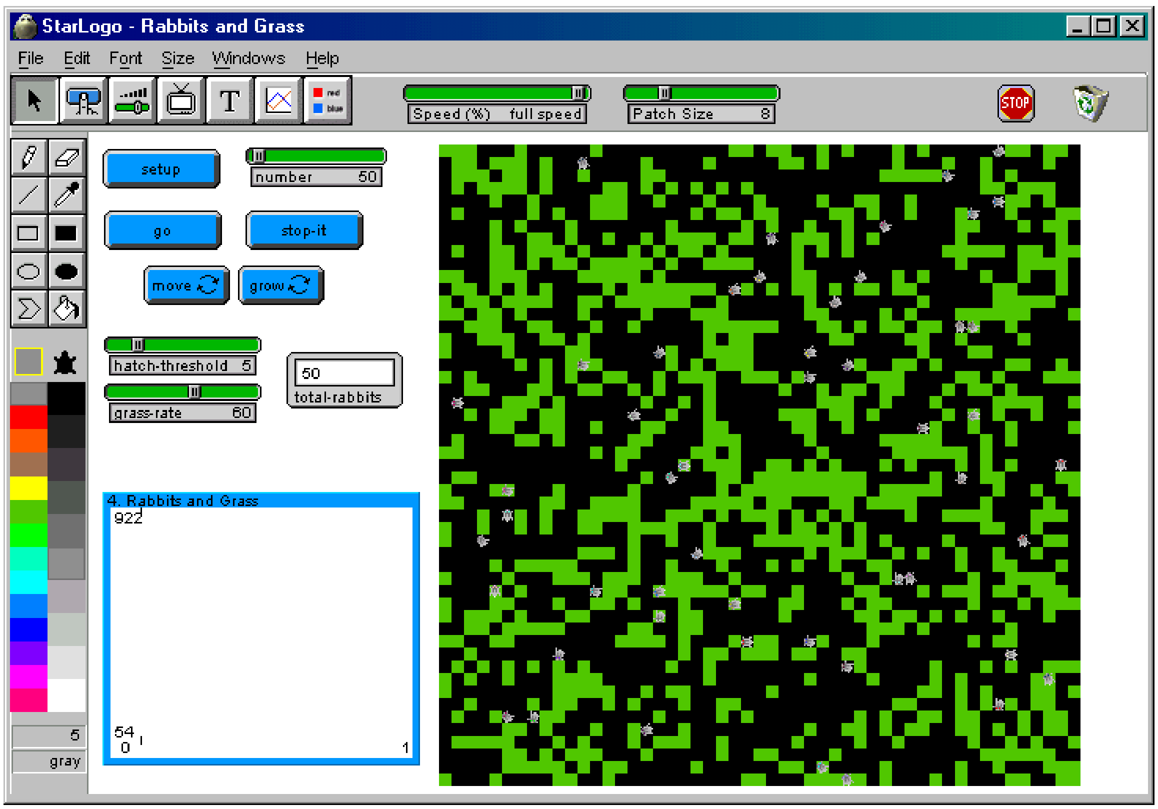
Download Star Logo from the following website, http://www.media.mit.edu/starlogo/, and follow the instructions for installing it. You will also find more detailed information about the program there (such as, how to program it yourself).

**Rebekah Gould developed some of the materials in this section.*

Using the Simulations on Your Computer

To open the programs, click on the **Simulation #1 (*Rabbits and Grass*)** icon or the **Simulation #2 (*Rabbits and Foxes*)** icon. Be sure you have downloaded and installed StarLogo first. You can have only one simulation open at a time. It may take over a minute for the program to load so be patient. When the program opens, you will first see the **Control Center** (this is explained further below). Do not close it, minimize it. Click on the ***Setup*** button to refresh the screen. Every time you want to run the simulation you must click ***Setup*** first. This resets the program to its original state. Then click the ***Go*** button. The program will run and a graph will be created.

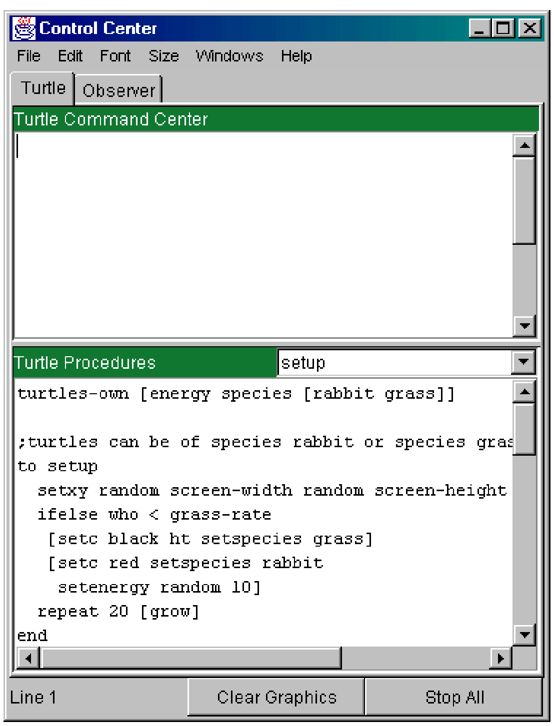
What you see when you open the program



This is the StarLogo window. The main screen with the black and green squares (which are called "turtles" in StarLogo language) is where the simulation occurs. When a rabbit or fox goes off one side of the screen, it comes right back on the opposite side. It "wraps" around so it is always

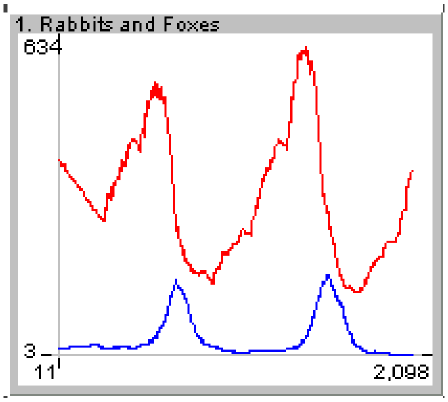
on the screen. The icon buttons above the screen and the drawing and coloring tools to the left-hand side are used to create buttons, sliders, monitors and turtles in StarLogo. You do not need to create anything to use the simulations, so you do not have to learn how to use these.
In both simulations, we used rabbit icons for the rabbit "turtles." They look gray in the above image. In Simulation #1, the green squares are the grass and in Simulation #2, the blue squares are the foxes.

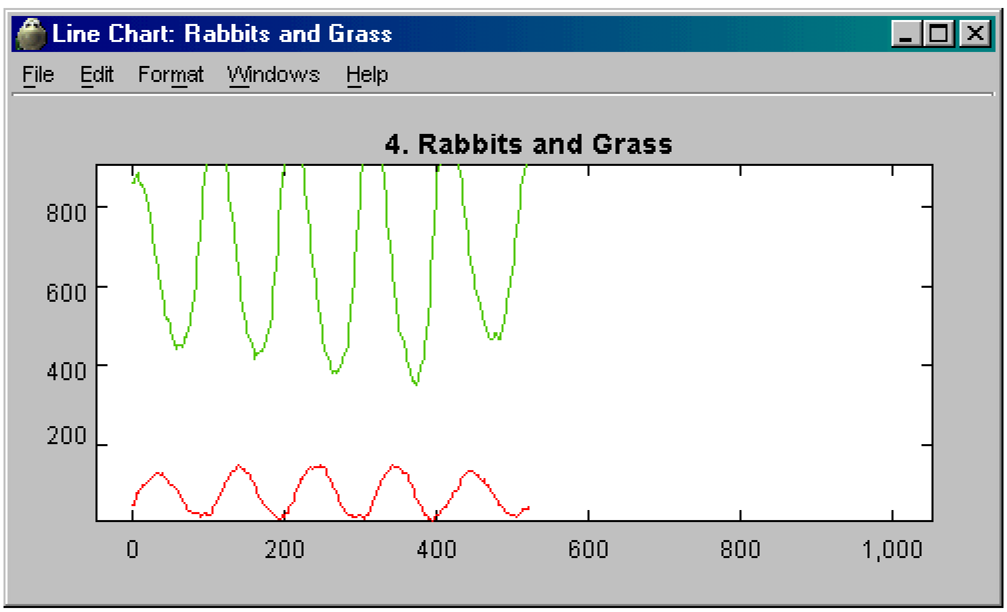
The buttons to the left of the main screen control the simulation. You will see several sliders. The number slider controls how many rabbits or foxes you have. The grass-rate controls how fast the grass grows. The higher it is, the faster the grass grows. The hatch-threshold slider controls the amount of energy that is needed for a population to reproduce. This means that it is inversely related to the birth rate of the rabbits or foxes. The lower the hatch-threshold is, the higher the birth rate will be. You will also see monitors. The total-rabbits and total-foxes monitors tell you the number of rabbits and foxes currently interacting on the main screen. You can watch the numbers decrease or increase. The blue buttons are used to begin, reset or stop the program. The two buttons called move and grow or move and graph-it (depending on which simulation it is) automatically depress when the go button is clicked. The move button makes the rabbits begin eating the grass and the grow button makes the grass grow. A small graph below the buttons displays the population's interactions.



When you open the program, the ***Control Center*** also opens. This is where you can see the language used to program StarLogo. Notice that there are two tabs, one for the "turtles" (the grass, foxes, and rabbits) and one for the observer. The ***Turtle Command Center*** is where the code is written that moves the turtles, and the ***Observer Command Center*** is where the code is written for the things that you and your students will be able to interact with. You do not need to add or remove anything. You DO need to leave the command center open. If you close it, the whole program will close.

There is a graph that is created automatically next to the main screen. You can use just this graph, or if you'd like a larger representation you can open a bigger graph. To open the bigger graph, go to the control center screen and click on the ***Windows*** menu. Select ***Plot Window*** or double click on the smaller graph in the main window. A second, larger graph will automatically appear. If the ***Go*** button has already been clicked you will see the data being plotted in real time as it is happening. The graph will not show anything until the ***Go*** button has been clicked. The graph is already set up for the students to use. They do not have to do anything to the graph but observe and note what occurs.





Notes to the teacher: Depending upon which version of StarLogo you use, it may have a few bugs. (For instance, the larger graph has had problems, so you may just want to stick with the one on the main screen. StarLogo may freeze if a project is left running and your screensaver comes on so if you want to leave it running for an extended period of time, it would be best to turn your screensaver off first.

Student Guide Sheet

This activity explores how populations can affect each other in ecosystems. You will work in small groups at a computer.

Simulation #1: Rabbits and Grass

Task 1: Observe what happens when you run Simulation #1 without making any changes.

Steps:

1. Click the ***Setup*** button.
2. Click the ***Go*** button and carefully observe what happens.
3. As a group, think about the answer to this question: *What do you think is going on between the rabbits and the grass?* Leave the program running while you discuss what is going on so you can see the beginning of a pattern in the simulation and graph.
4. As a group, discuss what you think the pattern means. *Why are you seeing this pattern? What is happening to the rabbit population?*
5. Write down your group's answers to both questions in your journals or on a separate piece of paper.

Task 2: As a group you are going to try to create different patterns by changing one slider at a time. Before you click ***Go*** you will need to write down the group's predictions for what will change about the pattern.

Steps:

1. Predict what will happen if you increase the number of rabbits. Increase the amount as much as you want.
2. Click the ***Setup*** button.
3. Make sure you write down the original number and the new number in your journal so you can reproduce your results.
4. Click the ***Go*** button after you change the number in the slider.
5. Observe the changes. Write down what happened and if it matches your predictions.

6. Do this again but make the number of rabbits smaller than the original number.
7. Write what the new number is in your journal so you can reproduce your results.
8. Observe the changes and write down what happened, and if it matches your predictions.
9. Now return the number value to its original amount and change the birth rate of the rabbits using the hatch-threshold slider. The hatch-threshold sets the energy level at which a population reproduces, so it works in the opposite direction to what you might expect. If you <u>decrease</u> it, it means that it takes less energy to reproduce so the rabbits will have babies <u>faster</u>. If you <u>increase</u> it, the rabbits will have babies <u>slower</u>.
10. Make sure you write down your predictions and the new number.
11. Once you have finished observing the changes write down what happened, and if it matches your expectations.

Task 3: Now that you have played around with this simulated environment, you have a sense of how it works and how changes can affect the system. Try to create a balance between the two populations where each population can survive.

Steps:
1. Before you begin this experiment discuss with each other what it means to create *balance* between the two populations. *What does balance between the populations mean to you? What kinds of things will you need to think about?* Come up with a group definition and write it in your journals.
2. Click the **Setup** button.
3. Play around with the sliders and see if you can create a simulation that shows your definition of balance between the two populations.
4. Click the **Go** button after you have changed the numbers in the sliders.
5. Write down the numbers so your simulation can be reproduced.

Before moving on to Simulation #2, your teacher will call you back together to discuss what you have learned so far.

Simulation #2: Rabbits and Foxes

Task 1: Observe what happens when you run the Simulation #2 without making any changes.

Steps:
1. Click the ***Setup*** button.
2. Click the ***Go*** button and carefully observe what happens.
3. As a group, think about the answer to this question: *What do you think is going on between the rabbits and the foxes?* Leave the program running while you discuss what is going on you can see the beginning of a pattern both in the simulation and in the graph.
4. As a group, discuss what you think the pattern means. *Why are you seeing this pattern? What is happening to the fox population? What is happening to the rabbit population? Why?*
5. Write down your groups' answers to both questions in your journals or on a separate piece of paper.

Task 2: As a group you are trying to create different patterns by changing one slider at a time. Before you click ***Go*** you will need to write down the group member's predictions of what you all think will change about the pattern.

Steps:
1. Predict what will happen if you increase the number of rabbits. Increase the amount as much as you want.
2. Click the ***Setup*** button.
3. Click the ***Go*** button after you have changed the number in the slider.
4. Discuss the results. What happened? Write a brief summary of what you think changed. Describe the new graph.
5. Click the ***Setup*** button
6. Predict what will happen if you increase the number of foxes.

You can increase the amount as much as you want.
7. Click the ***Go*** button after you have changed the number in the slider.
8. Discuss the results. What happened? Write a brief summary of what you think changed. Describe the new graph.
9. Don't forget to write the new number in your journal so you can reproduce your results.
10. Observe the changes and write a brief paragraph recording your observations and predictions.

Task 3: Now that you have played around with Simulation #2, you have a sense of how it works and how changes can affect the system. Try to create a balance between the two populations where each population can survive.

Steps:
1. Click the ***Setup*** button.
2. Play around with the sliders and see if you can create a simulation that shows balance between the populations.
3. Click the ***Go*** button after you have selected the numbers on the sliders.
4. Write down the numbers so your simulation can be reproduced.
5. Write a brief paragraph discussing how hard or easy it was to create a "balance" and why you think that is.

After Simulation #2*, your teacher will call you back together for another class discussion on what you have learned.

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*StarLogo v1.2.2 Developed by Mitchel Resnick, Andrew Begel, Vanessa Colella, Eric Klopfer, Molly Jones, Bill Thies, Brian Silverman, Matthew Notowidigdo, Adam Eames, Max Planck, and Sumita Kumar at the Media Laboratory, MIT, Cambridge, Massachusetts, with support from the National Science Foundation and the LEGO Group.Prior development by Monica Linden, Alice Yang, and Ankur Mehta.For use by members of the StarLogo Users Group. For information about joining the StarLogo Users Group, send email to starlogo-request@media.mit.edu. For more information, see http://www.media.mit.edu/starlogo. This distribution is approved by Walter Bender, Executive Director of the Media Laboratory at the Massachusetts Institute of Technology. Copyright 2001 by the Massachusetts Institute of Technology. All rights reserved.

Teacher Guide Sheet

Classroom Demonstration

You can do a classroom demonstration if there are not enough computers for small groups. Work at your computer with the students sitting so they can all see the screen. Click the ***Setup*** button, then the ***Go*** button to run either simulation. Begin with Simulation #1.

Simulation #1: Rabbits and Grass

Task 1: Tell the students that they are going watch a simulation and discuss what they see. Run the simulation as described in the student guide. Then discuss the patterns they saw and why the graph looks the way it does.

Task 2: Tell the students that they are going to predict what will happen when one variable at a time is changed. Tell them they need to think about how they think the populations will react to these changes.

Steps:

1. Have the students predict what will happen if you increase the number of rabbits. Agree on how many rabbits to add with your students, but make sure to write down what the new number is so you can reproduce your results.
2. Once you have observed the results discuss what really happened and whether it was the same as the students' prediction.
3. If the number was increased dramatically, try increasing it only slightly (from the starting number) to see if similar results occur. Discuss with your students why they think this happened.
4. Repeat steps 1-3, but this time, make the number of rabbits smaller than the original number.

Task 3: Tell the students that this time you are going to change the birth rate of the rabbits. In order to do so, in this particular program, you need to reduce the energy level (hatch-threshold) at which they are able to reproduce. So lowering the hatch-threshold will increase the birthrate, raising it will decrease the birthrate. This is counterintuitive so make sure that students understand it. You want them to predict what will happen when birth rate is changed. Ask them to think about how an ecosystem will react to these changes.

Steps:

1. Return the number value to its original amount and change the birth rate (higher or lower) of the rabbits using the hatch-threshold slider. Make sure you write down the new number and discuss the student's predictions.
2. Once they have finished observing the changes have them discuss what happened, and if this matched as their expectations.

Task 4: Now that the students have played around with the program, they have a sense of how it works and how changes in one population can affect the other. Try to create balance between the populations. Decide with your students what to change and by how much. You can try more than one idea out to see what happens. Before beginning this experiment, discuss what balance between two populations would look like. Ask, "How easy or hard is it to create balance between two populations?" "Is balance the opposite of flux? Why or why not?"

After you finish, discuss what happened as in Step #6 in the directions in the lesson plan.

Simulation #2: Rabbits and Foxes

Task 1: Tell the students that they are going watch the simulation and discuss what they see. Run the simulation, then discuss the patterns they saw and why the graph looks the way it does.

Task 2: Tell the students that they are going to predict what will happen when one variable at a time is changed. Tell them they need to think about how the other population might react to these changes.

Steps:

1. Have the students predict what will happen if you increase the number of rabbits. Agree with your students on how much to increase the rabbits by, but make sure to write down what the new number is so you can reproduce your results.
2. Once you have observed the results, discuss what happened and if this matched their expectations.
3. Have the students predict what will happen if you increase the number of foxes. Agree with your students on how much to increase the foxes by, but make sure to write down what the new number is so you can reproduce your results.
4. Once you have observed the results, discuss what really happened and if this matched their expectations.

Task 3: Tell the students that this time you are going to change the birth rate of the rabbits (raising birthrate by lowering hatch-threshold and lowering birthrate by raising hatch-threshold). You want them to predict what will happen when the birth rate is changed. Ask them to think about how the foxes will react to these changes.

Steps:

1. Return the number value to its original amount and change the birth rate of the rabbits using the hatch-threshold slider. You

and your students can choose to increase it or decrease it. Make sure you write down the new number and discuss the student's predictions.

2. Once the students have finished observing the changes, have them discuss what happened and if this matched their expectations.

***Task 4:** Now that the students have played around with this simulated environment, they have a sense of how it works and how changes can affect the system. Try to create balance between the populations. Decide with your students what to change and by how much. You can try more than one idea out to see what happens. Before beginning this experiment, discuss what balance between two populations would look like. Ask, "How easy or hard is it to create balance between two populations?" "Is balance the opposite of flux? Why or why not?"

After you finish, discuss what happened as in Step #8 in the directions of this lesson plan.

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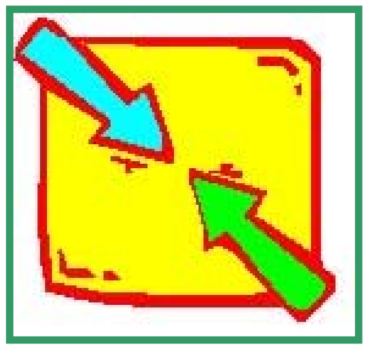
What is Two-Way Causality?

We are used to thinking about cause and effect as one-way: one thing makes another thing happen. But it is not always this simple. Sometimes one event or relationship has two-way effects. The event has an effect in both directions. For instance, when a bee pollinates a flower, the bee and the flower are both affected. The bee gets the nectar it needs for food energy and the flower gets pollen picked up by the bee from other flowers. This enables it to reproduce.



Sometimes the effects are beneficial for both things, such as in the example above. However, sometimes the effect on one is negative and the other is positive, such as when a tapeworm attaches to the intestines of a dog. The tapeworm benefits by getting the energy that it needs, but the dog loses energy to the worm and may be weakened.

Often we think about one-way effects in the ecosystem, such as how a predator benefits from eating prey, but we don't always notice the effects on the prey. For the individual animal that gets eaten, it is a bad thing. But for the population of the prey, it might help to maintain the balance of the population.

Questions to Think About:

- How is Two-way Causality different from Domino Causality?
- What examples of Two-way Causality can you think of?

Endnotes for Section 5

[1]Commensalism is another type in which one species benefits and the effect on the other species is neutral.

[2]Leach, J., Driver, R., Scott, P., & Wood-Robinson, C. (1996). Children's ideas about ecology 3: Ideas found in children aged 5-16 about the interdependency of organisms. *International Journal of Science Education, 18,* 19-34.

[3]StarLogo v1.2.2 Developed by Mitchel Resnick, Andrew Begel, Vanessa Colella, Eric Klopfer, Molly Jones, Bill Thies, Brian Silverman, Matthew Notowidigdo, Adam Eames, Max Planck, and Sumita Kumar at the Media Laboratory, MIT, Cambridge, Massachusetts, with support from the National Science Foundation and the LEGO Group. Prior development by Monica Linden, Alice Yang, and Ankur Mehta.
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[4]Wilensky, U. & Reisman, K. (2006). Thinking like a wolf, a sheep or a firefly: Learning biology through constructing and testing computational theories--an embodied modeling approach. *Cognition and Instruction*, 24(2), pp. 171-209

[5]Keil, F. C. (1996) The growth of causal understandings of natural kinds. In Sperber, D., Premack, D., & Premack, A. J. (Eds.), *Causal Cognition: A Multidisciplinary Debate*. Oxford: Clarendon Press.

[6]Leach, J., Driver, R., Scott, P., & Wood-Robinson, C. (1996).

SECTION 6

Thinking About Steady States and Balance Over Time

This section introduces the idea of balance as a dynamic concept that plays out over time. It considers the "wiggle" within balance that is a natural part of ecosystem dynamics as well as oscillations that introduce significant changes into the nature of the system. It grapples with the question of change over time and how one assesses change in a given period of time.

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Thinking About Steady States and Balance Over Time

Section 6 Thinking About Steady States and Balance Over Time

This section uses a combination of activities and discussions to introduce concepts of balance and the challenges of reasoning about balance over time. It grapples with the question of what time scale to reason within.

Understanding Goals

Subject Matter

- ❖ Ecosystems are dynamic and always involve a certain amount of change.
- ❖ Even ecosystems that are called "balanced" involve some flux or changes.
- ❖ Studying the dynamics of flux is a way of understanding the nature of the system.
- ❖ Whether an ecosystem appears "balanced" or not often depends upon the time scale that we are analyzing it within.

Causality

- ❖ Balance is a dynamic concept.
- ❖ Using "snapshots" of systems in time can be misleading when trying to analyze the balance within a system.
- ❖ Using "video reasoning" or "viewing a system over time" is necessary for reasoning about concepts such as balance and flux.
- ❖ A system might appear balanced in one time scale and unbalanced in another depending upon which excerpt over time one is analyzing.
- ❖ Balance often comes in cycles. While a population of two interdependent populations may not look stable, when examined from a multi- year perspective or more, they are balanced.
- ❖ We can't necessarily predict what analyzing balance on different time scales will tell us about a system.
- ❖ We often focus on time scales relevant to how humans value certain outcomes in ecosystems.

Background Information

Change in Nature

Change is the essence of nature. Ecosystems are constantly changing. To understand ecosystems, one must examine them with spatial and time factors. Balance is dynamic and involves continual fluctuations. Ecosystems do not fluctuate randomly. They are incredibly complex and contingent on, among other things, their history and present state.

Disturbance is a natural part of regimes. The dynamic forests we have now have never existed before and they won't exist in the future, they will be different. Healthy ecosystems maintain certain trajectories and these trajectories are strongly influenced by balance in species composition, species groups, landscape patterns, soil and atmospheric chemistry, and various other factors. Instead of having a balance point they come back to, they may be bouncing among multiple equilibrium points, or they don't reach equilibrium and there is a tremendous amount of change.

Larger systems have more inertia than smaller systems. Small systems have more fluctuation than larger systems. Larger systems tend to be more stable, however once a large system loses stability and begins to wobble, it is difficult to rebalance. Understanding the interrelationship between balance and flux, or in other words between structure and process in nature is the essence of modern ecology. Ecologists also look at things as patterns over time: energy flows, inputs, and outputs.

Sections six and seven introduce concepts of balance, flux, and change. Section six introduces the idea of balance as a dynamic concept—that even within balance, there is considerable flux and that whether or not we view something as unbalanced often relates to the time scale at which we examine it. Section seven explores more dramatic flux in ecosystems. It considers how flux tells us about connections between populations. It also considers how flux can create new opportunities in ecosystems.

Balance Over Time is Wiggly

We often think about balance as the outcome of what happens when you put two things on a scale that weigh the same and the scales reach an equilibrium point. The snapshot of the equilibrium point is a strong anchoring conception of balance. However, in a dynamic system, balance is much more "wiggly." There is flux within balance as minor changes take place. Populations go up and down but don't necessarily die out, weather related events cause shifts in resources, etc.

Thinking About Balance Over Time

In order to recognize the concept of flux within balance or "dynamic balance," we need to look at balance over time. This involves reasoning about the processes of the steady states in the system instead of reasoning about snapshots, events, or points in time. This distinction is introduced as the difference between "snapshot reasoning" and "video-reasoning."

One of the puzzles about reasoning about balance over time is that systems can look balanced or unbalanced depending upon the length of time analyzed and the period of time chosen. This is an important lesson for students. It often comes up in relation to climate change. People reason about a period of weeks that are abnormally cold or analyze charts and see that it was as hot as it is now many years ago. The more you zoom out in terms of time span, the more information you have.

At the same time, it can be challenging to decide what time span to use to analyze a system. The activity in this lesson looks at the yearly batting averages of a baseball player and asks students to reason about what the averages suggest. They will see that longer time scales convey different information about the player's ability than shorter time scales. We can decide what a useful time scale is for a baseball player because we have information about other ball players over the course of their careers. However, in some cases, we do not have easily available reference points to help us to decide. In the case of climate change, we have only one earth and so we can't use other earths as reference points. The lesson considers graphs of global temperature over time to illustrate this point.

LESSON PLAN:
Thinking About Steady States and Balance Over Time

Materials

- *Journals or paper*
- *Graphs of Batting Average Snapshots*
- *Graph Paper*
- *Rulers, pencils, and erasers*
- *Graphs of Global Temperature Snapshots*
- *Batting Average Interpretation* Activity Sheet
- *Global Temperature Interpretation* Activity Sheet
- *Reasoning About Patterns in Your Grades: Connecting Forward* Activity Sheet

Prep Step

- Read the background information.
- Review the lesson plan.
- Photocopy the Batting Average Snapshots (p. 182); the Interpretation Activity sheets (pp. 183 and 184); and the Reasoning About Patterns in Your Grades sheets (pp. 188, 189, and 190).
- Photocopy or arrange a way to project the Global Temperature Graphs (p. 185).

LESSON PLAN

Reveal Thinking

Step 1: Gather Students' Ideas and Questions

Remind students of the discussions that they had in Section 5 while working with Star Logo. Consider the students' current ideas about whether flux and balance are opposites of each other or not. Ask the students to each write down their ideas about balance and about flux in their journals or on a piece of paper.

Collect some of their thoughts about each. Instead of collecting all of their ideas about balance and then their ideas about flux, have students share both at once. It will help them set the ideas in contrast to each other and may invite more sophisticated comparison.

Step 2: Discovering the Dynamic Aspects of Balance

Ask the students to stand on one foot and balance for at least 30 seconds. Making it into a contest to see who can stay balanced the longest may invite interesting discussion on what enabled the balance. Alternatively, you could have them balance their pencil or pens on their hands. You may have some students who are able to balance with little wiggle but most of them will use their arms and torsos to make corrections to their dynamic equilibrium in order to stay balanced.

Ask what they did to maintain their balance. Were they perfectly balanced the entire time? Make sure that they see the corrections that they made as a part of the process, not cheating. Was there any point where they knew that they had "gone too far"? …where they could no longer get the balance back?

Remind them of other experiences that they have had with balance. Have they ever tried to balance someone else on a seesaw? How about using a balance scale?

Ask the students to contrast what they did in maintaining their own balance to the Star Logo demonstrations in the last section. What similarities and differences were there? Push beyond surface level similarities by drawing out the similarities between the different examples. Usually there are fluctuations that are a part of the overall pattern of balance that one is trying to achieve. Come back to their ideas about what balance and flux mean in ecosystems. What do they think now about whether or not they are opposite of each other. Help the students to realize that there are fluctuations within balance and that balance is a process more than a state.

Step 3: Discovering How Time Frames Matter in our Interpretations: Baseball Averages

Explain to the students that next they will be doing an activity to consider how we think about patterns that will help them to think ecosystems patterns later.

Pass out graph paper. Ask the students to make a graph with "years" across the bottom on the X axis (horizontal axis) and "batting average" on the Y axis (vertical axis). They should set their Y axis up so that it has points from .150 to .400 going up by .01 each time. In order to do so, they will need at least 25 points. They should set their X axis up showing the years from 1993 to 2008.

Explain that you are going to give them some points to graph and then will ask them to interpret the graph. The points are the batting averages for a baseball player. Explain that these numbers tell the average number of times that a player is able to hit a ball. Usually anything over .300 is considered to be very good.

Give them the numbers in the first time frame. Have them graph the numbers and connect them with a line.

Pass out the interpretation sheet for the baseball averages. Ask them to reflect upon what the pattern means and to write their ideas.

Then ask them to extend their line by giving them the next set of averages. Afterwards have them interpret what this line tells them.

Finally, give them the averages in the third time frame and have them interpret the pattern. What does this pattern suggest?

Finally, discuss how their ideas changed with the information that they had available to them. How did their thinking shift as they saw more or less of the pattern? Afterwards, you can reveal to them that the baseball averages are those of Manny Ramirez who has been considered one of the best sluggers of all time.

Step 4: Discovering How Time Frames Matter in our Interpretations: Global Temperature Averages

Pass out the sheet on interpreting global temperature averages. Next, show the students graphs of temperatures on earth starting with the short term, then medium term, then longer term. After each, pause and let the students write down their impressions.

Consider the interpretations together. Notice how different one's interpretation can be depending upon the time scale in question.

Explore Causality

Step 5: Considering the Importance of Time Scale

Afterward discuss how the period of time that was considered influenced how the pattern was interpreted. Compare this to how it felt to try to balance on one foot. Some of the time, you could be more in balance than others. Any "snapshot" of time would have given you a different picture of what was going on.

When you watch a videotape, you tend to see more of the story than a photograph can tell you. This is one of the differences between "Snapshot" and "Video-Reasoning." Snapshot reasoning can often tell you a very lot about a single point in time, however, it can be hard to know how to interpret that point in time without longer term "video-reasoning."

Ask the students, "How do we know if a baseball player is good at batting or not?" They may respond that it depends upon his average over time or that it depends how high his average is. These things are true, but how do we decide what is considered a good average? Often we compare it to the past or to other ball players.

Ask, "How do we know if the temperature on Earth is getting warmer or not?" We can compare it to the past. "How do we know what time frame is the right time frame to answer the question well?" This is a challenge in science. While we have many ball players to compare to, we only have one planet Earth. So we only have our past data to help us decide upon what time frame to analyze the pattern within. Given that the pattern often depends upon the time scale, figuring out how to think about what time scale is most relevant is a challenge for ecosystem scientists.

Review, Extend Apply

Step 6: Connecting Forward: Reasoning About Ecosystems

How do these ideas apply to reasoning about balance and flux in ecosystems more generally? What does it suggest about the time scales that we use? Have the students reflect on this question in their journals.

Reinforcement Activities

Reasoning About Patterns in Your Grades: Connecting Forward Activity Sheet – (p. 188) Have students work on the sheet about making the best case for their grades to a parent. Encourage them to think about what they learned in today's lesson and how it is similar or different.

Resources for Section 6

Batting Averages for Baseball Player: Three Time Spans

Batting Averages Interpretation Activity Sheet

Global Temperature Graphs

- Temperature Graph Time Span #1
- Temperature Graph Time Span #2
- Temperature Graph Time Span #3

Global Temperature Averages Interpretation Activity Sheet

Reasoning About Patterns in Your Grades: Connecting Forward Activity Sheet

Batting Averages for Baseball Player

Time Span #1: 2003-2005

Year	Batting Average
2003	.325
2004	.308
2005	.292

Time Span #2: 2003-2008

Year	Batting Average
2003	.325
2004	.308
2005	.292
2006	.321
2007	.296
2008	.332

Time Span #3: 1993-2008

Year	Batting Average
1993	.170
1994	.269
1995	.308
1996	.309
1997	.328
1998	.294
1999	.333
2000	.351
2001	.306
2002	.349
2003	.325
2004	.308
2005	.292
2006	.321
2007	.296
2008	.332

Name: ____

1. How would you interpret this graph? What are your thoughts about this baseball player?

2. How would you interpret the graph now? What are your thoughts about this baseball player?

3. How would you interpret this graph now? What are your thoughts about this baseball player?

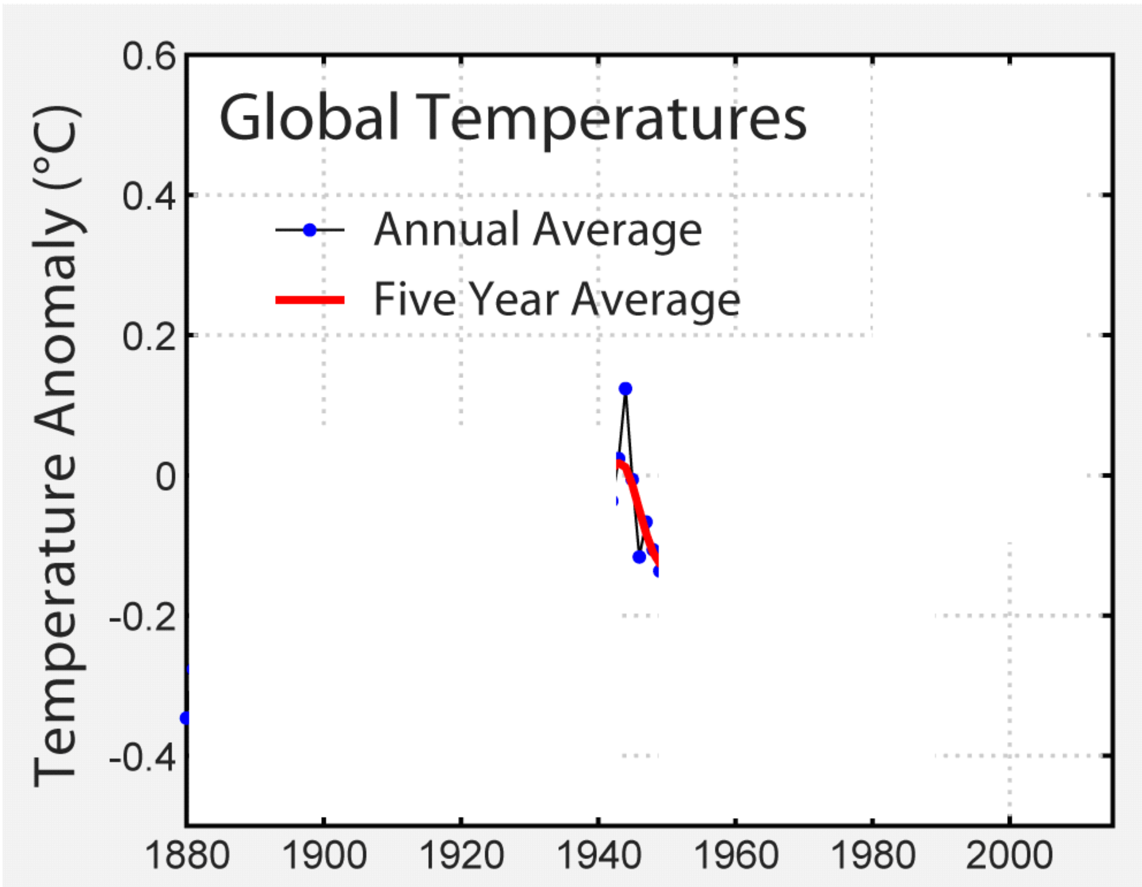
Name: ____________________________________

1. How would you interpret this graph? What are your thoughts about what is happening to temperatures on Earth?

2. How would you interpret the graph now? What are your thoughts about what is happening to temperatures on Earth?

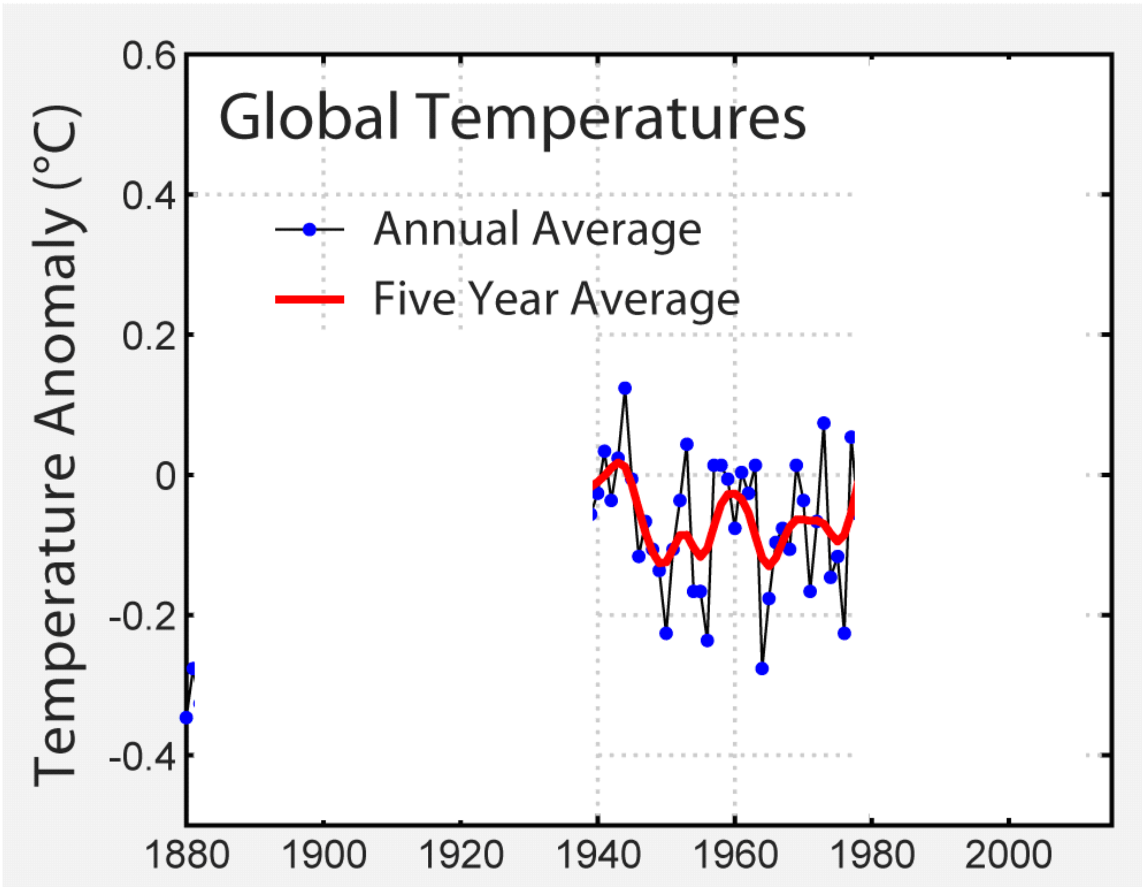
3. How would you interpret this graph now? What are your thoughts about what is happening to temperatures on Earth?

Temperature Patterns Time Span #1



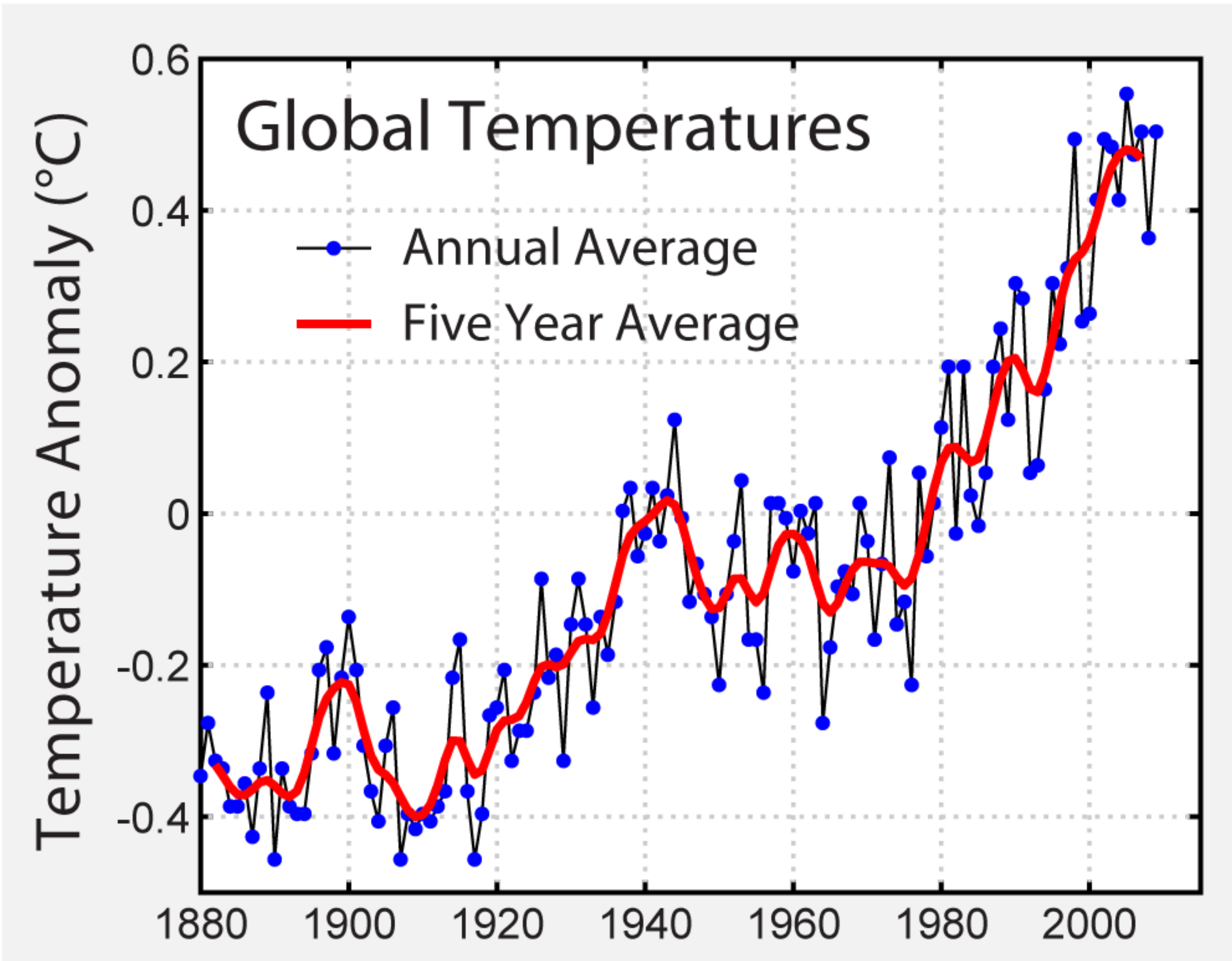
[1]Data Source: National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies (GISS) Graph from:
http://upload.wikimedia.org/wikipedia/commons/f/f4/Instrumental_Temperature_Record.png
Modified to reveal a portion of the data

Temperature Patterns Time Span #2



[1]Data Source: National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies (GISS), Graph from:
http://upload.wikimedia.org/wikipedia/commons/f/f4/Instrumental_Temperature_Record.png
Modified to reveal a portion of the data

Temperature Patterns Time Span #3



[1]Data Source: National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies (GISS), Graph from:
http://upload.wikimedia.org/wikipedia/commons/f/f4/Instrumental_Temperature_Record.png
Modified to reveal a portion of the data

Name: ___________________________________

Making Connections: Reasoning About Patterns in Your Grades

Imagine you are taking a math class that you really enjoy. You have been studying hard all year, and your test scores are steadily improving. But the most recent test was very difficult, so your score decreased a little bit from the previous test. When you bring the test home, your parent or guardian is angry that your score has declined, so decides to ground you. Your task is to use your test score data to show him/her that he/she shouldn't be worried and that you shouldn't be grounded.

1. Data chart

TEST NUMBER	SCORE
1	83%
2	88%
3	89%
4	88%
5	91%
6	95%
7	94%
8	92%
9	90%

2. Make a line graph using only the last two points, your last two tests. Make a line of best fit (the straight line that does the best job going through those dots) for those two points. What does that graph show you?
3. Now make a graph for your test scores for the whole semester. Make a line of best fit. How do you interpret that graph? How is it different from the first graph?

4. Now write out how you would explain these graphs to your parent or guardian. Which one represents short-term change, and which one represents overall change? Why shouldn't your parent/guardian be worried?
5. Your parent/guardian agrees with you and decides not to ground you. But he/she tells you that if your scores show a downward trend for at least three weeks, then you will be grounded.
6. Now it's three weeks later. For the past three weeks, your scores have been decreasing, and your parent/guardian is worried again. He/She decides to meet with you to determine whether he/she should ground you this time.
7. Updated data chart

TEST NUMBER	SCORE
1	83%
2	88%
3	89%
4	88%
5	91%
6	95%
7	94%
8	92%
9	90%
10	93%
11	92%
12	91%

8. Make a graph of the entire data set. Make a line of best fit through all the data. Now, with dotted lines, make a line of best fit through the first 6 points. Then make a line of best fit through the last 6 lines.

Now imagine that you are your parent/guardian. Which line would you choose to try to prove that your child's scores are getting worse and worse? What do the lines tell you about how your grades are changing over the course of the semester?

Endnotes for Section 6

[1]Global Temperature Graphs: Data Source: National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies (GISS), http://upload.wikimedia.org/wikipedia/commons/f/f4/Instrumental_Temperature_Record.png

Section 6 Cover Photo Credit: A seesaw in a Montreal park. By en:User:aarchiba. Released to Public Domain for any use.

SECTION 7

Understanding Balance and Flux in Ecosystems

This section addresses students' tendency to over-emphasize balance in ecosystems to the exclusion of flux. It helps students to realize that balance and flux are natural states in an ecosystem and that each state plays a role in ecosystem dynamics.

Section 7 Table of Contents
Understanding Balance and Flux in Ecosystems

Section 7 Understanding Balance and Flux in Ecosystems

This section uses a combination of stories, discussions, and games to help students realize that balance and flux are natural states in an ecosystem and that each state plays a role in ecosystem dynamics.

Understanding Goals

Subject Matter

- ❖ Ecosystems are dynamic and include balance and flux.
- ❖ There is flux within balance that is a part of dynamic balance.
- ❖ There is also flux that is more dramatic—that is part of boom and bust patterns that involve significant change in ecosystems.
- ❖ Because of interdependencies in the ecosystem, the fates of the populations are linked. Events that affect one population typically have ripple effects—affecting other populations. When one population is out of balance, others may be too.
- ❖ The greater the biodiversity in a system, the more resilient and stable an ecosystem is likely to be.
- ❖ Studying the dynamics of flux is a way of understanding the nature of the system.
- ❖ Dramatic flux is not necessarily harmful to an ecosystem. It can introduce new opportunities for species to gain a foothold in an ecosystem. However, if dramatic flux reduces the biodiversity within a system, it can decrease the stability of the system over time.
- ❖ Organisms in a food web have a certain amount of ability to adapt, and a certain amount of redundancy exists. This provides a kind of overall stability in the food web.

Causality

- ❖ Balance and flux in a system can cause complex effects.
- ❖ The balance of one population affects the balance of others. When one population becomes unstable and its numbers begin to oscillate, others typically become unstable too.
- ❖ Some events do not have strong or direct adverse effects on ecosystem members because the ecosystem members are able to adapt.

Background Information

Different Ways of Characterizing Flux

Flux refers to changes in an ecosystem. As we considered in the last section, there is flux within balance and ecosystems are always changing. More dramatic forms of flux can upset the overall dynamic balance of an ecosystem. Here, we are referring to more severe oscillations often referred to as "boom and bust" patterns. These types of patterns can lead to significant change in an ecosystem.

Even dramatic flux is not necessarily harmful to an ecosystem: it can create patterns in an ecosystem that are ultimately healthy. For instance, flux can allow for new species to become established. Unidirectional change is not always negative. There is no invisible hand guiding and balancing the system. Some processes that appear to be unidirectional are actually a component of balance and flux if we look at them on a broad spatial or time scale.

Flux doesn't always mean that a population will die out. It can simply mean that the population size changes over time. For some populations, flux is a necessary part of their existence. They go through seasonal or yearly cycles where their populations diminish greatly and in some cases altogether. For instance, Ferry Shrimp live in vernal pools that dry out completely in the Fall and reappear in the Spring. Cicadas go through a seven year cycle where the population increases dramatically and then resume their normal levels.

Ecosystem scientists refer to "press" and "pulse" disturbances. Pulse disturbances refer to short-term oscillations where the system undergoes sudden changes but returns to the earlier state and press disturbances refer to continuous disturbances that result in more permanent change.[1] The puzzle is to determine which is which and what time scales are relevant.

Sometimes flux occurs when there have been changes to the environment. This type of change can be a one-time event, such as a fire or a very harsh winter from which an ecosystem eventually recovers to a previous state. This type of change can also be permanent, forcing organisms to adapt in new ways or die.

The fates of populations are linked

There are many interdependencies within ecosystems. Events that affect one population typically have ripple effects—affecting other populations. When the size of one population becomes too large or too small for its niche (or role) in the ecosystem, it is out of balance and may throw others out of balance too. The simulations in Section 5 revealed some of the patterns of boom (when a population size is too big[2]) and bust (when a population size is too small) that can occur.

The lesson in this section introduces a story describing how the World Health Organization inadvertently interrupted the balance of an ecosystem when trying to solve a health issue. The story illustrates the complex connections that existed and what happened when those were disrupted. The consequences came as a surprise to the officials, who had not anticipated the many non-obvious connections.

Patterns of Balance and Flux Can Tell Us <u>How</u> Things Are Connected in Ecosystems

School curricula often focus on the connections in ecosystems. This makes sense because ecology is about connections. However, it is important to pay attention to *how* things are connected, rather then just assuming that all things are connected in one way, and that an event involving that particular thing will have a strong and direct effect on other things.[3] There are events that don't necessarily affect other ecosystem components because there is a fair amount of "insurance" built into ecosystems. A predator does not necessarily die off because its prey dies off. It may change its diet. One food source may dwindle while another flourishes. For example, perhaps a storm washes an abundance of mussels on shore, resulting in a feeding frenzy among shorebirds. The "surprise" mussel supply becomes depleted, and the birds must shift to their regular diet, which might have included only small amounts of mussels. This example stresses the insurance that provides balance, but it is also about flux.

Patterns of balance and flux are interesting because they offer information about the nature of the connections within the ecosystem, both their limits and their flexibility. While balance or equilibrium might be viewed as a system's "goal," flux is probably the more common state of the system. The dynamics of flux can play out in many ways. There may be shifts in the proportion of prey to predators. For instance, more mice than their predators can keep in check may result in an unbalanced population size until an event such as a dry spell causes large numbers of mice to die off. This re-establishes a balance of prey population size and predator population size, without the predators being the cause.

It is important to help students learn to reason about both balance and flux. The activities in this section are designed to address that need. The understanding goals build upon those taught in the previous lessons, so this particular lesson set should be taught after those understandings are evident.

Adaptations that Contribute to Stability Over Time

Ecosystems involve both balance and flux—both the flux within balance and greater oscillations that result in boom and bust patterns as discussed in the next section.[1] Flux can also represent a smaller, regular fluctuation pattern within a broader pattern

[1] The differentiation between flux within balance and more dramatic oscillations is contingent on the scale at which one considers the system and the perspective that one adopts. Both can be viewed as on a continuum and dependent upon how one interprets the broader patterns.

of balance. For instance, flux may occur in a cyclical pattern, with seasonal or yearly cycles. Balance often takes the form of cycles. While a population or two interdependent populations may not look stable, when examined form a multi year perspective, they are stable.

Studies of ecosystems in school curricula typically *stress* balance. Indeed there is a great deal of redundancy and adaptability in ecosystems that provides balance. Redundancy means that organisms have multiple acceptable food sources or habitats. The ability to adapt means it is possible for organisms to switch food sources or habitats. Opportunistic feeding patterns and caloric loading are different strategies that organisms have for meeting their energy requirements despite fluctuations in available food sources.

School curricula often focus on the connections in ecosystems. This makes sense because ecology is about connections. However, it is important to pay attention to *how* things are connected, rather then just assuming that all things are connected in one way, and that an event involving that particular thing will have a strong and direct effect on other things.[2] There are events that don't necessarily affect other ecosystem components because there is a fair amount of “insurance” built into ecosystems. A predator does not necessarily die off because its prey dies off. It may change its diet. One food source may dwindle while another flourishes. For example, perhaps a storm washes an abundance of mussels on shore, resulting in a feeding frenzy among shorebirds. The “surprise” mussel supply becomes depleted, and the birds must shift to their regular diet, which might have included only small amounts of mussels. This example stresses the insurance that provides balance, but it is also about flux.

LESSON PLAN: Balance and Flux Reveal How Organisms Are Connected in Ecosystems

Materials

- *Parachuting Cats into Borneo* Story
- *The Lemmings of Norway*: *An Example of Balancing Ecosystems by Flux* Story
- *Lynx-Hare Cycles* Sheet
- *Passenger Pigeon Story*

Prep Step

- Read the background information.
- Review the lesson plan.
- Photocopy the story, *Parachuting Cats into Borneo*, (p.205) if you plan to have them read it (alternatively, this story may just be read aloud to them).
- Photocopy the *Lynx-Hare Cycles* sheet (p.208) for each student.
- Photocopy the story *Passenger Pigeons* (p. 209) for students to read

Analyze Thinking

Step 1: Revisiting the Questions from Section 5: Gather Students' Ideas and Questions

Explain to students that they have talked a lot about ecosystems and what happens to populations of animals in ecosystems. Split them into small groups for discussion and ask:

- Do you think a population always has the same number of animals in it, or can it change?
- If you think it changes, how does it change? Yearly? Monthly? Once in a great while? What might cause changes at these intervals?
- Are there ever any patterns to how populations change? If so, how would you describe the patterns? If so, what are some things that make it hard or easy to see the patterns?
- Do you think that change in an ecosystem helps or hurts? Why?
- Can we use words like "good" or "bad" to describe changes in population size?

Note to the Teacher: *If students did the simulation in Section 5, draw their attention back to the patterns in the accompanying population size graphs. Go back to the simulation and discuss the up and down patterns that are evident.*

Bring groups back together and have them take turns sharing their reactions to the idea of change in ecosystems. *Most students view the changes, especially the boom and bust patterns, as negative.*

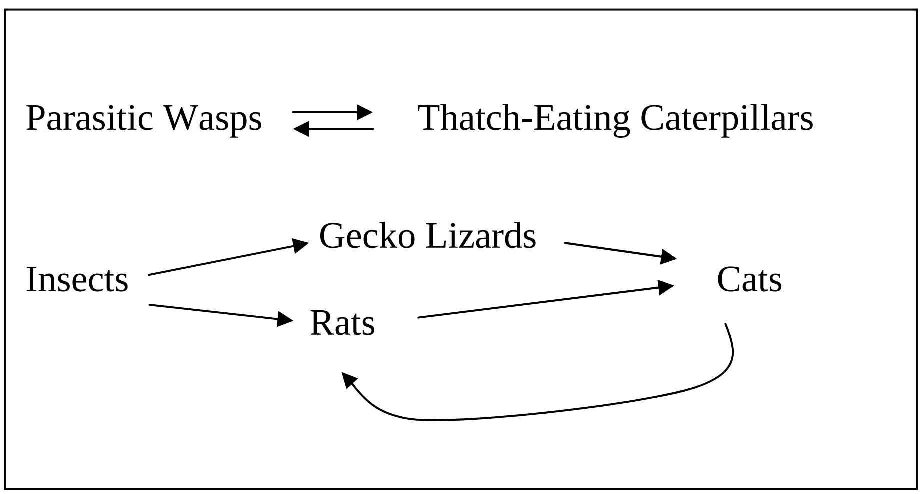
RECAST Thinking

Step 2: Investigating the Important Role Predators Play in Controlling Population Size

Read the story, *Parachuting Cats into Borneo*. Ask: "What questions do you have about what happened?" Make sure that the students understand what happened and why.

Step 3: Map the Interdependencies Amongst Populations

Ask, "What happened and why did it happen? What would a diagram showing what made what happen look like?" On the board, map out what the story revealed about the interdependencies amongst the populations. Your mapping might look something like this:



This mapping shows a two-way relationship between the wasps and the caterpillars because the wasps give energy to the caterpillars and the caterpillars keep the size of the wasp population under control. Insects give energy to lizards that in turn give energy to cats. The cats get energy from the rats but also keep the size of the rat population in balance.

Make sure that students understand that the predators play an important role in keeping certain population sizes under control. For instance, wasps keep the thatch-eating caterpillars to a minimum and the cats keep the numbers of rats down.

Ask, "Is there ever a time when keeping the numbers of a population down can help the animal whose population size is kept down? …where it actually helps the animal who is being eaten?" Collect and discuss students' ideas.

Step 4: Discuss Why Flux is Not Always Bad

Explain that the example above shows how balance can be important in the ecosystem. Often people think that ecosystems must be balanced in order to be "healthy." However, change or "flux" is not always harmful for an ecosystem. It is an important part of the complex tapestry of ecosystem dynamics. In fact, some might say that flux is a part of balance—that balance is not a static thing. When there is change, it can offer opportunities for new populations to become established. For instance, if a rabbit population dies down, other animals that eat the same kinds of things and live in the same sorts of places might start to establish themselves, adding stability to the ecosystem. (In general, the greater the number of species, the greater the resulting stability.) Balance AND flux are parts of the dynamic of ecosystems.

Step 5: Read the Story, The Lemmings of Norway

Show the image of a lemming. Explain to your students that they are going to hear a story about a tiny rodent who lives in the far north where it is often cold and snowy. You may want to get a map of the world and show the students where the arctic regions are and where the country of Norway is in particular. Reinforce that there are no landmasses off the coast of Norway.

Read the story out loud to your students. Use the follow-up questions to discuss the story with your students and gather their ideas.

Step 6: Read the Lynx-Hare Cycles Sheet

Read and discuss the page about the Lynx-Hare Cycles as another example. Make sure that the students understand how flux is an essential dynamic that alternately results in balance.

Step 7: Read and Discuss the Passenger Pigeon Story

Read and discuss the Passenger Pigeon Story and consider the follow-up questions. What does the story tell you about *how* the populations were linked?

Explore Causality

Step 8: Review Balance and Flux Concepts

Make the following points about the nature of balance and flux:

- Balance and flux in one population can have ripple effects to other populations—they become affected by the flux as well. Populations are intimately connected.
- Even if populations are affected by certain changes, this does NOT always mean that they will die off. If a certain food source disappears, the animals that ate that food may shift to other diets. Chance events can cause this to happen. For example, if a storm washes an abundance of mussels on shore, it might result in a feeding frenzy among shorebirds, but this depletes the mussel beds. The birds must again shift their diets (which might have previously included small amounts of mussels) to other foods.
- Flux can open up opportunities for other species within an ecosystem. When the dinosaurs became extinct, they left a huge gap in the ecosystem. The mammals were able to fill that gap and increased their numbers and their diversity. Without flux, mammals (don't forget humans are mammals!) would not be as prevalent as they are today. In this case, flux created both positive and negative results. The event was negative for the dinosaurs because they died out, but it was positive for the mammals, which could then evolve without intense pressure to compete for resources and without the worries of dinosaur predation.
- Balance and flux are valuable dynamics in ecosystems. An ecosystem in balance is a stable ecosystem doing well. Flux can provide opportunities for weaker populations to gain a stronger foothold in their ecosystem. Balance and flux in a system can cause complex effects, and these effects can be positive, negative, or both for the populations involved.

Review, Extend, and Apply

Step 9: Connect Back to the Web of Life

Ask your students to recall the first activity that they did in this module where they made a "Web of Life." Ask:

- How does what you learned in this section change the way that you think about what you learned from that game?
- How would you revise the game in order to make it reflect what you now know?

Reinforcement Activities

Population Shuffle (p. 211) **—** In this game, each student represents an organism in an ecosystem. These organisms are divided into two teams, one that lives on land, and one that lives in the water. Each team consists of a primary producer, an herbivore and a carnivore. Each square on the game board represents a possible population size for each organism, and the goal of the game is to neither overpopulate nor go extinct. Players draw cards, which describe events in the ecosystem, such as a productive growing season, or pollution introduced by humans. These events trigger changes in the player's population size, which in turn trigger changes in the population sizes of the other organisms on that player's team, based on their predator-prey relationships. It is expected that this game will help students to understand the balance between populations of interdependent species in an ecosystem, and to see the results of large fluxes in those populations.

The Mystery of Saint Matthew Island **—** Read and discuss "The Mystery of Saint Matthew's Island" in the book, "The Case of the Mummified Pigs and Other Mysteries in Nature" [4] by Susan E. Quinlan (1995, Boyds Mills Press, Honesdale, Pennsylvania). It introduces the mysterious disappearance of an entire population of reindeer due to a lack of predators.

What is Balance in an Ecosystem? Activity Sheet (p. 235) **—** Have the students complete the sheet to reveal their thinking about the concept of balance in relation to ecosystems. Then you can use the sheet for a group discussion or to help you assess that their thinking is like at that particular point in the unit.

Invasive Species in Ecosystems Discussion Guide (p. 236) **—** This discussion guide invite students to reason about what can happen when an invasive species is introduced to an ecosystem.

Flux in Ecosystems Discussion Guide (p. 237) **—** This discussion guide invites students to reason about ideas related to dynamic flux in ecosystems in new ways. It introduces the idea that there are adaptations that enable organisms to live in environments that involve considerable flux. Opportunistic feeding, caloric loading, and other adaptations make organisms able to thrive despite the flux.

Balance, Flux and the On-Going Story of Zebra Mussels Discussion Guide (p. 238) **—** This discussion guide invites students to consider the on-going case of the invasion of Zebra Mussels in lakes. It explores the problem from the perspective of what has been predictable and what has not. It presents the notion that what we might consider problematic a human perspective may turn out to be less so from other perspectives.

Resources for Section 7

Parachuting Cats into Borneo Story

Lemmings of Norway Story

Lynx-Hare Cycles Sheet

Passenger Pigeon Sheet

Population Shuffle Game

- Teacher Preparation
- Directions
- Game Pieces
- Population Cards
- Playing Cards
- Danger Cards
- Game Board

What is Balance in an Ecosystem? Activity Sheet

Balance in Ecosystems Discussion Guide

Flux in Ecosystems Discussion Guide

Balance, Flux and the On-Going Story of Zebra Mussels Discussion Guide

Endnotes for Section 7

Parachuting Cats Into Borneo[5]

In the early 1950s, there was an outbreak of a serious disease called malaria amongst the Dayak people in Borneo. The World Health Organization tried to solve the problem. They sprayed large amounts of a chemical called DDT to kill the mosquitoes that carried the malaria. The mosquitoes died and there was less malaria. That was good. However, there were side effects. One of the first effects was that the roofs of people's houses began to fall down on their heads. It turned out that the DDT was also killing a parasitic wasp that ate thatch-eating caterpillars. Without the wasps to eat them, there were more and more thatch-eating caterpillars. Worse than that, the insects that died from being poisoned by DDT were eaten by gecko lizards, which were then eaten by cats. The cats started to die, the rats flourished, and the people were threatened by outbreaks of two new serious diseases carried by the rats, sylvatic plague and typhus. To cope with these problems, which it had itself created, the World Health Organization had to parachute live cats into Borneo.

The Lemmings of Norway: An Example of Balancing Populations by Flux

Lemmings are tiny rodents that live in the Arctic regions. Lemmings are what scientists call a “key species.” That means that a lot of what goes on in the lemmings’ ecosystem is linked to the size of their population. Animals like snowy owls and arctic foxes depend on lemmings for food, and how many babies they have depend on how many lemmings there are to eat.

Lemmings keep the ecosystem balanced through flux. Every three to four years, the numbers of the lemming population go through a cycle. During one part of the cycle, there are almost no lemmings anywhere. They have all died from starvation or been eaten.

One lemming can have as many as eleven babies, so even if there are only a few lemmings, their population size will grow. Over the next three years the size of the lemming population grows very quickly, and becomes enormous. After a female lemming is one month old, she can give birth to her first litter. So can all of her sisters and cousins. Can you imagine how many babies could be born after only one month?

After a few years, there are so many lemmings that they begin to fight. They fight for space, and vegetation – their main food source. Eventually there are so many of them that there isn’t enough food. Some starve to death, and some get eaten, but one species of lemmings in Norway just picks up and leaves. In a mass migration (moving from one home to another all at the same time) they leave, eating everything in their path. They swim across rivers to get to the other side and simply continue on. When they get to the ocean, it just looks like a very big river to them, so they start swimming. In fact, some lemmings have even been seen out in the ocean on floating ice. If you find Norway on a map, you’ll see that the nearest landmass off the coast of Norway is very far away. One tiny little lemming can’t swim that far, and many of them drown.

People used to think that the lemmings were trying to kill themselves so their population size would decrease and their ecosystem would be able to support them again. Scientists don't believe this now. Instead, they believe that lemmings, like all other organisms, just want to continue to reproduce, and they look for the space, food, water, and other things that will enable them to do so. In order to find these things, they migrate in large numbers, and sometimes this search leads them out to sea, where they die. This causes the size of the lemming population to decrease dramatically so that there is a complete cycle.

The other animals in the arctic regions depend on lemmings for food. No lemming lives longer than one winter. When there are very few around to eat, some animals, like snowy owls and arctic foxes, won't have many babies, but when the size of the lemming population reaches its peak, other animals will have bigger litters of babies. The other animals' population cycles are tied in with that of the lemmings. That is why lemmings are a key species.

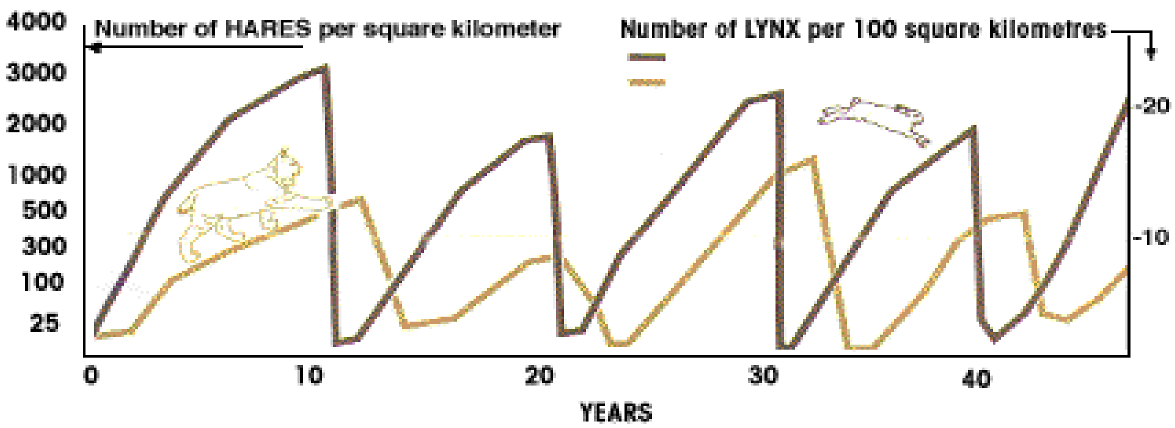
The flux in the lemming's population size is what keeps their ecosystem in balance. The numbers increase so dramatically that it forces the lemmings to do drastic things to compete for food and other resources and this in turn dramatically decreases the population size. If there was no flux in the size of the lemming population and they didn't have this cycle of what scientists call boom (when there are too many lemmings) and bust (when they all die and very few are left), the entire arctic ecosystem would behave very differently.

Follow-up Questions for Teachers

1. Can you tell me what you think flux means when we talk about ecosystems and this story? What does balance mean?
2. Can you tell me if you think there is any flux in this story? Can you give me an example?
3. Did you see any evidence of balance in the story?
4. What do you think an ecosystem would look like without any flux? How about any balance?
5. Do you think that this ecosystem would still work without the boom and bust of the lemming population?

Lynx-Hare Cycles

Look at the graph. It illustrates the relationship between the size of the hare population and the size of the lynx population. Notice how each population has a boom (when there are too many lynxes or hares for the available resources) and a bust (when many hares or lynxes die and very few are left) pattern. Look at the pattern in the graph. Notice how the lynxes' pattern closely follows the hares' pattern, but that the lynxes' peaks and valleys happen a bit after the hares' peaks and valleys. Why do you think the lynx population so closely follows the hare population?



What is happening is complex. The lynx and hare populations have a predator-prey relationship. Disease, food supply and other predators are variables in this complex relationship. The flux in this cyclic relationship is what allows for the ecosystem dynamic to work. Without flux, vegetation wouldn't have a chance to recover from the hare population's continuous eating, and without vegetation, the hare population could no longer exist in its habitat, and therefore neither could the lynx population that depends upon the hare population for food.

Every ten years or so, the hares' reproduction rate increases. As more hares are born, they eat more of their food supply. They eat so much food that they are forced to supplement their diet with less desirable and nutritious food. As the hare population size grows, the lynx population size begins to increase in response. Because there are so many hares, other predators opportunistically begin to hunt them along with the lynxes. The hares' less nutritious and varied diet begins to have an effect, the hares begin to die due to illness and disease. Fewer hares are born because there is less food. The hare population size begins to go into a steep decline. Therefore, the lynx population also begins to decline. Some lynxes starve and others die due to disease. Both the lynx and hare populations have fewer babies and this decrease in population gives the vegetation a chance to recover. Once there is enough vegetation for the hares to begin to increase their population the whole cycle begins again.

Graph taken from the following website: http://www3.gov.ab.ca/srd/fw/watch/rabb_cycles.html
9/30/02
Courtesy of Alberta Sustainable Resource Development

Passenger Pigeon Story

Passenger Pigeons were a bird that used to live in the Eastern United States. Their flocks were so big and their population densities so high that they would actually blot out the sun! It would take hours for a flock to pass overhead. They roosted in trees so densely at night that the branches would break. People went out with poles and knock them off of the branches to collect them for food. Passenger pigeons are now extinct. Scientists used to think that over- harvesting by people was the main reason there are no longer any passenger pigeons. However, when we look back and study the past, we see other causes.

Humans living in the Eastern Unites States derived much of their food from tree nuts such as acorns, hickory nuts, pecans, walnuts, chinquapins and chestnuts. Today the primary consumers of tree nuts in the eastern forests are white-tailed deer, raccoon, squirrel and turkey. Native Americans in the Eastern United States ate mostly deer, turkey and squirrel and other creatures that competed with the natives for the nuts. It appears that passenger pigeons did not become abundant until after European settlement began. Their abundance appears to have been a consequence of the ecological disruption that accompanied settlement. At the time of European settlement, the ecological community in the eastern woodlands had reached a balance in which passenger pigeons were not abundant. That lack of abundance was mainly because the pigeon's main food source, acorns was part of an enormous competitive network. The food that the pigeons would consume was being shared by many other animals and people. There simply was not enough food for large passenger pigeon flocks.

All of that changed with European settlement. European settlement resulted in more food available for passenger pigeons both in the form of new sources like grain fields, as well as greater access to original sources like acorns. Acorn competition was reduced in the areas around European settlement because the settlers reduced passenger pigeon competitors like deer raccoon, turkey, and squirrel through hunting, but they did not harvest acorns. From the perspective of the passenger pigeon, there was as sudden abundance of food.

When we track accounts of passenger pigeon abundance, we finds accounts of the birds being numerous in areas that moved west over time. Historic accounts beginning in Massachusetts in the early 1600s indicated that passenger pigeons were locally and irregularly abundant; in contrast, accounts from the 1600s and 1700s in Kentucky and Illinois never mention passenger pigeon as being as abundant as say turkey or geese. The flocks of billions witnessed by Audubon in central Kentucky in the early 1800s were witnessed there, not in the Massachusetts of the 1670s. As settlement moved inland, the passenger pigeon populations shifted west staying on the leading edge of settlement. Their western-most geographic limit would come at the prairie savanna border, and it is there that they became extinct. While traveling in their immense flocks, the birds consumed a vast amount of food. In the northern US, they primarily ate red oak acorns when they migrated north for nesting. White oak acorns germinate in the fall, so they were not consumed. Red oak acorns do not germinate until spring.

This widespread consumption of red oak acorns created a forest dominated by white oak trees. Once the birds became extinct, red oaks were able to out compete white oaks. Red oak acorns dominate modern forests, unlike the older forests of colonial times which were mostly white oak

Follow-up Questions for Teachers

1. Can we find examples of balance in this story?
2. Which populations in story experienced flux?
3. Is this story an example of a cycle?
4. Can we use words like "good" or "bad" to describe parts of the story?
5. How did food choice of Native Americans, Colonials, mammals and pigeons play a role in the story, and how has that effected the way forests look today?
6. Is the forest today the same as it was two hundred years ago? Can we expect the forest to look the same in two hundred years?
7. Are there any trees that drop acorns near your house or near your school?
8. What time of year to the acorns fall?
9. Who eats them?
10. What do those animals eat when there are no acorns?
11. Who eats those animals?
12. Do you ever see the predators? Why/Why not?
13. Additional questions for students living in suburban or rural areas with deer and turkey:
14. What do deer and turkey eat when there are no acorns on the ground?
15. Who or what eats the deer and turkey near your house or school?
16. Explain the population balance and flux of deer and turkey that live near you.

*Passenger Pigeon write-up and activity by Jacob Holzberg-Pill.

Population Shuffle Game
Teacher Preparation

Materials

- 1 set of directions for each group
- 6 game pieces
- 6 population cards
- 64 playing cards
- 15 danger cards
- 1 game board (printed in color)

Goal

The goal of Population Shuffle is to introduce students to the concepts of balance and flux in ecosystems.

Getting Started

- Assemble the game board by taping the two halves together (the board is printed on two standard-sized pieces of paper). Laminating the board will make it last longer. You can also download the game board from our website: http://pzweb.harvard.edu/ucp/curriculum/ecosystems/ .
- Prepare the species cards by cutting them out. Laminate if possible.
- Prepare the playing cards and danger cards by printing them back-to-back or cutting them out if you already have a hard copy. Laminate if possible.
- Prepare the game pieces by cutting them out. They will work better if mounted on a heavier paper, card stock, or cardboard.
- Split your students into groups of six, or have six students work on this as a separate activity. Each group needs one board, one set of directions, one set of questions, and one set each of game pieces, species cards, playing cards, and danger cards.

Playing the Game

See the Directions on the following page for instruction on how to play the game and strategy questions to consider while playing.

**This game was created by Rebecca Lincoln.*

Follow-up Questions for Class Discussion

1. Did it seem easy or hard to stay in the 'safe population zone'? Do you think that's true for a real ecosystem too?
2. How were the "danger zones" different from the rest of the board?
3. Are there any events that you can think of in an ecosystem that would affect one species, but not the other species connected to it? List a few.
4. Did any of the cards seem like they would not have the same result in a real ecosystem? Make a list of them. Why wouldn't these happen? How could you rewrite them so that they would?

Population Shuffle
Directions

Goal

This is a game about predator-prey relationships, and the balance and flux that occurs in ecosystems. Each player represents a species that is part of one team/habitat within an ecosystem. Players are divided into two teams/habitats. The goal is to make sure that you and the other members of your team keep your population sizes from getting too big or too small.

Getting Started

- Before you begin, think about how different levels of an ecosystem are connected and rely upon each other. When populations in an ecosystem are connected, things that affect one population might affect other populations too. Keep this in mind as you play.

- The players are six different species/populations living in the same ecosystem, and they're separated into two teams:

	Carnivores		Herbivores		Primary Producers
1. **Water team/habitat**:	**Herons**→	eat →	**Minnows**→	eat →	**Algae**
2. **Land team/habitat**:	**Hawks**→	eat →	**Mice**→	eat →	**Wheat**

- On each team, there is a **carnivore**, an **herbivore**, and a **primary producer.** The carnivores (**Herons and Hawks**) eat the herbivores (**Minnows and Mice**), and the herbivores eat the primary producers (**Algae and Wheat**).

- The board has 24 squares, labeled from 5 to 120. These numbers represent the "size" of your population. (In real ecosystems, there aren't the same numbers across species. There would be many more wheat than mice, and many more mice than hawks. So the real number for square 25 would be more like 25 x 1000 = 2500 wheat, and 25 x 20 = 500 mice, and 25 x 1= 25 herons.) The board is divided into three zones:
  1. **The "safe population zone":** The **green** middle part of the board, from **25 to 100**. When you are in this area, your population size is stable and the rest of your team can be stable too.
  2. **The "high danger zone":** The **red** top of the board, from **105 to 120.** When your population size goes above 100, your population is in danger of overpopulating and unbalancing the ecosystem.
  3. **The "low danger zone":** The **blue** bottom of the board, from **0 to 20**. When your population size goes below 25, your population is in danger of becoming extinct and unbalancing the ecosystem.

- The goal is for all members of your team to stay in the "safe population zone" for as many turns as possible. As soon as any member of the ecosystem over-populates (above 120) or goes extinct (below 5), their team is out, and the other team wins.

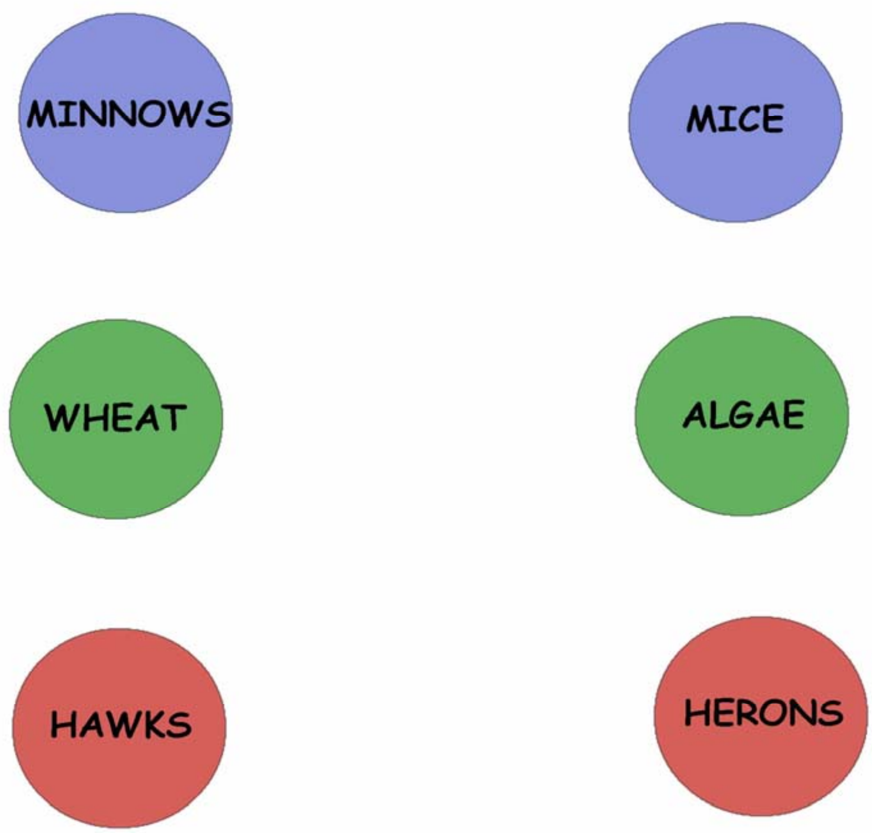
Playing the Game

1. Moving clockwise from the person whose birthday is closest to the winter solstice, December 21st, each player picks a species to be in the game.
2. Each player gets: a game piece; a "population card" with a picture of their organism on it; and a pile of cards with the name of their organism on the back.
3. Identify the other members of your team, and make sure you all understand the relationships between your populations.
4. All players start in the green "safe zone" of the board. Each player picks the number that she or he wants to start on.
5. More than one person can share a number at any time.
6. Make sure the different cards are all shuffled and put in the right spots on the board. Each player's cards should be in front of them. Red "Too high!" and blue "Too low!" cards on the left of the board
7. The person whose birthday is closest to the summer solstice, June 21st, gets to start. After the first person, play goes clockwise.
8. When it's your turn, draw a card from your pile. The cards tell you about things that happen that affect the populations of your team. Follow the directions for your population and the other populations on your team, and then put the card back at the bottom of the pile.
9. If you end up in the **red danger zone**, follow the directions on the game board. Then draw a card from the **red pile** on your next turn. Keep taking cards from the **red pile** on your turns until you return to the green "safe population zone" or get out.
10. If you end up in the **blue danger zone**, follow the directions on the game board. Then draw a card from the **blue pile** on your next turn. Keep taking cards from the **blue pile** on your turns until you return to the green "safe population zone" or get out.

Questions to Think About

1. Where is the "best" place on the board to start so you don't overpopulate or go extinct?
2. Is the "best" place to start different or the same for different populations?
3. Are there "good" or "bad" events in this game? What makes an event "good" or "bad"? What does it depend on? Does it matter what the size of your population is?
4. Do some species stay in the "safe population zone" better than others? Why or why not?

Population Shuffle Game Pieces



Population Shuffle Game Pieces

HAWKS
LAND TEAM
Predator: None
Food source: Mice

WHEAT
LAND TEAM
Predator: Mice
Food source: Sunlight

ALGAE
WATER TEAM
Predator: Minnows
Food source: Sunlight

MICE
LAND TEAM
Predator: Hawks
Food source: Wheat

MINNOWS
WATER TEAM
Predator: Herons
Food source: Algae

HERONS
WATER TEAM
Predator: None
Food source: Minnows

Population Shuffle Playing Cards

Pollution Your population is very sensitive to some weed killer that got into your water supply. Your population size goes down, and your predator **and** your food source are affected. ↓ You lose **10** ↓ Hawks lose **5** ↑ Wheat gains **20**	**Habitat** Your population finds a nice habitat and your population size goes up. You are eating more, and your predator has more to eat. ↑ You gain **10** ↑ Hawks gain **5** ↓ Wheat loses **15**	**Weather** It's a dry season, and your population's habitat gets too dry. ↓ You lose **15** ↓ Hawks lose **10** ↑ Wheat gains **25**
Storm An early hailstorm destroys your habitat. ↓ You lose **10** ↓ Hawks lose **5** ↑ Wheat gains **20**	**Invader** An outside population invades your habitat and competes with you for your food source ↓ You lose **5** ↓ Wheat loses **10** ↓ Hawks lose **5**	**Fire** A forest fire sweeps through your habitat. The whole ecosystem is affected. ↓ All populations lose **25**
Habitat A foraging animal destroys your population's habitat. ↓ You lose **10** ↓ Hawks lose **5** ↑ Wheat gains **20**	**Predator** Your predator's population finds another food source, and you get a break. ↑ You gain **10** ↓ Wheat loses **20**	**Disease** A disease makes some of your population sick. ↓ You lose **10** ↓ Hawks lose **5** ↑ Wheat gains **20**
Weather Spring comes early this year! The entire ecosystem is affected. ↑ All populations gain **10**	**Invader** An outside population invades your ecosystem and competes with your predator for its habitat. ↓ Hawks lose **5** ↑ You gain **10** ↓ Wheat loses **20**	**Food source** Your population finds another food it likes, and eats less of your food source. ↑ Algae gains **10**

Population Shuffle Playing Cards

MICE	MICE	MICE
MICE	MICE	MICE
MICE	MICE	MICE
MINNOWS	MICE	MICE

Population Shuffle Playing Cards

Predator Your population has found a place to live that your predator can't find. ↑ You gain **10** ↓ Algae loses **20**	**Pollution** Your population's water supply becomes polluted. ↓ You lose **10** ↓ Herons lose **5** ↑ Algae gains **15**	**Weather** It's a long, cold winter, and the whole ecosystem is affected. ↓ All populations lose **5**
Pollution Garbage is dumped in your habitat! ↓ You lose **10** ↓ Herons lose **5** ↑ Algae gains **20**	**Humans** Laws are passed against air pollution. The air in your habitat becomes much cleaner and the whole ecosystem is affected. ↑ All populations gain **15**	**Weather** The weather is too hot for your population this summer. ↓ You lose **10** ↓ Herons lose **10** ↑ Algae gains **15**
Weather You have a hard winter and your population size goes down. Your food source survived the winter fine, and now there are less of you to eat them. ↓ You lose **10** ↑ Algae gains **20**	**Habitat** Your population finds a nice habitat in the ecosystem. ↑ You gain **10** ↓ Algae loses **15** ↑ Herons gain **10**	**Food source** Your food source had a good year. ↑ Algae gains **15** ↑ You gain **10** ↑ Herons gain **5**
Habitat You find a nice place to live, and your population thrives. ↑ You gain **15** ↓ Algae loses **20** ↑ Herons gain **10**		

Population Shuffle Playing Cards

MINNOWS	MINNOWS	MINNOWS
MINNOWS	MINNOWS	MINNOWS
MINNOWS	MINNOWS	MINNOWS
		MINNOWS

Population Shuffle Playing Cards

Weather A serious drought happens; the whole ecosystem is affected. ↓ All populations lose **5**	**Pollution** Garbage is dumped in your habitat! ↓ You lose **5** ↑ Mice gain **10** ↓ Wheat loses **15**	**Disease** A disease makes some of your population sick. ↓ You lose **10** ↑ Mice gain **15** ↓ Wheat loses **20**
Weather Spring comes early this year! The entire ecosystem is affected. ↑ All populations gain **10**	**Invader** An outside population invades your habitat and competes with you for your food source. ↓ You lose **5** ↓ Mice lose **10** ↑ Wheat gains **20**	**Habitat** Your population finds a nice habitat in the ecosystem. ↑ You gain **10** ↓ Mice lose **15** ↑ Wheat gains **20**
Food source Your population finds another food it likes, and eats fewer mice. ↑ Mice gain **10** ↓ Wheat loses **20**	**Storm** A heavy rainstorm creates flash floods. The entire ecosystem is affected. ↓ All populations that live on land lose **15** (Herons, Hawks, Mice, Wheat)	**Food source** Your food source had a good year. ↑ Mice gain **15** ↑ You gain **10**
Pollution Your population's water supply becomes polluted. ↓ You lose **15** ↑ Mice gain **25** ↓ Wheat loses **30**	**Habitat** A foraging animal destroys your population's habitat. ↓ You lose **5** ↑ Mice gain **10** ↓ Wheat loses **20**	**Weather** You have a hard winter and your population size goes down. Your food source survived the winter fine, and now there are less of you to eat them. ↓ You lose **10** ↑ Minnows gain **20** ↓ Algae loses **30**

Population Shuffle Playing Cards

HAWKS	HAWKS	HAWKS
HAWKS	HAWKS	HAWKS
HAWKS	HAWKS	HAWKS
HERONS	HAWKS	HAWKS

Population Shuffle Playing Cards

Habitat You find a nice place to live, and your population thrives. This means you're eating more. ↑ You gain **10** ↓ Minnows lose **15** ↑ Algae gains **30**	**Humans** Traffic around your habitat has increased, and the noise and pollution affect the entire ecosystem. ↓ All populations lose **10**	**Humans** Humans turn part of your ecosystem into a parking lot, and the whole ecosystem is affected. ↓ All populations lose **10**
Weather The winter is mild and the spring is warm. The whole ecosystem is affected. ↑ All populations gain **15**	**Habitat** An environmental group preserves some land in your ecosystem that is perfect for your population. That is good for you, and affects your food source and your food source's food source as well. ↑ You gain **10** ↓ Minnows lose **15** ↑ Algae gains **20**	**Storm** A bad storm destroys your population's habitat. Your population size goes down, and that means you're eating less. That allows your food source to grow, and they start to eat **more.** ↓ You lose **5** ↑ Minnows gain **10** ↓ Algae loses **15**
Weather It's a dry season, and your population's habitat gets too dry. ↓ You lose **10** ↑ Minnows gain **15** ↓ Algae loses **25**	**Storm** An early hailstorm destroys your nests. ↓ You lose **10** ↑ Minnows gain **15** ↓ Algae loses **30**	**Weather** The weather is too hot for your population this summer. ↓ You lose **5** ↑ Minnows gain **10** ↓ Algae loses **15**

Population Shuffle Playing Cards

HERONS	HERONS	HERONS
HERONS	HERONS	HERONS
HERONS	HERONS	HERONS

Population Shuffle Playing Cards

Weather Spring comes early this year! The entire ecosystem is affected. ↑ All populations gain **10**	**Humans** An environmental group cleans up the pollution in your habitat. The entire ecosystem is affected. ↑ All populations gain **20**	**Predator** Your population has found a protected place to live that your predator can't find. ↑ You gain **20**
Weather This was a very sunny season. Your population size grows, and this affects your predator and your predator's predator. ↑ You gain **25** ↑ Minnows gain **15** ↑ Herons gain **10**	**Pollution** Your population's water supply becomes polluted. ↓ You lose **15** ↓ Minnows lose **10** ↓ Herons lose **10**	**Habitat** Your population finds a nice habitat in the ecosystem. ↑ You gain **10** ↑ Minnows gain **5** ↑ Herons gain **5**
Disease A disease makes some of your population sick. ↓ You lose **30** ↓ Minnows lose **20** ↓ Herons lose **10**	**Weather** This year there was just the right amount of rain. The whole ecosystem is affected. ↑ All populations gain **10**	**Predator** Your predator had a bad year. ↓ Minnows lose **10** ↑ You gain **20**
Weather The ice comes off the lakes early this year. The entire ecosystem is affected. ↑ All populations that live in the water (Minnows, Algae) gain **20**.	**Habitat** A foraging animal destroys your population's habitat. ↓ You lose **15** ↓ Minnows lose **10** ↓ Herons lose **5**	**Habitat** You find a nice place to live, and your population thrives. ↑ You gain **30** ↑ Mice gain **25** ↑ Hawks gain **20**

Population Shuffle Playing Cards

ALGAE	ALGAE	ALGAE
ALGAE	ALGAE	ALGAE
ALGAE	ALGAE	ALGAE
WHEAT	ALGAE	ALGAE

Population Shuffle Playing Cards

Weather The winter is mild. The entire ecosystem is affected. ↑ All populations gain **25**	**Predator** Your predator species finds some other food, and you get a break. ↑ You gain **20**	**Weather** It's a dry season, and you don't get enough water. ↓ You lose **20** ↓ Mice lose **10** ↓ Hawks lose **5**
Pollution Garbage is dumped in your habitat! ↓ You lose **20** ↓ Mice lose **15** ↓ Hawks lose **10**	**Humans** Logging takes place in your habitat. The entire ecosystem is affected. ↓ All populations lose **15**	**Invader** An outside population invades your ecosystem and competes with your predator for its habitat. ↓ Mice lose **10** ↑ You gain **15** ↓ Hawks lose **5**
Pollution Harmful chemicals have gotten into the ecosystem, and they make it hard for you to grow. This affects your predator and your predator's predator. ↓ You lose **15** ↓ Mice lose **10** ↓ Hawks lose **5**	**Fire** A forest fire has replenished the nutrients in the soil of your ecosystem. ↑ You gain **25** ↑ Mice gain **20** ↑ Hawks gain **15**	**Weather** The weather is too hot for your population this summer. ↓ You lose **15** ↓ Mice lose **10** ↓ Hawks lose **5**

Population Shuffle Playing Cards

WHEAT	WHEAT	WHEAT
WHEAT	WHEAT	WHEAT
WHEAT	WHEAT	WHEAT

Population Shuffle Danger Cards

TOO HIGH! Your population is getting too crowded in its habitat and your population size goes down. ↓ You lose **15**	**TOO HIGH!** As your population size continues to grow it moves into a new habitat. ↑ You gain **20**	**TOO HIGH!** Your population finds a new food source. ↑ You gain **10**
TOO HIGH! Your population size is getting too big and you are using too many resources. ↓ Your food source loses **25**	**TOO HIGH!** Your population can't find enough food! ↓ You lose **15**	**TOO HIGH!** Your population has another good reproductive season. ↑ You gain **10**
TOO HIGH! Your population size is getting too big! In order to stabilize, you **miss a turn**.		

Population Shuffle Playing Cards

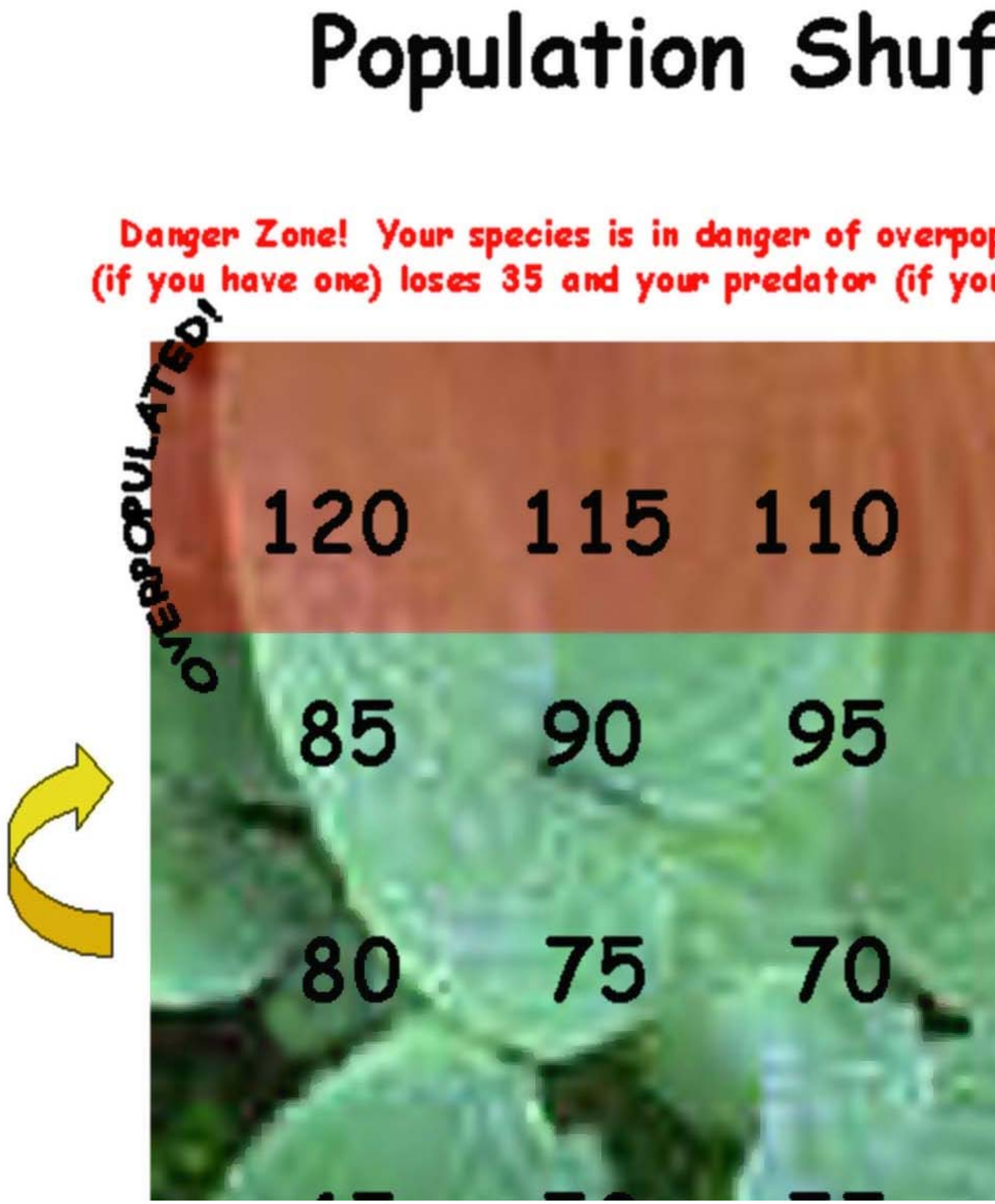
DANGER: TOO HIGH!	DANGER: TOO HIGH!	DANGER: TOO HIGH!
DANGER: TOO HIGH!	DANGER: TOO HIGH!	DANGER: TOO HIGH!
		DANGER: TOO HIGH!

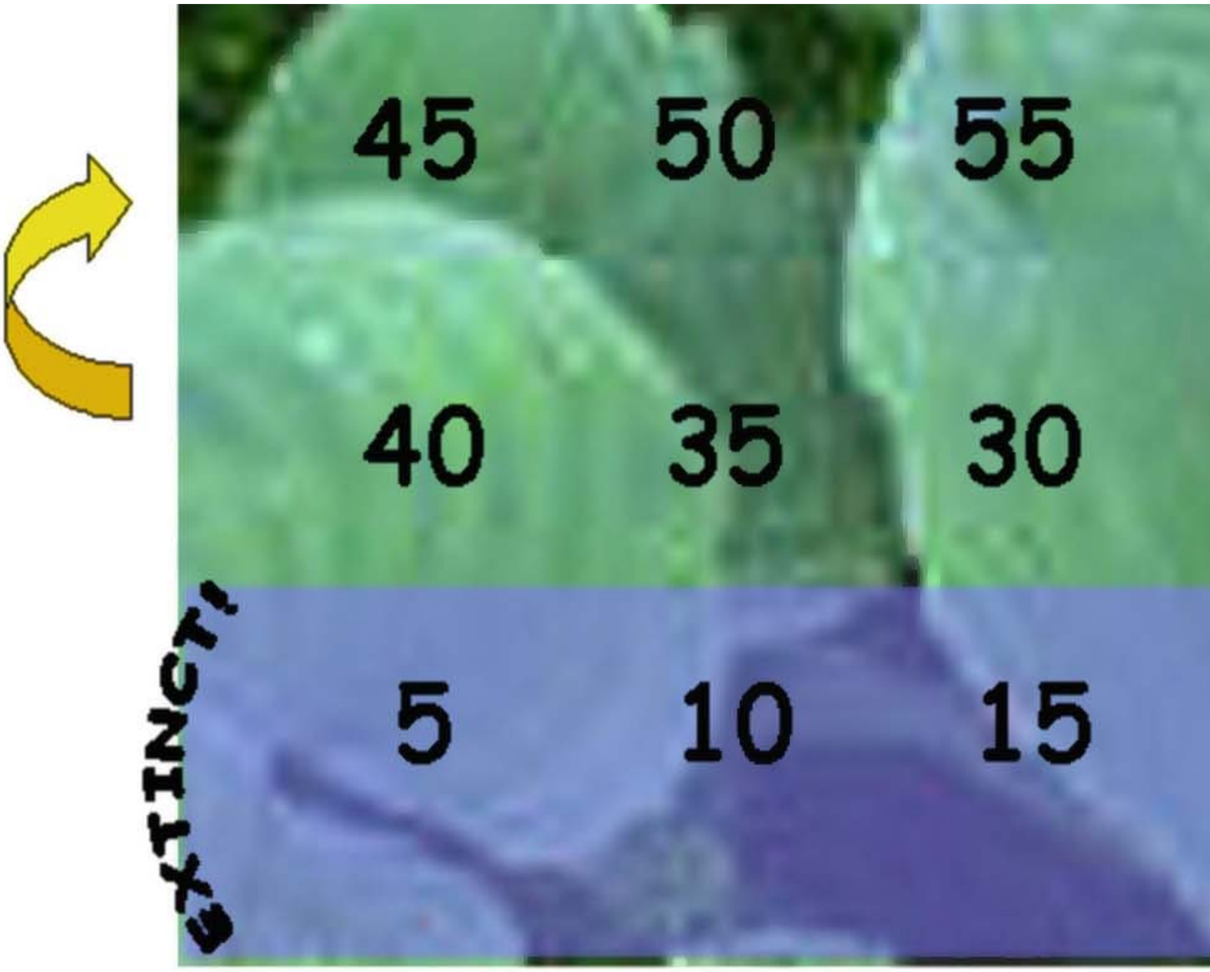
Population Shuffle Danger Cards

TOO LOW! Your population size is shrinking and your predator is having a hard time finding food. ↓ Your predator loses **5**	**TOO LOW!** The construction of a new road destroys some of your habitat. ↓ You lose **15**	**TOO LOW!** Your population is struggling and can't find food. ↓ You lose **20**
TOO LOW! Your population is in danger of going extinct! Your predator has less to eat and finds a different food source. ↑ You gain **5**	**TOO LOW!** Spring comes early and your population can renew itself. ↑ You gain **30**	**TOO LOW!** Your population is designated as endangered and your population size rebounds. ↑ You gain **20**
TOO LOW! Your population size is dwindling; you need to take a break. **Miss a turn**.	**TOO LOW!** Your population is hit with a disease. ↓ You lose **10**	

Population Shuffle Playing Cards

DANGER: TOO LOW!	DANGER: TOO LOW!	DANGER: TOO LOW!
DANGER: TOO LOW!	DANGER: TOO LOW!	DANGER: TOO LOW!
	DANGER: TOO LOW!	DANGER: TOO LOW!


Population Shuf
Danger Zone! Your species is in danger of overpop
(if you have one) loses 35 and your predator (if yo
OVERPOPULATED!
120 115 110
85 90 95
80 75 70



Danger zone! Your species is in danger of going extinc
have one) gains 40 and your predator (if you hav

LOW DANGER
CARDS

HIGH
CA

Name________________________________

What is Balance in an Ecosystem?

1. We have been talking about balance in ecosystems. What does the word balance mean to you when thinking about ecosystems?

2. Some people think of a balance scale when they hear the word balance. In what ways does a balance scale do a good job helping us think about balance in eco-systems? Explain what it can do a good job showing.

3. In what ways does a scale NOT do a good job explaining balance in ecosystems? (For example, if you show rabbits on one side and foxes on another, do you need the same numbers or different numbers for balance in the ecosystem?)

Invasive Species in Ecosystems
Discussion Activity:

Read the following text to your students and ask them to think about what happened.

> Mongooses were introduced to Hawaii from India by sugar farmers to protect their crops from rats. While mongooses do eat some rats, they are not nocturnal like rats, so they found other food sources. They eat so many things that they have destroyed the diversity of the organisms on the islands. They have nearly destroyed the bird population by killing them and destroying their eggs. They also eat crabs, fish, fruit, reptiles, frogs, and even small or young mammals. They have no natural predators on the islands so there are now many mongooses on the islands. Hawaii now has more endangered species per square mile than any other place in the world.

Possible Discussion Questions:

1. Why didn't the mongooses eat mostly rats?

2. What kinds of things did the mongooses eat?

3. Why is it good for the mongooses that they eat so many different things?

4. Why is it a problem for the diversity of the Hawaiian Islands that the mongooses eat so many things? Would it be a problem if there were just a few mongooses?

5. Why are there so many mongooses?

6. Do you think that the number of mongooses is increasing or decreasing?

7. What do you predict will happen if the patterns (increasing numbers of mongooses, decreasing numbers of birds and other organisms) continue?

Flux in Ecosystems
Discussion Guide

We often think about balance in ecosystems but flux is a natural part of what happens, too. Flux does not necessarily mean an unstable ecosystem, but it can mean changes in the ecosystem that allow for new opportunities. One way to think about flux in ecosystems is to contrast ecosystems that undergo more or less change over time. Consider the example of sandy beaches and estuaries:

> Sandy beaches are always physically in flux. So there are no permanent communities of inter-tidal plants growing there. The energy to sustain the plants and animals are all imported, mostly from the sea. The ocean brings in phytoplankton and zooplankton. It is captured in the subtidal areas by filter feeders and suspension feeding invertebrates like mole crabs and surf clams. Enormous populations of these animals here but the size of the population is limited by the height of the waves. This is because they capture food best where the sand and organic particles are trapped within the sand and then spread out again by the waves. But they must follow the tides to get enough food. Seaweed drifts ashore and rots to enrich the sands. Beach amphipods and isopods accumulate near the piles of seaweed and are eaten by birds and others digging for prey. Coyotes, rats, seagulls and others scavenge for what they can find.

Ask your students to consider the following questions:

1. What is life on a sandy beach like? How do creatures get the energy that they need to survive?
2. In what ways is this similar and in what ways is this different from how organisms get the energy to survive in a hardwood forest, for example? *[Make sure that your students know that things grow fairly slowly and can be fairly stable in a hardwood forest.]*
3. In what ways is this similar and in what ways is this different from how organisms get the energy to survive in a rainforest, for example? *[Make sure that your students know that things grow fairly quickly in a rainforest and that trees can topple over easily and the physical terrain is less stable than in a hardwood forest.]*

Balance, Flux and the On-Going Story of Zebra Mussels

In 1985 or 1986, a European cargo ship heading to Canada emptied some of its ballast water (water it takes on to balance the ship) into a lake near Lake Huron and Lake Erie. A species of mussel called the Zebra mussel is believed to have been in the ballast water. The species had no natural predators and grew in amazing and frightening numbers. These mussels colonize the near shore waters and since these are also the places where many fish lay their eggs, they are impacting the birth of new fish and the fishing industry. They began to enter water pipes and to clog them. At first, there was great worry about the mussels and very costly estimates of what would be involved in cleaning the pipes.

It has cost many millions of dollars to remove the mussels from pipes and it has impacted tourism. The big clams that used to live there are gone. On the other hand, some things are not as first predicted. Another mussel seems to have kept the zebra mussel somewhat under control. (However, those two mussels have killed off native mussels and insects.) The mussels have also cleaned up much of the algae and other particulates from the water so that the lakes are much cleaner than they were. (However, this has also caused toxic algae to form so even though the water might look cleaner, the toxin may be harmful to humans and other animals.) Some of the fish have come back because the green algae are gone and they are now eating the small baby mussels!

Questions to Consider:

1. How is the story of the mussels like the story of the mongooses in Hawaii? How is it different?
2. Make a diagram showing some of the effects of introducing the Zebra Mussel to the Great Lakes. Next put a +, -, or ? along the connections to show whether the effect was good, bad, or indifferent/we don't yet know
3. How has the zebra mussel taken advantage of an opportunity?
4. How has the zebra mussel made opportunities for other organisms?

Endnotes for Section 7

[1]Bender, E. A., T. J. Case, and M. E. Gilpin. 1984. Perturbation experiments in community ecology: theory and practice. Ecology 65:1–13.

[2]This refers to whether the population size is too big or small from the perspective of scientists looking in on the ecosystem. Scientists reason that the goal of organisms is to reproduce, therefore, from the perspective of the organisms, there is no such thing as a population size that is too many or too big.

[3]Pickett, S. (1999, March). Everything is connected? EcoNotes Column, *Taconic Newspapers*, pp. A5-6.

[4]Quinlan, S.E. (1995). The Case of the Mummified Pigs and Other Mysteries in Nature. Boyds Mills Press, Honesdale, Pennsylvania.

[5]This story is based on an actual event reported in *The New York Times*, November 13, 1969. It has been retold in various places. There is a book by Pomerantz, C. (1971). *The Day They Parachuted Cats on Borneo: A Drama of Ecology*. Reading, MA: Young Scott Books. It has also been told by Amory Lovins, Director of Research at the Rocky Mountain Institute, Old Snowmass, Colorado.

SECTION 8

Reasoning About Ecological Succession

This section introduces the concept of succession and the importance of reasoning over time. It juxtaposes "snapshot reasoning" with "video-reasoning in helping students consider the differences in what is learned from each. It aims to help students recognize succession as a natural part of ecosystems dynamics.

Section 8 Table of Contents
Reasoning About Ecological Succession

Section 8 Lesson Plan
Reasoning About Ecological Succession

This section introduces the concept of succession and the importance of reasoning over time. It helps students to realize that temporal scales are essential to understanding ecosystems.

Understanding Goals

Subject Matter

- Ecosystems are dynamic and include change over time.
- Ecological succession is a change in species composition and associated substrates in an ecosystem over time.
- Variables such as climate, plants, animals, soil, and especially time affect the rate and scale of succession.

Causality

- It can be hard to detect long-term changes when we reason about time in steady states, or "snapshots." We need to think about long-term ecosystem changes using "video reasoning," the ability to play out constant change over time.

Background Information

Long-Term Change Can Make it Difficult to Detect Causal Patterns

When we think about changes that happen over long periods of time, we often do not understand how those changes are occurring. Most people focus on a primary and an end state, but don't necessarily remember or notice evidence of what transpires in-between. This is especially true about long-term change in an ecosystem, a concept known as ecological succession.

We tend to reason about long periods of time in "snapshots," comparing one state in time to another and ignoring the transformative processes responsible for the change. The alternative is referred to here as "video reasoning," or reasoning about ecosystem changes as dynamic processes that work in concert over a large span of time. Another reasoning difficulty has to do with non-obvious processes and the perceptual scale at which we consider them. Especially at the scale of an entire ecosystem, we tend not notice the slower, smaller changes that have played out over time and can have dramatic effects on what the ecosystem comes to look like. We may not notice changes like a shortage of pollinators or a few-degree average temperature increase, so it seems as if ecosystem changes just happen spontaneously.

Lesson Plan: Reasoning About Ecological Succession

Materials

- Photographs brought in by students
- Ecological Succession Time Lapse Video

Prep Step

- Prior to this lesson, ask students to bring two photographs of themselves to class: one baby photo and one closer to present day
- Review understanding goals and background information
- Read the lesson plan
- Arrange a method to show the video.

Note to Teacher: Videos of succession can be downloaded on-line. Preview them first. Here is one showing succession in a Montana forest: http://www.playingwithtime.org/cgi-bin/browser/gallerydisplay.pl?clipID=0120

Analyze Thinking

Step 1: Connect Backward with Personal Photographs

Students will have an easier time understanding a complex phenomenon like ecological succession if they can relate it to something they are already familiar with. To start this lesson, students will use the two photographs they've brought to class as an entry point to the topic of change over time. Tell students to place their photographs on their desks and take some time to look at them.

Ask: "What do you notice about the two photographs? What has changed?" Collect ideas. String together common elements from the discussion and write them down so everyone can see.

Ask, "How do you know if changes are happening?" Explain that changes that take place over long periods of time are difficult to detect. We need to look closer at underlying processes in order to know that changes are happening. If we only look at snapshots of primary and end states ("snapshot reasoning"), we ignore the often less visible processes that are responsible for change.

Gather students' thoughts about how we understand changes over long periods of time. [*The students might, in this example, imagine that slow processes like bone* *growth or muscle build are responsible for the changes they see in their faces and bodies.*]

Note to Teacher: Depending on the age group of your students, you might want to focus only on facial change if the topics of puberty or adolescence will be sensitive or distracting.

RECAST Thinking

Step 2: Explain and Watch the Video

The video is a time-lapse animation that invites students to reason about how effects play out over time. Remind them to keep thinking about how changes happen over time and how even the smallest changes to the ecosystem - precipitation, the presence of certain animal or plant species, or the fertility of the soil – might have affected what they are seeing. Explain that succession is, like the changes we see in our appearance over time, the result of barely detectable underlying processes that are captured better by “video” (seeing the time lapse animation play out) than just looking at the beginning and the end state.

Watch the video at least three times. After each time, gather the students’ ideas about the changes that they witnessed and what might be contributing to them.

Explore Causality

Step 3: Snap Shot Reasoning Can Make it Hard to See Causal Patterns

Discuss with your students the differences between “before and after snapshots” and “video” reasoning. Highlight the important advantages and disadvantages to both. Make sure students understand that we typically use snapshot reasoning to understand long-term changes and often forget about the underlying processes evident in video reasoning. Draw out key ideas from this discussion and summarize the points on the board or ask the students to do so in their journals.

Review, Extend, Apply

Step 4: Review Understanding Goals

Review the understanding goals for this lesson to give students the opportunity to Reflect on what they have learned.

Step 5: Extend the Concept

Students started this lesson by connecting backward to their own experience in appearance change; they will finish by connecting forward to their own experience once more, this time in the form of different ecosystems they will encounter. First, ask students to imagine an ecosystem that they have seen change over the years. This can be any ecosystem, from a state park to a park down the street. For some students, this may be an urban ecosystem (loosely defined) like a playground or a city block.

Ask,
"How has this ecosystem changed over time? What intermediate states might have been?

Prompt students to imagine a time lapse video of their ecosystem changing over the years. Ask them to consider how this type of reasoning is different from the reasoning that they did with their photographs in the "Snapshot" exercise at the beginning of the lesson.

Reinforcement Activities

Simulating Ecological Succession with a Flipbook - Have students create a flip-book using drawings of an ecosystem of their choosing. To create a flip book, students will need to draw a scene of their ecosystem several times, keeping most parts of the drawing constant and manipulating a few components that change over time. Have students describe the period of time over which their flip-book takes place. This activity will reinforce the distinction between "snapshot" and "video" reasoning and highlight how non-obvious processes change an ecosystem over time.

Endnotes for Section 8

***Note:** There are no resources for Section 8.*

This lesson was modified from a lesson initially developed by Sean Kramar. He assisted in all aspects of this write-up including the background information.

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