

SimBio Virtual Labs®

# EcoBeaker®: Top-Down Control

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**Student's Name:** \_\_\_\_\_

**Signature:** \_\_\_\_\_

**Date:** \_\_\_\_\_

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# Top-Down Control

## Introduction

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In the Baltic Sea, the decline in cod populations has led to a major increase in the abundance of large algae, even though cod don't eat algae. Around the Aleutian Islands, a rapid decline in sea otter populations was followed by the elimination of economically and biologically important kelp forests and many of their associated species, even though otters don't eat kelp. The invasion of Flathead Lake in Montana by opossum shrimp resulted in the loss of a bald eagle population, even though shrimp and bald eagles don't have any direct interactions. What's going on in these communities?

These puzzles illustrate some of the complexities that arise as a consequence of the trophic (feeding) structure of communities. As primary producers, plants provide the "fuel" that ultimately feeds the rest of the community; a reduction in plant biomass would obviously affect the organisms higher in the food web. We can also easily imagine that herbivores, which are organisms at the second level of the food web, would affect both primary producers below and predators above them. Finally, because predators eat herbivores, we can envision mechanisms by which changing predator abundance could affect plants in the community.

Which organisms ultimately control the structure of the community: the producers, herbivores, or predators? This question has driven many interesting studies in ecology and conservation biology. In any given system, predicting which trophic level exerts the most control over community structure is nearly impossible, and good arguments can often be made for all levels. The loss of top predators from numerous terrestrial and aquatic communities makes the question of more than just theoretical interest.

John Brooks and Stanley Dodson were among the first to address these questions, prompted by observations they had made about lake communities in New England. In this lab, you'll have the opportunity to re-create some of those studies and to discover for yourself one of the most interesting ecological principles, playing a critical role in many ecological communities.

## Lab Overview

Lakes are ideal places to conduct experiments on communities. They are big enough to contain fairly complicated communities, but small enough to do experiments on the whole lake at once. There are two fairly distinct environments in lakes: the mud on the bottom, called the “benthic” part of the lake, and the water itself, known as the “pelagic” part of the lake. The base of the food chain for both environments is primarily composed of phytoplankton, which are single-celled, plant-like organisms that photosynthesize. Many species of zooplankton, which are small, odd-looking animals (they could easily masquerade as cartoon aliens), make their living directly or indirectly from phytoplankton in the water column. Eating zooplankton are, of course, fish.

Fish, however, are not found in every lake, and lakes that contain fish are quite different from those that do not. In this lab, you will explore why there is such a difference, using a series of simulated lakes that include six different species. There are two species of phytoplankton: green algae and cyanobacteria (also known as blue-green algae). Both are pelagic, meaning they primarily float in the water. There are also two zooplankton species in these lakes, *Bosmina* and *Daphnia*. Finally, there are alewife, a smallish type of fish, and trout, which are larger.

You’ll be able to use several techniques commonly used by limnologists (fresh-water ecologists) to examine lakes. These include adding and removing species, examining individuals to figure out what different species eat, and analyzing population growth rates and feeding efficiencies. Your goal is to describe the changes that take place in a lake community when you add fish and then explain why these changes take place.

## The Top-Down Control Model in SimBio Virtual Labs

The Top-Down Control model reproduces some basic behavior of lakes. If you’re interested, here’s how the model works (minus a few details that you will figure out in the lab). Growth in lakes is usually limited by nutrients, often phosphorus or nitrogen. To make things simple, the whole lake economy in this model is based around phosphorus and nitrogen. Although you can’t see them, the lakes in this lab contain pools of these two nutrients, such that every part of the lake always has the same nutrient concentrations. Individual phytoplankton grow at a rate that depends on each species’ efficiency at absorbing each nutrient at its current concentration (according to Michaelis-Menton kinetics). Phytoplankton growth is also affected by the amount of sunlight reaching them through the water column. The other species need nutrients to grow as well, which they obtain either directly or indirectly by eating phytoplankton. Each time an individual zooplankton or fish encounters a food item, it has a certain chance of catching the food. When it eats food, a certain percentage of the food item’s carbon and nutrients are taken up, and the rest are excreted back into

the general nutrient pool. A small amount of each nutrient is continually added to the lake from outside, and a percentage of what's currently in the lake is always disappearing. Other details in the system are among the things you will figure out in the lab.

## Exercise 1: Interactions in a Two-Level System

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- [ 1 ] Before you start playing with the simulation model, you should read the introductory section of the workbook. The background information will help you understand the simulation model and answer questions correctly.
- [ 2 ] If you haven't already, start **SimUText**® by double-clicking the program icon on your computer or by selecting it from the Start menu. When the program opens, enter your Log In information and select the **Top-Down Control** lab from your **My Assignments** window and make sure that **Begin** is selected from the drop-down menu of exercises at the top of the screen.

You will see two main panels on the screen:

- The large panel on the left shows the simulated lake. Its inhabitants are two types of phytoplankton (green algae and cyanobacteria) and two herbivorous zooplankton species (*Daphnia* and *Bosmina*).
  - The panel on the right includes bar graphs showing the population sizes of all species in the lake and buttons you can click to learn more about each species.
  - A **Control Panel** in the bottom left corner of the screen lets you start and stop the simulation, control its speed, and measure how long it has run. Additional tools will be described as they are needed.
- [ 3 ] Read the library descriptions of Green Algae, Cyanobacteria, *Daphnia*, and *Bosmina*.
    - [ 3.1 ] **Which of the two is the better competitor under most conditions—green algae or cyanobacteria?**
    - [ 3.2 ] **Which of the two can grow to the larger size—*Daphnia* or *Bosmina*?**
  - [ 4 ] Click the **STEP 150** button on the **Control Panel** to run the simulation for 150 weeks. (Alternatively, you can use the **GO** and **STOP** buttons.)
    - [ 4.1 ] **Examine the graphs of population size and record the number of each species in the DATA TABLE 1 below, in the Trial 1 column. You can click on the bars on the graph to obtain exact values.**
  - [ 5 ] Reset the simulation back to its initial state by clicking the **RESET** button on the **Control Panel**. Repeat this process twice more.
    - [ 5.1 ] **Record the population sizes for Trial 2 and Trial 3 in the respective columns in DATA TABLE 1.**
    - [ 5.2 ] **Calculate the average population size for each species from your three trials and record in DATA TABLE 1.**

**DATA TABLE 1. POPULATION SIZES PRESENT IN THE LAKE**

	<b>TRIAL 1</b>	<b>TRIAL 2</b>	<b>TRIAL 3</b>	<b>AVERAGE</b>
Green Algae				
Cyanobacteria				
<i>Daphnia</i>				
<i>Bosmina</i>				

★ *NOTE: You can click the calculator icon in the **Tools** panel to launch the computer's system calculator.*

**[ 5.3 ] Are your results consistent with what you learned about each species from the library entries? Explain.**

[ 6 ] Click the **TEST YOUR UNDERSTANDING** button in the lower right and answer the question.

As an aside, you might notice that the algae move up and down in circles near the surface of the water. Vertical circles of current, called Langmuir cells, often happen in the surface waters of lakes and oceans when the wind blows.

## Exercise 2: Adding Alewife

- [ 1 ] Select **Adding Alewife** from the drop-down menu of exercises. Read the description of alewife from the library.
- [ 2 ] Add 3 alewife to the lake by clicking the **ADD ALEWIFE** button (the highlighted button with the small fish on it) on the **Tools** panel. Then click 3 times in different areas of the lake.
- [ 3 ] Run the simulation for about 150 weeks using the **STEP 150** button or the **GO** and **STOP** buttons.
  - [ 3.1 ] **Examine the graphs of population size and record the number of each species in DATA TABLE 2 below.**
- [ 4 ] **RESET** the simulation. Repeat steps [ 2 ] and [ 3 ] two more times.
  - [ 4.1 ] **Record your data in the Trial 2 and Trial 3 columns in DATA TABLE 2.**
  - [ 4.2 ] **Calculate the average population size for each species from your three trials and record in DATA TABLE 2.**

**DATA TABLE 2. POPULATION SIZES WITH ALEWIFE PRESENT**

	<b>TRIAL 1</b>	<b>TRIAL 2</b>	<b>TRIAL 3</b>	<b>AVERAGE</b>
Green Algae				
Cyanobacteria				
<i>Daphnia</i>				
<i>Bosmina</i>				

- [ 4.3 ] **Combine your two sets of average population sizes into DATA TABLE 3.**

**DATA TABLE 3. AVERAGE POPULATION SIZES WITH AND WITHOUT ALEWIFE**

	<b>AVERAGE POPULATION SIZE WITHOUT ALEWIFE</b>	<b>AVERAGE POPULATION SIZE WITH ALEWIFE</b>
Green Algae		
Cyanobacteria		
<i>Daphnia</i>		
<i>Bosmina</i>		

**[ 4.4 ] Write a short description of each lake community (with and without alewife). Then use the information you've recorded to list as many differences as you can between them. Because there is a lot of variability between runs (just as in real life), you may choose to do more runs with or without alewife as you write your description.**

**[ 4.5 ] In your observations above, did you comment on whether the total population size in each trophic level had changed? Did you comment on whether the dominant species within each trophic level had changed? If not, make observations on those changes below.**

[ 5 ] Click the **TEST YOUR UNDERSTANDING** button in the lower right and answer the question.

The differences you saw in this exercise are similar to those found in real lakes with and without fish. Your goal for the remainder of the lab will be to design observations and experiments that will allow you to explain how and why those differences occurred. You'll have several ways of exploring the system. You can, of course, re-run the lake simulation as many times as you wish with and without fish. In addition, you will have a set of **Experimental Lakes** and a set of **Experimental Tanks** that will allow you to do a variety of other experiments. These will be introduced in the next two exercises.

Finally, in Exercise 5, you are on your own to use whichever tools you wish in order to explain what is happening in the simulated lake.

## Exercise 3. Experimental Lakes

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The change you observed in phytoplankton abundance following the addition of fish in a lake is an example of a **trophic cascade**. A community's trophic structure begins with plants, the primary producers. The consumers that eat the plants (the herbivores) are primary consumers, predators that eat the herbivores are secondary consumers, big predators that eat smaller predators are tertiary consumers, etc. A trophic cascade occurs when the abundance of individuals at one trophic level affects the abundance of individuals several trophic levels removed from them. For example, you witnessed a trophic cascade when you added alewife, because the addition of a secondary consumer changed the abundance of a primary producer.

Limnologists have studied trophic cascades by conducting experiments in lakes. By manipulating variables such as the presence, absence, and relative abundance of each species, they can study feeding habits, competition, and other interactions. In this exercise, you will learn to build your own experimental lake in which individual species behave the same way they did in your original lakes. They move, live, and die the same, but you are able to control which species are present in the lake. In the next exercise, you will be introduced to a virtual fish tank where you can conduct additional experiments. In the final exercise, you will be turned loose to conduct your investigations.

### Your Experimental Tools

- [ 1 ]      Select **Experimental Lakes** from the **Select an Exercise** drop-down menu.
- [ 2 ]      Examine the **Tools** panel at the bottom of the screen. The first 6 buttons should be highlighted.
  - Each button with a + sign and a picture of an organism allows you to add that organism to the lake. Click on the organism you want to add; then click inside the lake to add one individual of that organism. You can click and drag to add multiple individuals more easily.
  - The **MICROSCOPE** button allows you to examine gut contents. Select the microscope by clicking on the **MICROSCOPE** button. Then click on any *Daphnia*, *Bosmina*, or alewife in the lake to see what its most recent meal (if any) was.
- ★ *NOTE: You can examine gut contents under "natural" conditions with and without alewife by returning to the Add Alewife exercise; the same microscope tool is available in that exercise. This might allow for useful comparisons with results from your experiments.*
- [ 3 ]      To clean out your experimental lake and start over with a new experiment, click the **RESET** button on the **Control Panel**.

## Your Experiments

These tools—being able to observe species in different combinations and to examine gut contents—will allow you to develop a well-supported explanation for how and why the addition of alewives changed your lake system, and your other observations. Here is one example of something you could do in the **Experimental Lakes**.

- [ 1 ] To familiarize yourself with the experimental lake, you will conduct an experiment to determine which species of zooplankton is the best competitor in the absence of predators.
  - [ 1.1 ] **Based on your results so far, which species do you predict is the better competitor? Why?**
  
- [ 2 ] Add about 20 green algae and 20 cyanobacteria to the lake by clicking on the **ADD GREEN ALGAE** and **ADD CYANOBACTERIA** buttons respectively. To do this more quickly, you can click and drag the mouse inside the lake to create a rectangle of each algae. The number of algae you are adding will be shown in the top left of the rectangle. Remember, algae need sun and the top of the lake is towards the top of the screen.
- [ 3 ] Click on the **GO** button to run the simulation until the green algae population is about 200 individuals, then **STOP**. Do not reset the simulation.
- [ 4 ] Now add 5 *Daphnia* to the lake. To do this, click the **ADD DAPHNIA** button in the **Tools** panel, and then click 5 times in and around the phytoplankton in random places. Next, add 5 *Bosmina* to the lake in the same fashion using the **ADD BOSMINA** button. Zooplankton must be placed near their food, or they will die (rendering your experiment rather useless).
- [ 5 ] Run the simulation for about 150 weeks, or until you feel like the pattern of population sizes between the species is clear. Repeat the experiment if necessary to confirm the pattern.
  - [ 5.1 ] **Did you predict correctly? Explain, using your results to support your explanation.**

- [ 6 ] Note that here and throughout this lab, you will notice that there is a lot of variability in the model. This reflects the reality of studying natural systems. Your results won't necessarily be clean, or even be the same each time. You will have to decide how many times to run each experiment until you feel confident of the results.
- [ 7 ] Click the **TEST YOUR UNDERSTANDING** button in the lower right and answer the question.

This exercise demonstrated one possibility for using the **Experimental Lakes**. In the next exercise you will be introduced to another powerful tool: **Experimental Tanks**.

## Exercise 4. Experimental Tanks

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**Experimental Lakes** are useful for studying large-scale questions. In contrast, you will see that **Experimental Tanks** are particularly useful for short-term experiments on one or a small number of individual organisms at a time. They mimic the controlled laboratory setups ecologists might use, for example, to study food preference, feeding rate, and other aspects of individual behavior.

To mimic the conditions of these short-term experiments, the organisms you add to your tanks will neither reproduce nor die. In addition, phytoplankton in the **Experimental Tanks** do not move. Remember this as you design your experiments!

### Your Experimental Tools

- [ 1 ]      Select **Experimental Tanks** from the **Select an Exercise** drop-down menu.
- [ 2 ]      Examine the **Tools** panel at the bottom of the screen. As with the previous exercise, you can add individuals to the tank in any combination and examine gut contents. Observe the **Time Elapsed** box. Your experiments last only a few hours rather than weeks.
- [ 4 ]      For short-term experiments, you might want to take advantage of the **STEP 1** button on the **Control Panel**. This moves the simulation forward one hour at a time. You can use this feature, for example, to follow the feeding behavior of one individual over time.
- [ 5 ]      To clean out your experimental tank and start over with a new experiment, click the **RESET** button on the **Control Panel**.

### Your Experiments

What you do with these tools will depend on the questions prompted by your previous experiments, observations, and findings. Again, to familiarize you with the setup, here is one example of something you could do in an **Experimental Tank**. To give you an idea of how you can use the experimental tank to study behavior, you will conduct a study to determine how long it takes an individual *Daphnia* to catch a green algae cell.

- [ 1 ]      Add one green algae cell to the tank, and add one *Daphnia* right next to it.
- [ 2 ]      Click the **MICROSCOPE** button so that you can examine gut contents.
- [ 3 ]      Advance the model one time-step by clicking on the **STEP 1** button.
- [ 4 ]      If the green algae disappears, click on the *Daphnia* and see if it has anything in its gut. If not, keep advancing the model one hour at a time until the *Daphnia's* gut shows that it ate algae.
  - [ 4.1 ]    **Record the number of time-steps required for the *Daphnia* to eat the algae.**

- [ 5 ] That particular *Daphnia* may have been especially lucky or unlucky while you were watching it and caught its food either faster or slower than normal. Therefore, you should always repeat your behavioral experiments multiple times and determine the average result (i.e., repeat steps 1 through 4 several more times).

This exercise demonstrated one possibility for using the **Experimental Tanks**. Now you're ready to venture out on your own!

## Exercise 5. Go For It

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You now have a large set of tools with which to explore this lake system. Your goal is to develop and test hypotheses that explain the trophic cascade you saw. To do that, you will need to do more experiments. There is no one “correct” set of experiments for you to do. You can come up with a good explanation using a number of different approaches, and you can also explore subtleties of the system. Below are some ideas to get you started. Review the natural history information in the species descriptions for more ideas. And use your imagination!

- Which species of zooplankton is the best competitor in the presence of predators?
- Which species of phytoplankton and zooplankton grow the most rapidly?
- What does each species of zooplankton eat when no alewife are present? What do they eat when alewife are present?
- What do alewife eat?
- Can alewife or an individual zooplankton species exist on just one prey species, or are both necessary?
- If one species of herbivore is competitively dominant over another, can you figure out why?
- If you observed a food preference in your artificial lake, can it be confirmed (or better supported) by a controlled food choice experiment in an experimental tank?

Before you begin, remember that your goal is to develop and test hypotheses. Start with one or more tentative explanations, derive some predictions, and design *well-controlled and replicated* observations and experiments to test them. Write down your hypotheses, predictions, and experimental designs, and then record your resulting data appropriately!

You may also find that you have some experiments you would like to do for which you don't have the tools available. You can include these in the conclusions of your report as ideas for future research.

[ 1 ] You can switch back and forth between the different experimental setups to do different experiments using the **Select an Exercise** menu.

[ 1.1 ] **If you want to see which species of phytoplankton grows most rapidly, which experimental setup would you use (Experimental Lakes, Experimental Tanks, or the original simulated lake in Add Alewife)? Why?**

[ 2 ] Remember, inside the **Experimental Tanks**, organisms do not reproduce or die, and phytoplankton remain stationary. This can be very useful for certain experiments, but more natural settings (like the **Experimental Lakes**) may be more appropriate. Choose wisely.

[ 2.1 ] **If you want to see which species of phytoplankton *Daphnia* prefer to eat, which experimental setup would you use?**

[ 2.2 ] **Now conduct your experiments! You may need additional paper as you develop your ideas but be sure to record your hypotheses, predictions, experimental protocols, and resulting data in the space provided below. Then go on to summarize your results.**

## **HYPOTHESES**

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## **EXPERIMENTAL PROTOCOLS**

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## RESULTS

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[ 5 ] Look back at Question [ 4.4 ] in **Exercise 2. Adding Alewife**, where you described the differences between a lake with and without alewife.

[ 5.1 ] **Write a 1-2 page report on your results, explaining what changes take place when small fish are added to a lake, why the changes take place, and how you know why they take place (i.e., your observations, experiments, results, and interpretations).**

## Extension: The Fourth Dimension

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Now that you understand the dynamics of a 3-level system, you can put your understanding to use. Here's the scenario. You have learned about a (hypothetical) proposal to add brown trout, a predator on alewife, to the local lake you are studying. Proponents favor the proposal, because brown trout are a popular game fish; introducing it will benefit local anglers and will potentially attract tourist revenue. Others oppose the proposal, arguing that the addition of trout could cause devastating changes in the lake community.

What do you predict will happen to the lake when a fourth trophic level is added? Investigate with the following experiment.

[ 1 ]      Select **The Fourth Dimension** from the **Select an Exercise** drop-down menu. Your lake is already stocked with phytoplankton, zooplankton, and alewife. In addition, unlike before, alewives now occasionally immigrate to the portion of the lake you are watching from other parts of the lake.

[ 2 ]      Without adding anything, run the simulation for around 150 weeks.

[ 2.1 ]    **Record the size of each population before the top predator is added.**

**Green algae:** \_\_\_\_\_

**Cyanobacteria:** \_\_\_\_\_

**Daphnia:** \_\_\_\_\_

**Bosmina:** \_\_\_\_\_

[ 2.2 ]    **Based on your understanding of the trophic cascade in this system, what do you predict will happen if you add a predator or alewife to the system? Be as specific and complete as possible, both in listing the changes you think will happen and why.**

[ 3 ]      Test your prediction by adding 2 trout to your lake and running the simulation until the populations stabilize. Make sure that you wait long enough to see changes that may occur at all trophic levels. As the number of trophic levels increases, the amount of time required for the populations to stabilize may also increase.

**[ 3.1 ] Were your predictions correct? Explain.**

**[ 3.2 ] Write a letter to the editor of the local newspaper about the changes to the lake community that are likely to occur if trout are added. Feel free to take a stance, for or against trout addition, and justify your stance with the information from your experiment.**

## Graded Questions

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- [ 1 ] Use the **SELECT AN EXERCISE** menu to launch "**Graded Questions**".
- [ 2 ] Enter your answers for each of the questions and click the **SUBMIT ALL** button. **NOTE:** You must answer all of the questions before you click the **SUBMIT ALL** button.

## Wrap-Up

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### Trophic Cascades

As you have seen, the influence of top predators can extend across multiple trophic levels. The presence or absence of top predators can have profound effects on populations, community structure, and, by extension, ecosystem structure and function. Pronounced change in population size that result when changes at one trophic level affect a population two or more levels removed is called a **trophic cascade**. Communities whose structure is regulated primarily by top predators in this way are said to be under **top-down control**, as opposed to those regulated by the abundance of producers, which are said to be under **bottom-up control**.

Ecologists began studying trophic cascades in aquatic systems in the mid-1960s. One goal of such studies was to try to characterize the communities most likely to exhibit trophic cascades and to be regulated by top predators. Initially, they concluded that top-down control is most important in food webs with low species diversity, few trophic levels, and one or two herbivores with strong influences on primary producers. They also found evidence of trophic cascades primarily in aquatic systems. In a 1999 review, however, Pace et al. noted that trophic cascades have now been documented in a wide range of habitats and communities. Therefore, understanding the characteristics of systems under top-down control remains a research priority, as do other questions, such as how far “down” the chain top-down effects are felt, how the presence of omnivores at “middle” levels of food webs might buffer the effects of top predators, and how top-down effects interact with bottom-up effects to structure communities.

Again, these questions are of more than just theoretical interest. Top-down control can affect water quality and primary productivity in aquatic systems. The addition of brown trout to one New Zealand stream, for example, increased primary productivity six-fold. Increasing productivity may sound like a positive outcome, but increasing primary productivity can mean dramatically increasing algal biomass, potentially decreasing water clarity and dissolved oxygen, which greatly affects other aspects of the stream’s structure and function.

Trophic cascades can also lead to **predator release**, which is the ability of prey populations to either hold steady or increase once their predators are removed. In Australia, for example, feral cats and foxes, both introduced by Europeans, have decimated populations of Australia’s endemic marsupials. In some areas, dingoes (wild dogs found in Southeast Asia and Australia) prey on cats and foxes. In those areas, populations of endangered marsupials are larger than they are in dingo-free areas. In the Alps, eagle owls prey on tawny owls, which, in turn, either compete with or prey upon smaller owl species, some of them conservation targets.

Finally, according to the Food and Agriculture Organization of the United Nations, 75% of the fisheries for which data are available are either fully exploited, overexploited, depleted, or recovering from overexploitation. Many of these species are top predators. Marine food webs are notoriously difficult to study, and we simply don't have enough information to predict the consequences of these practices. However, based on what we know about trophic cascades, it seems likely that there will be large effects on marine ecosystems.

## **Pieces of the Puzzles**

Let's return briefly to our introductory puzzles and put a few more pieces together. Cod and other top predators have declined in the Baltic Sea over the last decade. Their loss from the community has allowed three-spined stickleback (smaller predatory fish) to move into regions where previously they were absent. The stickleback prey on invertebrate herbivores, releasing large algae from grazing pressure.

Sea otters, once hunted to near extinction, are recovering along the Pacific coast from California to Alaska. Sea otters prey on sea urchins, which, in turn, graze on the kelp that are the primary producers for the community. In the 1990s, sea otter populations in some areas began to crash. No otters meant more sea urchins, which in turn eliminated the kelp. The cause of the sea otter decline hasn't been determined with certainty; James Estes, an expert on the system, has hypothesized that orcas have begun feeding on otters because their preferred prey (seals and sea lions) are in decline.

Flathead Lake in Montana has a long and complex ecological history. In the early 1980s, bald eagles established a large population near the spawning grounds of kokanee, a species of salmon that had invaded the lake in the early 1920s. In the mid-1980s, however, opossum shrimp, ironically introduced to other lakes as potential food for the kokanee, became established in the lake. Unfortunately, kokanee don't eat opossum shrimp, but lake trout do. The lake trout population grew, eliminating the kokanee and, subsequently, the bald eagles.

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