LESSON 40

Biological ... *Control?:*
Cascading Effects of Biological Control of Knapweed

Grade level: 9-12
Subject Areas: Biology, writing, technology
Duration: One to two class periods
Setting: Classroom
Season: Any
Conceptual Framework Topics: Invasive species ecology, weed management, biological control, herbivory, human health impacts

(Adapted from the Ecological Society of America's *Teaching Issues and Experiments in Ecology Curriculum*)

OBJECTIVES
Students will understand the direct and indirect effects of biological controls on non-target species in an ecosystem.

METHOD
Students use cooperative learning to teach each other about the cascading effects resulting from an introduced biological control agent, involving the invasive plant knapweed, the biological control agent (gall flies), mice, and hantavirus.

MATERIALS
✎ **Student Biocontrol Pages**

BACKGROUND
Invasive species present serious threats to the biological diversity and ecological integrity of ecosystems throughout the world. Biological control ("biocontrol") is the introduction of an organism (usually an insect, fungus or bacteria) that has evolved with the target plant species and causes deleterious effects on it through herbivory or disease. Biocontrols are promising for weed control for a number of reasons. They have been effective at reducing plant numbers in some cases, they reduce the need for other control methods such as herbicides, and they are self-perpetuating. Biocontrols must undergo thorough screening for host-specificity (that is, that they will only eat or cause direct harm to the target plant species and not other plants) to reduce the chance for their negative impacts on desirable species.

However, this type of careful screening doesn't prevent the use of biocontrols that may have significant impacts on food web interactions in the ecosystem to which they are introduced. These kinds of indirect impacts may be virtually impossible to foresee before introductions, although some general predictions can be made.

U.S. Forest Service and University of Montana researchers studying deer mice in western Montana realized that deer mice populations seemed to be much higher in spotted knapweed-infested areas than in native grasslands. They also found that deer mice were feeding heavily on the larvae of gall flies (*Urophora* species) that had been introduced in the 1970's to cause gall formation in seed heads and reduce seed production in knapweed. The gall flies have considerably reduced the seed production in knapweed, but it has not been enough to effectively control knapweed, which continues to increase in many areas. The gall flies, however, have become as abundant as the knapweed, and are now many times more plentiful than in their native habitats in Europe.

Researchers Dean Pearson and Ray Callaway began to more closely study the interactions among these species. They found that as the gall fly larvae overwinter in the knapweed seed heads, they provide an abundant food source for Montana's native deer mice at a time when food is otherwise scarce. In fact, in areas heavily infested with knapweed, gall fly larvae make up 85% of deer mice diets in the winter! This allows deer mice populations to double and even triple in knapweed/gall fly areas in some winters, compared to the populations in native grasslands.

This change in a small mammal population may, of course, have further effects on the ecological web of the grasslands in western Montana, potentially affecting the predators and competitors of deer mice, as well as the native plants and insects they prey upon. But an additional very interesting twist to this story is that deer mice are the primary reservoirs, or carriers, of the Sin Nombre Virus, also known as hantavirus. Hantavirus causes a deadly respiratory disease (Hantavirus Pulmonary Syndrome – HPS) in humans, with a 37% fatality rate among those who contract it (perhaps much higher if left untreated). The virus becomes airborne when disturbed, and humans catch it through exposure to mouse feces, usually in a building, since the virus is destroyed by ultraviolet light.

Pearson and Callaway also collected data on the hantavirus occurrence in the deer mice in their study. They found that not only did the much more abundant mice in the knapweed areas carry hantavirus, but that a greater proportion of them carried it than did the mice in the grasslands (although that difference was not great enough to be statistically significant.) So the prevalence of hantavirus in areas with a lot of knapweed (and gall flies) is more than three times that in other areas. (Montana in 2005 was ranked as second only to New Mexico in the number of cases per capita of HPS in humans).

For more detailed information on this research, go to **http://www.rmrs.nau.edu/publications/2006_Pearson_Callaway/2006_Pearson_Callaway.pdf**

For more information on hantavirus, go to **http://www.hantavirus.net/**

(For information about use of the *Jigsaw* teaching method in this lesson see **http://tiee.ecoed.net/teach/teach_glossary.html.**)

In this lesson students will piece together the relationships between the invasive knapweed, gall flies, deer mice, hantavirus, and human health. The figures on the students' sheets come from three papers, each of which investigates separate aspects of the indirect effects of an introduced biological control agent.

Figure 1, from Pearson, McKelvey, and Ruggiero (2000), shows that the monthly variation in % stomach content (of deer mice) that consists of gall fly larvae corresponds with the yearly cycle of gall fly and deer mouse life cycles. (Students should realize after seeing this figure that deer mice are consuming gall flies as a large portion of their diet, and are only consuming gall flies when they exist as larvae within the seed heads of the knapweed. You may want to question students to make sure they understand this portion of the figure. For example, ask students why the dependent variable declines in June-Aug.)

Figure 2, from Pearson and Callaway (2006), illustrates that gall fly larvae density is higher in areas with higher knapweed density.

Figure 3, also from Pearson and Callaway (2006), illustrates that the abundance of deer mice, the *abundance* of seropositive (carrier of virus) mice, and the *proportion* of seropositive mice are all higher in populations containing higher densities of knapweed.

PROCEDURE

1. If necessary, explain to your students the basic concept of using biological controls as a method of managing invasive plants. Then tell them only the following about this specific case of biocontrol use: that gall flies were introduced in the 1970's to control knapweed; that gall flies lay their eggs in the flower heads of knapweed; that the developing larvae stress the plant and decrease seed production of the knapweed; and that this decrease in seed production has not been not enough to reduce the populations of the invasive knapweed.

2. Divide students into equally sized groups to form 3 total groups. Assign one group to Figure 1, one group to Figure 2, and one group to Figure 3. In a larger class, you can divide students into 6 groups (two groups to each figure). There are three different portions of the story represented by the three figures. Students are to interpret the data given in their figure and ensure that each member of their group thoroughly understands the information, as they will be required to explain it to someone who has not seen the figure yet. Give students sufficient amount of time to accomplish this. Make sure all the terms and concepts are understood (proportions as opposed to total number, life cycles resulting in changes of availability over time, etc).

Extensions

Have students create a concept map to depict the relationships between knapweed, gall flies, deer mice, hantavirus, and human health. Ask them to consider other components of the system, such as native plants, native insects, small mammals, and predators. If your students have not worked with concept maps before, briefly describe what they are, perhaps with an example.

Have your students research biocontrol agents for invasive plants in Montana.

Make sure that students read the figure legends. In particular, make sure students understand that 'seropositive' means that the mice are carriers of hantavirus. You may need to inform students that transmission rates will increase with increases in the density of the carriers. You could enforce this concept by asking students to consider the conditions under which diseases spread more rapidly (among those living in crowded cities, when people are crowded together in schools or other large buildings, etc.)

3. Then assign students to new groups, so that each member of each new group has information from a different figure. Therefore the new groups should each contain 3 members, one student having information about Figure 1, one from Figure 2, and one from Figure 3. These students are now to teach each other their "pieces" of information to "piece together the puzzle" with the goal of understanding the indirect effects of the introduced biocontrol agents.

4. As a breakdown of the figures, students should be able to conclude that (1) gall fly larvae are present in large densities in areas that contain knapweed, (2) deer mice are present in large densities in areas that contain knapweed, (3) deer mice diets primarily consist of gall fly larvae and their diets fluctuate with the life cycle of the gall fly, and (4) both the density and proportion of deer mice that carry hantavirus are higher in areas that contain knapweed. Therefore the continued presence of knapweed allows for the persistence of gall flies, which provide additional food for deer mice, carriers of hantavirus, a virus that is transmitted to humans and can be fatal.

5. After all the final groups have had a chance to share their pieces of the puzzle with one another, discuss the issue with your class as a whole. You may want to address the following:

Ask if the *correlations* between knapweed and gall flies, gall flies and mice, and mice and hantavirus *prove* that the biocontrol increases hantavirus occurrence. (Although the separate pieces of the puzzle suggest that more knapweed allows more flies to flourish, which allows more mice to live in knapweed areas, which in turn causes more and a greater proportion of seropositive mice, you can explain that these were *correlations*, and *causation* has not yet been supported by manipulative experiments, which would give stronger evidence. You can discuss with students how an experiment could be designed in this system.)

Student Biocontrol Page 1

Read through this page of directions and information thoroughly before examining the accompanying figure.

Individually examine **Figure 1 (graphs a and b)** and understand what the axes and data points mean. What information do the graphs provide? After everyone has completed this, discuss the figure with the other members of your group and decide what the authors wanted to convey with the data presented in the graphs. *You will need to understand the information thoroughly as you will be teaching others about it shortly!*

Share with your group any questions or difficulty you may have had with the graphs so everyone will be ready to explain them to others. Practice teaching it to each other within your group. For example, ask your fellow students: why does the dependent variable decline in June-Aug?

Figure 1 is from a paper published by University of Montana and U.S. Forest Service scientists in the scientific journal *Oecologia* in 2000. The researchers examined how much gall fly larvae make up the diets of deer mice throughout the year. The results of their study are an important piece in the ecological puzzle you will be putting together to understand the unplanned effects of an introduced biological control agent.

Gall flies (*Urophora* species) were introduced to control populations of the invasive spotted knapweed,. This species of knapweed has spread throughout the western United States and can cause many problems on rangelands and in natural areas. The biocontrol agents successfully reduced seed production of the knapweed, but not enough to effectively control populations of knapweed. However, the introduced gall flies, because knapweed still exists, continue to persist and have indirect effects on food webs and can potentially indirectly affect human health.

Now, check out your piece of the puzzle!

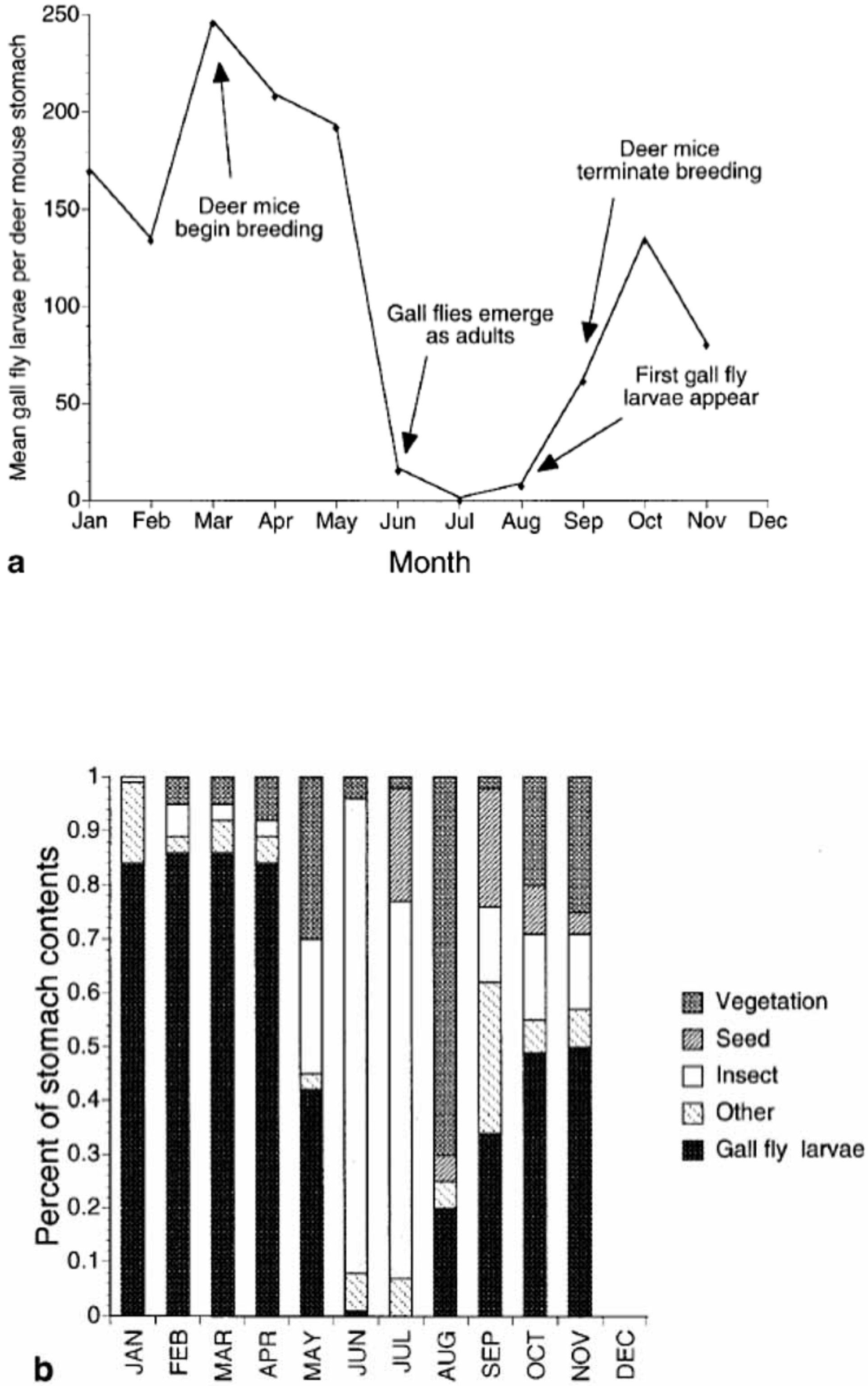

Figure 1. Stomach content analysis of deer mice from 1997-1998. Data in (a) represent mean (average) number of gall fly larvae found per deer mouse stomach each month. The arrows show different points in both the life cycle of the deer mouse and the gall fly. Data in (b) show the percent of different food items in deer mouse stomachs each month. (From Pearson, D.E., McKelvey, K.S., and L. F. Ruggiero. 2000. Non-target effects of an introduced biological control agent on deer mouse ecology. *Oecologia* 122: 121-128.)

Student Biocontrol Page 2

Read through this page of directions and information thoroughly before examining the accompanying figure.

Individually examine **Figure 2** and understand what the axes and data points mean. What information is the graph are trying to convey? After everyone has completed this, discuss the figure with the other members of your group and decide what the authors wanted to convey with the data presented in the graphs. *You will need to understand the information thoroughly as you will be teaching others about it shortly!*

Share with your group any questions or difficulty you may have had with the graphs so everyone will be ready to explain them to others. You may want to practice teaching it to each other within your group.

Figure 2 is from a paper published by University of Montana and U.S. Forest Service scientists in the scientific journal *Ecology Letters* in 2006. The researchers studied populations of knapweed (in low and high densities). One of the objectives of their study was to compare the numbers of gall flies in low densities of knapweed (where it was <2% of the vegetation) to high densities of knapweed (where it was >20% of the vegetation). They wanted to know if more knapweed means more gall flies. The results of their study are an important piece in the ecological puzzle you will be putting together to understand the unplanned effects of an introduced biological control agent.

Gall flies (*Urophora* species) were introduced to control populations of the invasive spotted knapweed, *Centaurea maculosa.* This species of knapweed has spread throughout the western United States and can cause many problems on rangelands and in natural areas. The biocontrol agents successfully reduced seed production of the knapweed, but not enough to effectively control populations of knapweed. However, the introduced gall flies, because knapweed still exists, continue to persist and have indirect effects on food webs and can potentially indirectly affect human health.

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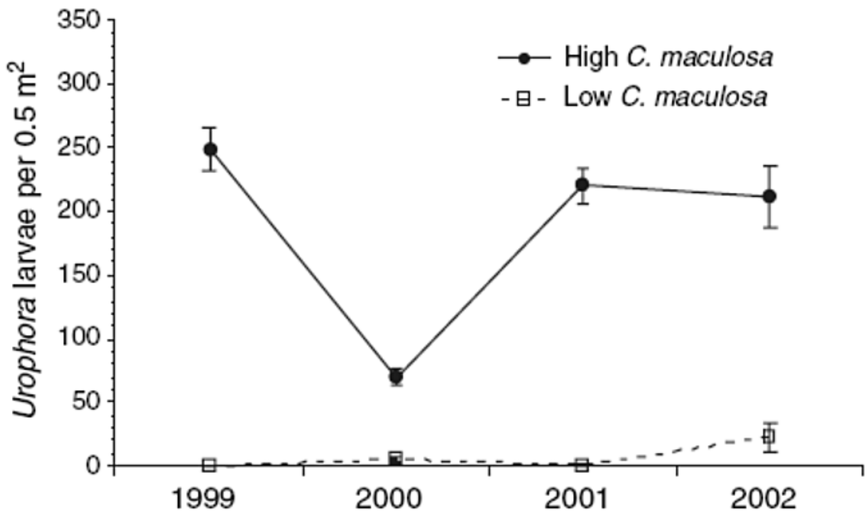

Figure 2. The mean density of gall fly larvae (+ 1 standard error) present in two populations of knapweed, one of high density (solid points) and one of low density (open points) across four years (From Pearson, D.E. and Callaway, R.M. 2006. Biological control agents elevate hantavirus by subsidizing deer mouse populations. *Ecology Letters* 9: 443-450.)

Student Biocontrol Page 3

Read through this page of directions and information thoroughly before examining the accompanying figure.

Individually examine **Figure 3** and understand what the axes and data points mean. What information is the graph are trying to convey? After everyone has completed this, discuss the figure with the other members of your group and decide what the authors wanted to convey with the data presented in the graphs. *You will need to understand the information thoroughly as you will be teaching others about it shortly!*

Share with your group any questions or difficulty you may have had with the graphs so everyone will be ready to explain them to others. You may want to practice teaching it to each other within your group.

Figure 3 is from a paper published by University of Montana and U.S. Forest Service scientists in the scientific journal *Ecology Letters* in 2006. The researchers studied populations of knapweed (in low and high densities). One of the objectives of their study was to compare the numbers of mice in low densities of knapweed (where it was <2% of the vegetation) to high densities of knapweed (where it was >20% of the vegetation). They wanted to know if more knapweed means more mice. The researchers also wanted to know if these mice were *seropositive* (which means they are carriers of Hantavirus, a potentially deadly disease in humans), how many mice were seropositive, and what proportion of the mice were seropositive in the different densities of knapweed. The results of their study are an important piece in the ecological puzzle you will be putting together to understand the unplanned effects of an introduced biological control agent.

Gall flies (*Urophora* species) were introduced to control populations of the invasive spotted knapweed, *Centaurea maculosa* This species of knapweed has spread throughout the western United States and can cause many problems on rangelands and in natural areas. The biocontrol agents successfully reduced seed production of the knapweed, but not enough to effectively control populations of knapweed. However, the introduced gall flies, because knapweed still exists, continue to persist and have indirect effects on food webs and can potentially indirectly affect human health.

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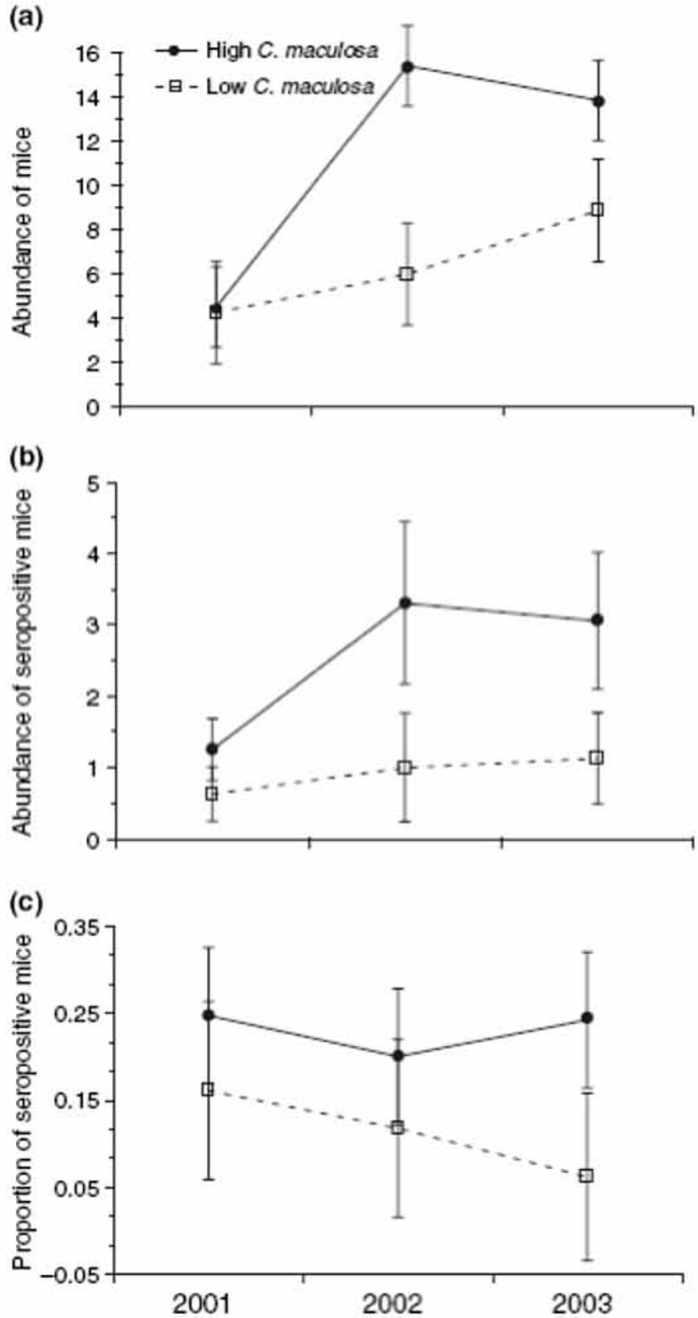

Figure 3. Data on deer mice populations in three years in areas of high knapweed density (solid circles) and low density of knapweed (open squares). (a) Abundance of deer mice. (b) Abundance of seropositive mice (mice that are carriers of hantavirus). (c) Proportion of deer mice captured that were seropositive (From Pearson, D.E. and Callaway, R.M. 2006. Biological control agents elevate hantavirus by subsidizing deer mouse populations. *Ecology Letters* 9: 443-450.)