SYSTEMS ENRICHMENT EXERCISE

How Earthworms Got Me into College

Students use a fictitious story about real research to draw a causal loop diagram and better understand the northern forest ecosystem.

Objectives

After completing this exercise, students will be able to

- explain the concept of indirect cause-effect relationships,
- describe how seemingly small changes can spread through a system and lead to major changes, and
- explain the impact that reinforcing feedback loops can have on a system.

Materials

- Student pages: How Earthworms Got Me into College and Diagramming Earthworms in the Northern Forest

Introduction

Causal loop diagrams are useful tools for encouraging students to pay close attention to indirect connections and to feedback loops affecting the behavior of a system. This exercise supplements Activity 5 by providing students with more practice in developing and using this tool.

Doing the Exercise

The story below is written in a light tone, but includes scientifically accurate information regarding the impact that non-native, invasive earthworms are having on northern forests. Whether you use this for homework or a class assignment, you may want to provide time for students to ask questions about any points of confusion.

1. Distribute the student pages, How Earthworms Got Me into College and Diagramming Earthworms in the Northern Forest. If your class worked through developing the diagram of a forest in Activity 5, this exercise can provide them with a chance to apply those skills in a different context. In this case, the cause-effect links are described on the worksheet, which allows students to work through the exercise without requiring step-by-step guidance.

Can tiny earthworms really impact the health of the northern forest?

2. When you are ready to discuss the responses, the answer key may be helpful. Some students may point out other relationships not included in the causal diagram that they will create from this story. You can remind students that the diagram is not meant to include every variable and relationship present in northern forests. Rather, it is a tool for focusing on those relationships that have the most significant impacts on the northern forests' response to the introduction of earthworms.

3. Once the students' causal loop diagrams are completed, students will follow the diagram to understand how the impacts of earthworms ripple through the ecosystem and affect each group of trees and plants. Four examples of those ripples are described below.

- Both Tree Groups: Earthworms affect the duff layer seed bank of trees in two ways. One, they decrease the thickness of the duff layer, making it more difficult for seeds to grow. Two, the worms can damage seeds directly or transport them to areas where they are less likely to grow.
- Mychorrizal Trees: Earthworms decrease the population of duff-layer fungi, causing the population of mychorrizal trees (trees that depend on fungi for nutrients) to decrease as well.
- Both Plant Groups: This situation largely parallels that described with the trees. Earthworms affect the duff layer seed bank of plants in two ways. One, they decrease the thickness of the duff layer, making it more difficult for seeds to grow. Two, the worms can damage seeds directly or transport them to areas where they are less likely to grow. In addition to affecting the plants' seeds, decreasing the duff layer can cause plants to dry out and die.
- Plants without Chemical Defenses: Overall, the decrease of available plants increases the predation pressure (hungry deer) on the remaining plants. Those deer tend to choose the plants that do not have chemical defenses against deer. This causes a further reduction in these plants.

Additional Resources

Great Lakes Worm Watch: Get more information on the impacts of exotic earthworms in forests around the Great Lakes. This website also includes a great short video reviewing the information in the story.
http://www.nrri.umn.edu/worms/

Scientific American: This article from *Scientific American* provides more details about the invasive earthworms around the Great Lakes.
http://www.scientificamerican.com/article.cfm?id=invasive-earthworms-harm-forests-near-great-lakes

Science Learning: The impact of exotic earthworms in New Zealand is quite different. This website explains why and includes interesting information about both native and exotic earthworms in New Zealand.
http://www.sciencelearn.org.nz/Science-Stories/Earthworms/Native-and-introduced-earthworms

How Earthworms Got Me into College (1 of 3)

Two things you should know about me. One, I worked at a conference center as a server during most of my high school career. I was one of the guys walking around with trays of little cucumber sandwiches or pigs-in-a-blanket, which I don't recommend. You'll just have to trust me on that.

And two, I needed to bring my environmental science grade up from a C to a B in order to have any hope of getting into college.

Those two things may seem unrelated, but I had waited until the last night to work on my project for environmental science. Then Ms. Leary, my boss, called and told me that six servers had called in sick with the stomach flu, so she needed me to cover the shift. This was three days after I'd gotten written up for general apathy on the job. That's literally what she wrote on the form: "General apathy." She accused me of not caring about my co-workers, or my job, or anything at all. I didn't let her know it, but the pronouncement kind of stung. Anyway, I agreed to cover the shift.

So picture me at this conference with a project due in about twelve hours on an invasive species and no idea what I'm going to write about. I told some of the other servers my problem and they agreed to let me serve sodas at the back bar. That meant I didn't have to walk around the whole time, and I had some free time to do research on my phone.

I was reading about Burmese pythons in the Everglades when a guy wearing khakis asked me if I had lemonade. I said that I did and put my phone down to fix his drink. I guess he could make out the picture, because he asked, "You reading about snakes?"

"I'm doing research for a project on invasive species," I explained, "but it's slow going on this phone."

He sized me up for a moment, and then he said, "If you want to read about an interesting example of invasive species, you should look at earthworms around the Great Lakes."

"If you want to read about an interesting example of invasive species, you should look at earthworms around the Great Lakes."

"Earthworms as invasive species?" I asked. "My mom gardens, and she's always happy to see earthworms because they enrich the soil for her vegetables."

"They can be very helpful," he acknowledged, "for some plants that require soil that is well mixed. However, they can present quite a hazard for species that thrive in forests that evolved without earthworms."

It was an interesting idea, and I thought maybe I could get points for originality. I knew of at least three other people doing their project on pythons. "Do you think I could find a lot of information on invasive earthworms online?" I asked.

"Sure you could, but you've got the world's foremost experts right here in the room." When I looked puzzled, he explained, "This is a convention of forest ecologists." When I still looked puzzled, he said, "Several people came here to present their findings on the connections between worms and the rest of the forest." Then he thanked me for the lemonade and walked away.

How Earthworms Got Me into College (2 of 3)

I saw a new ray of hope for my project. When the next person came up for a drink, I tried to be casual. As I scooped the ice for his drink, I said, "Worms, huh."

The guy just nodded politely, not really knowing where I was headed.

"That must be interesting," I offered, "especially the invasive species part."

"Are you talking about the European earthworm invasion?" he asked.

"Yes, yes I am," I said, hoping he'd provide more information.

"I have a friend who spent last summer in the hardwood forests around the Great Lakes looking at the impact they have on soil composition. Earthworms are soil engineers. They dictate much of its properties. And those properties dictate which plant species will be able to thrive in that soil. So, in a way, earthworms are ecosystem engineers."

This was just the kind of stuff I needed. "So how do the earthworms change the soil in those forests around the Great Lakes?" I asked.

"Well," he explained, "to understand that, you need to know what the soil in those forests is like. Think of it like a three-layer lasagna, except instead of pasta, cheese and sauce, the layers are the mineral layer, the duff layer, and the litter layer."

It was going great, and then he saw some people that he hadn't seen for a while and excused himself. I was left frantically writing down everything he'd just said. I looked up "mineral layer" first and learned that is the lower layer which consists mostly of minerals and just a little organic matter. The duff layer is in the middle and is partially decomposed leaves, needles, and other plant debris. And the litter layer is on top, made up of newly fallen leaves, needles, and branches that have not yet decomposed.

So I had my context, but I still had no idea what the invading earthworms did to this dirt lasagna. And no one was hitting the back bar for drinks. It was time to take my research on the road. I asked Tommy Evans if he'd swap with me. He'd been walking around all night passing out mini cheesecakes and was happy for the relief offered by the back bar.

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There were literally hundreds of forest ecologists in the room, and some of them had to be talking about worms. It was time to start eavesdropping. Since time was running short, I didn't want to waste any walking back and forth from the kitchen. Therefore, as I wandered about the room, the key was to move slowly enough to assess the topic of each conversation but too fast for anyone to actually take one of the mini cheesecakes from my tray.

Before that night, I had no idea how many different types of worm-related topics existed. I'd been cruising the conference room for forty-five minutes with no luck, and despite my best efforts, I was running dangerously low on mini cheesecakes. I decided to cut a wide route down the side of the room and back to the kitchen for supplies.

That's when I heard it: "They are destroying the duff layer," said a man in his fifties, wearing khakis. (Pretty much every guy in the room was wearing khakis.) He was talking to two other men and one woman. I offered my tray and listened in as the man continued: "We've been to sites where the duff layer drops from 20 centimeters in areas free of earthworms to less than 4 centimeters." He grabbed a mini cheesecake and thanked me.

"What does the duff layer do?" I asked. The question caught everyone off guard, even me just a little. "I mean, you're talking about invasive earthworms around the Great Lakes, right?" I gambled.

"In that general area," explained the woman.

"Are you interested in earthworms?" asked the man who'd been talking.

"I'm doing a report on them," I explained.

"Then you've come to the right place," he said, and then he jumped into his spiel: "The duff layer is very important for many of the plant species in these forests. For example, it protects seeds of many of the small understory plants. If the duff layer is too thin, then those seeds could be exposed to extreme temperatures or loss of moisture. Or the earthworms may damage seeds by digesting them, or move them down to the mineral layer. Any of these changes could be enough to cause the seeds not to germinate."

How Earthworms Got Me into College (3 of 3)

"The roots of many plants do not penetrate beyond the duff layer," added the woman, "so plants in a thin duff layer can dry out due to lack of moisture if the duff soil layer is thinned."

As she spoke, I caught a glimpse over her shoulder of Ms. Leary frowning at me. We weren't supposed to fraternize with guests. I didn't want to get written up again.

"This is just the kind of info I need," I explained, "but would you each like to take a cheesecake?"

They each kindly obliged me, and Ms. Leary seemed satisfied, at least for the moment.

"There's also the issue of mychorrizal vegetation," offered one of the other two men through a mouthful of cheesecake.

"What's that?"

He explained that some trees, called mychorrizal trees, depend on fungi in the soil for nutrients. If the earthworms disrupt those fungi, then the trees that depend on those fungi have a tougher time of it.

"And then there's the deer," added the woman.

"The earthworms affect the deer?" I asked.

"Well, they change the impact of the deer on the vegetation," she explained. "Deer are the most important grazers in these forests. When understory plants grow in a healthy duff layer of soil, there are plenty of plants available for deer to graze. However, when the herbs are less prolific, due to the thinner duff layer, the deer-to-plant ratio increases."

"Deer-to-plant ratio?" Math was never my best subject.

"Think of it like a fraction. Say that you have a population of 100 deer and you have 100 units of plants. That's a ratio of 100/100 or 1. Now if the amount of forest plants is cut in half due to the germination and soil moisture problems that we've been talking about, then the ratio becomes 100 deer to 50 units of plants, giving us a ratio of 100/50 or 2. In other words we have the same amount of deer grazing on fewer herbs, meaning a higher deer-to-plant ratio."

"I get it," I jumped in. "That increases the level of competition among the plants. So, the better a plant can defend itself against being grazed, the better its chances of surviving. But wait, how can a plant defend itself against a hungry deer?"

At this point, Ms. Leary was frowning again, and this time she was headed my way. I asked everyone to take another round of cheesecake, which they did.

"With chemical defenses," explained the first man through a mouth full of cheesecake. "For example, *Arisaema triphyllum*—a wild turnip, produces chemicals that can irritate the mouth and digestive system of deer. Since this plant is unaffected by changes in the duff layer, there are more of them than the other plants without such defenses. And then you have Trillium, which has shown significant declines in abundance. The deer love to eat them and they do not grow well in a thin duff layer."

"I think I get—"

"Is everything all right here?" It was Ms. Leary.

"Absolutely," said the woman, "I'm afraid we've been keeping this young man from his other duties, but let me just tell you how impressed we are with him. I wish more young people shared his enthusiasm and curiosity. He's quite remarkable."

"A lot of people my age think it's cool to be apathetic," I observed, looking more at Ms. Leary than the ecologist woman, "but that's just not me."

I wanted to bask in the glory of showing up Ms. Leary, but I had bigger fish to fry. I thanked the scientists for the interesting information and took my empty tray back to the kitchen. Before picking up a new tray, I wrote down everything I could remember about the conversation on earthworms. After work, I went home and developed a causal loop diagram showing how earthworms affect these northern forests. I presented it to my environmental science class the next day and got an A, which brought my C up to a B for the semester.

Before picking up a new tray, I wrote down everything I could remember about the conversation on earthworms.

Two more things you should know about me. One, I quit working at the conference center when I moved away to go to college. And two, I'm taking a soil science course as one of my free electives. It just seems right.

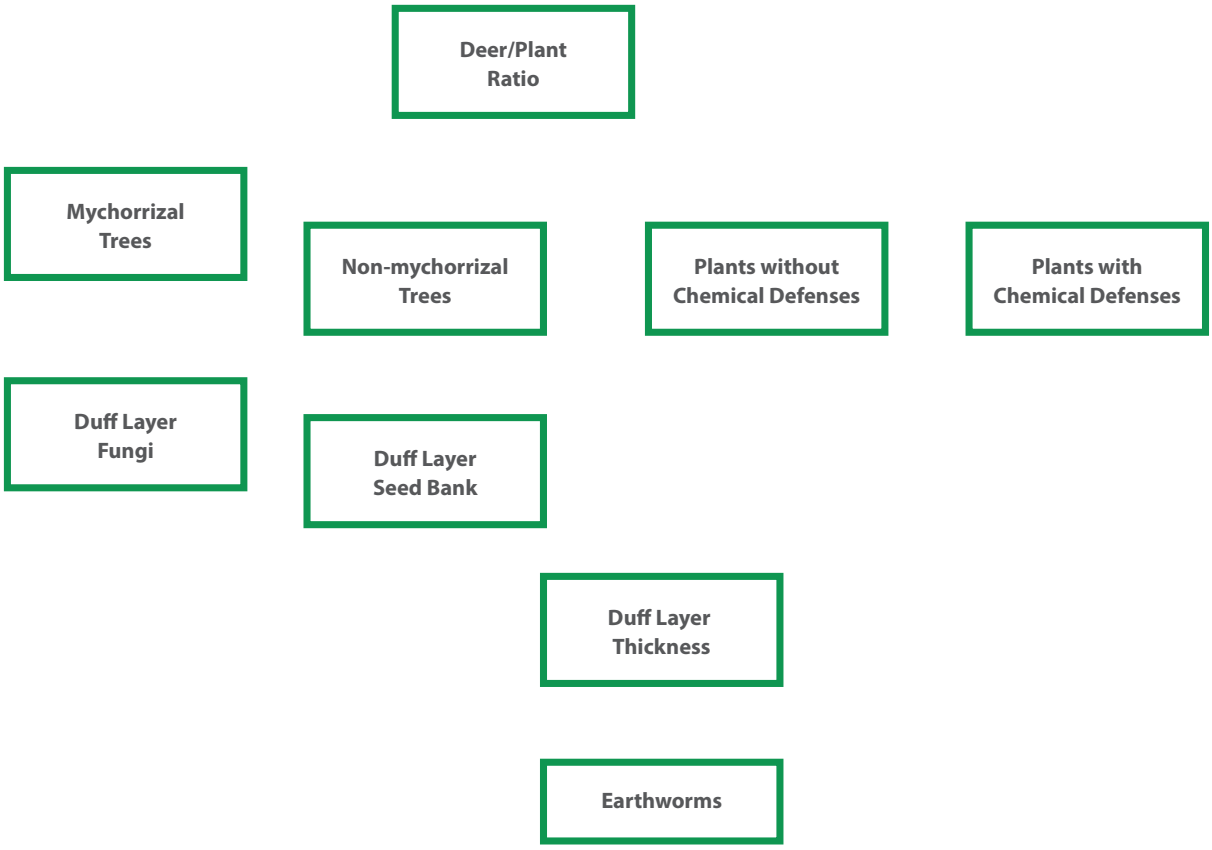
Diagramming Earthworms in the Northern Forest (1 of 2)

NAME DATE

Instructions: After reading How Earthworms Got Me into College, use the information in the story and the hints provided below to complete the causal loop diagram.

Cause-Effect Relationships

Using the numbered relationships on the next page, draw arrows on the causal loop diagram. Label each arrow you draw with the number of the connection, AND label each arrow with an S (for SAME) or an O (for OPPOSITE). An S indicates that the variables increase and decrease together (in the *same* direction). An O indicates that when the first variable increases, the other decreases (moving in *opposite* directions).



Diagramming Earthworms in the Northern Forest (2 of 2)

Cause-Effect Relationships

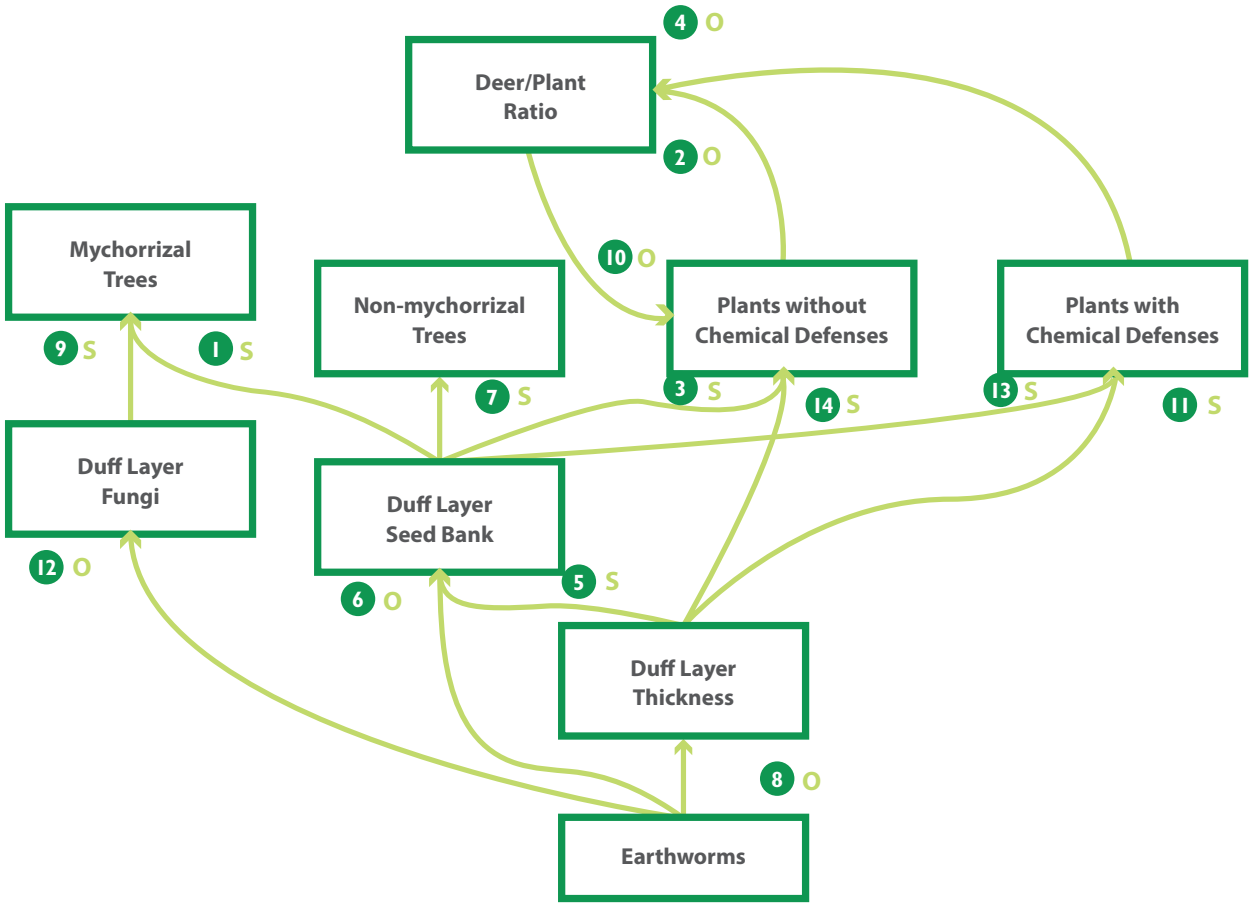
1. Decreasing the amount of viable seeds in the duff layer will decrease seedlings of mychorrizal trees.
2. Decreasing the amount of plants without chemical defenses while holding the deer population constant causes an increase in the deer-to-plant ratio.
3. Decreasing the amount of viable seeds in the duff layer will decrease seedlings of plants without chemical defenses.
4. Decreasing the amount of plants with chemical defenses while holding the deer population constant causes an increase in the deer-to-plant ratio.
5. Decreasing the thickness of the duff layer can cause seeds to be exposed to freezing or the open air, which causes them to die.
6. Seeds in the duff layer can be damaged by passing through an earthworm's digestive system or by being moved by the earthworm to a soil layer where they cannot grow.
7. Decreasing the amount of viable seeds in the duff layer will decrease seedlings of non-mychorrizal trees.
8. Increasing the earthworm population causes a decrease in the duff layer.
9. Decreasing the fungi population will decrease mychorrizal trees, which depend on the fungi for nutrients.
10. Increasing the deer-to-plant ratio causes a disproportionate grazing pressure on plants without chemical defenses, which decreases the abundance of those plants.
11. Decreasing the thickness of the duff layer will cause some plants to die from lack of soil moisture, decreasing abundance of plants with chemical defenses.
12. The earthworms disrupt the fungi in the duff layer.
13. Decreasing the amount of viable seeds in the duff layer will decrease seedlings of plants with chemical defenses.
14. Decreasing the thickness of the duff layer will cause some plants to die from lack of soil moisture, decreasing the abundance of plants without chemical defenses.

Discussion Questions

1. Identify two variables that are indirectly affected by the introduction of earthworms. Explain how each variable is connected.
2. Identify a feedback loop. Explain how the loop affects the variables involved in the loop.
3. Which group of trees is likely to be more significantly impacted by the introduction of earthworms? Explain your answer.
4. Which group of plants is likely to be more significantly impacted by the introduction of earthworms? Explain your answer.
5. Earthworms are often considered a gardener's friend. Explain how they can be helpful in a garden but harmful in northern forests.

Diagramming Earthworms in the Northern Forest (1 of 2)

This causal loop diagram shows all the connections listed on the student page.



Diagramming Earthworms in the Northern Forest (2 of 2)

1. Identify two variables that are indirectly affected by the introduction of earthworms. Explain how each variable is connected.

   Answers may vary here. Solicit answers from several students. The key is to emphasize indirect (rather than direct) connections. The earthworms affect the "Duff layer thickness" and "Duff layer fungi" directly. They affect every other variable on the diagram indirectly. See Example Paths for more details.

2. Identify a feedback loop. Explain how the loop affects the variables involved in the loop.

   There is only one feedback loop on the diagram. It involves "Plants without Chemical Defenses" and "Deer/Plant ratio." Since both of these arrows are O arrows, the loop is a reinforcing loop, which will tend to amplify small changes. A slight decrease in "Plants without Chemical Defenses" will lead to an increase in the "Deer/Plant ratio," which will lead to a further decrease in "Plants without Chemical Defenses" and on it goes around this loop.

3. Which group of trees is likely to be more significantly impacted by the introduction of earthworms? Explain your answer.

   "Mychorrizal trees" will be more affected because of the double whammy from both the loss of seeds and the loss of fungi on which the Mychorrizal trees depend. The decrease in Non-mychorrizal trees is solely from the loss of viable seeds.

4. Which group of plants is likely to be more significantly impacted by the introduction of earthworms? Explain your answer.

   "Plants without Chemical Defenses" will be more significantly impacted because the feedback loop discussed in question 2 will exacerbate any initial decreases in these plants.

5. Earthworms are often considered a gardener's friend. Explain how they can be helpful in a garden but harmful in these forests.

   Emphasize that a species is not simply "good" or "bad."The impacts of a species (positive and negative) depend on the context of a situation. Garden plants grow best in a mixture of mineral soil and duff. Some forest plants grow best in pure duff.