Food Webs, Energy Flow, Carbon Cycle, and Trophic Pyramids

I. Wolves in Yellowstone National Park

In the early twentieth century, humans eliminated wolves from Yellowstone. In the late twentieth century, humans brought wolves back to Yellowstone. How did these changes in the wolf population affect other animals and plants in Yellowstone? To answer this question, watch The Habitable Planet, Ecosystems, Unit 4 (http://www.learner.org/courses/envsci/unit/text.php?unit=4&secNum=1), beginning at 13 minutes and 40 seconds and ending at 22 minutes and 37 seconds.

These graphs summarize recent trends in the numbers of wolves and elk in the Northern Range in Yellowstone.

1. Why did the number of elk decrease after 1995?

2a. What was the maximum population size for wolves?

2b. What was the minimum population size for elk?

2c. Notice that the number of wolves is much lower than the number of elk. What is one possible explanation for this difference?

3. After 1995, the growth of willows increased in some parts of Yellowstone. What is one possible explanation for this trend?

We will return to these questions after you have learned more about food webs and trophic pyramids. **Trophic** refers to eating or nutrition.
II. Food Chains and Food Webs

A food chain summarizes a sequence of trophic relationships within an ecosystem. For example, in this diagram of a food chain, secondary consumers eat primary consumers which eat producers (plants).

4. Fill in the blank food chain with a Yellowstone example from the video.

There is another type of food chain that doesn’t begin with living plants.

5. Think about a forest where trees lose their leaves each fall and trees sometimes die. What happens to the dead leaves and trees?

Decomposers get their nutrition from dead organic matter. Decomposers include bacteria and fungi (e.g. mushrooms) which secrete digestive enzymes and absorb digested molecules from the dead organic matter.

This flowchart shows a food chain that begins with dead organic matter, with an example from Yellowstone.

6. If you visited Yellowstone, you would not notice this food chain. Why not?

7. Match each item in the top list with the best match or matches from the bottom list.

Producer ___
Primary consumer ___ ___
Secondary consumer ___ ___

a. an organism that consumes primary consumers
b. an organism that consumes producers
c. an organism that makes its own organic molecules from small inorganic molecules (e.g. uses photosynthesis to make sugars from CO₂ and H₂O)
d. includes some carnivores and Protista
e. includes herbivores
In real biological communities, the trophic relationships are much more complex than a simple food chain. These more complex trophic relationships are summarized in a **food web**.

This figure shows a small part of a food web. Notice that the food web contains multiple food chains.

8. Use asterisks to mark the organisms in one food chain in this food web.

Most of the organisms in this food web can be classified in one of these **trophic levels**:
- producers
- primary consumers
- secondary consumers.

However, not all organisms fit in a single trophic level. You may have heard of omnivores which eat both plants and animals. A more general category is a **trophic omnivore** which is any animal that eats organisms from more than one trophic level.

9. Match each item in the list on the left with the best matches from the list on the right.

Producer ___ ___
- a. deer
- b. frog
- c. grasses
- d. hawk

Primary consumer ___ ___
- a. deer
- b. frog
- c. grasses
- d. hawk

Secondary consumer ___ ___
- a. deer
- b. frog
- c. grasses
- d. hawk

Trophic omnivore ___
- a. deer
- b. frog
- c. grasses
- d. hawk

Your teacher will give you a deck of cards that you will use to make a Yellowstone food web. **Complete each step** in the procedure and check the box before beginning the next step.

A. To begin, draw the boxes in this chart on your lab table or on the large paper provided by your teacher. Each box should be big enough for the number of cards shown. Be sure to leave space for trophic omnivores between the two sets of boxes.

<table>
<thead>
<tr>
<th>Secondary Consumers (2 cards)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposers (2 cards)</td>
</tr>
<tr>
<td>Dead Organic Matter (1 card)</td>
</tr>
</tbody>
</table>

B. Find the cards for the producers and dead organic matter in your Yellowstone deck. Put these cards in the appropriate boxes.

C. Find the cards for the primary consumers (which eat only producers) and the decomposers (which consume only dead organic matter). Put these cards in their boxes. Draw an arrow to show each trophic relationship listed on the cards.
D. Use the remaining cards to put the secondary consumers in their box and the trophic omnivores in appropriate places outside the boxes. (Any animal that eats trophic omnivores is also a trophic omnivore. Yellowstone wolves are trophic omnivores, since they eat coyotes as well as primary consumers.) Draw an arrow to show each trophic relationship.

10. After your teacher has checked and approved your food web, draw a diagram of the food web on a separate sheet of paper. Include the categories, organisms’ names, and the arrows.

11. Some scientists distinguish between a green food web that begins with producers and a brown food web that begins with dead organic matter. In your Yellowstone food web, draw a circle around the brown food web. (Do not include organisms that are part of both the brown and green food webs (e.g. robins).)

Your Yellowstone food web may look complex, but a complete Yellowstone food web would be much more complex. Many more types of organisms live in Yellowstone, including more than 1000 different kinds of plants and more than 1000 different kinds of insects.

12. Humans are also part of the Yellowstone food web, since human hunters kill thousands of elk when they migrate out of Yellowstone Park during the colder months. Add humans to your food web.

Most organisms have more trophic relationships than the few that are shown on each card. Also, some of the trophic relationships shown are much more important than others. For example, Yellowstone wolves eat many elk and few beavers.

13. Make the arrow from elk to wolves fatter to represent the importance of this trophic relationship.

Even though your food web is incomplete, it can help you to predict and understand important ecological phenomena.

A trophic cascade occurs when a change in the population of a predator not only affects its prey population, but also has indirect effects on another population in the ecosystem. In this flowchart, each arrow represents a negative effect of one population on the size of another population.

14a. Fill in the blanks, using the example from page 1.

14b. Draw a curved arrow with a (+) to show the indirect effect of predators in this trophic cascade.

15. Explain how changes in the wolf population could produce these trends in the number of beaver colonies.
   - After wolves were eliminated from Yellowstone, the number of beaver colonies decreased.
   - After wolves were reintroduced to Yellowstone, the number of beaver colonies increased.
   (Hint: Beavers use tall willows for food and building dams.)
II. Carbon Cycle and Energy Flow

16. The main types of molecules in your body are water and carbon-containing organic molecules. To continue to live, you need to consume organic molecules in your food. What does your body use these organic molecules for?

17. The biosphere, with all of the Earth’s organisms, receives a continuous inflow of energy from the sun. In contrast, the biosphere does not receive an inflow of carbon atoms. What are some possible reasons why life in the biosphere needs an inflow of energy, but does not need an inflow of carbon atoms?

To better understand why the biosphere needs an inflow of energy, but does not need an inflow of carbon atoms, we will begin by reviewing several biological processes that transform energy and carbon-containing molecules.

**Photosynthesis**
Plant cells use the energy from sunlight to make sugar molecules from CO$_2$ and H$_2$O.

![Chemical equation]

The upper box shows changes in how the atoms are organized in molecules, and the lower box shows the associated energy changes.

18. Circle the organic molecule, glucose, which is produced by photosynthesis.

19. Use photosynthesis as an example to illustrate each of these general principles.

<table>
<thead>
<tr>
<th>General Principle</th>
<th>How Photosynthesis Illustrates this General Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matter (atoms) are neither created nor destroyed in biological processes.</td>
<td></td>
</tr>
<tr>
<td>Energy is neither created nor destroyed in biological processes, but energy can be transformed from one type to another.</td>
<td></td>
</tr>
<tr>
<td>During energy transfers and transformations, some of the input energy is transformed to heat energy.</td>
<td></td>
</tr>
</tbody>
</table>

**Cellular Respiration**
Some of the sugar molecules produced by photosynthesis are used for cellular respiration.

![Chemical equation]

20. The main function of cellular respiration is to produce ATP. Why do cells need ATP?
Biosynthesis
Some of the sugar molecules produced by photosynthesis are used for biosynthesis, which produces all the different organic molecules that make up an organism. For example, multiple glucose molecules are combined to make the polymer cellulose, which is used to make plant cell walls.

These biological processes result in the carbon cycle, where carbon atoms cycle between CO$_2$ in the air and organic molecules in living organisms or dead organic matter.

21a. The B arrow shows CO$_2$ entering a plant. How do the carbon atoms in CO$_2$ become carbon atoms in organic molecules in the plant?

21b. The A arrows show CO$_2$ leaving plants, animals and decomposers. How do the carbon atoms in the organic molecules of plants, animals and decomposers become carbon atoms in CO$_2$?

22. Explain how carbon atoms in organic molecules in a plant can become carbon atoms in organic molecules in an animal.

23a. The C arrow shows defecation and/or death. Add another C arrow to show part or all of the plant dying and becoming available to decomposers.

23b. What problems would occur if there were no decomposers?

24. Explain how a carbon atom in a giraffe could eventually end up as a carbon atom in a tree.
In this figure, energy flows (represented by the dashed arrows) have been added to the carbon cycle.

25a. To describe the through-flow of energy, label each of the dashed arrows with one of these abbreviations:

- **SL** = the inflow of energy in the form of sunlight.
- **CE** = chemical energy moving from one trophic level to the next in the food web or moving from a living organism to dead organic matter.
- **HT** = for arrows that show that biological processes produce heat, which leaves the organisms and ultimately is radiated out to space.

25b. Draw a single, longer arrow that shows the through-flow of energy, beginning with sunlight entering the ecosystem and ending with heat leaving the ecosystem.

26. How can the sun’s energy be transformed to provide the energy that a giraffe uses to move? Be specific about the multiple steps that are required.

27a. Explain why life in the earth’s biosphere needs a continuous inflow of energy.

27b. How can life continue in the earth’s biosphere without an inflow of additional carbon atoms?

IV. Trophic Pyramids
The average American consumes almost 2000 pounds of food each year. Obviously, we do not gain 2000 pounds of weight each year!

**28a.** What happens to all the weight of the food we eat? Where do the atoms in the food molecules go?

**28b.** The **biomass** of an organism is the mass of all the organic molecules in the organism. A person gains weight if his rate of biomass production is greater than zero. Describe two factors that can increase a person’s rate of biomass production.

Researchers have analyzed the rate of biomass production at different trophic levels in a forest food web in New Hampshire. Comparing all the producers in the forest combined vs. all the primary consumers combined, the rate of biomass production was much lower for the primary consumers.

![Flowchart showing biomass production](image)

**29a.** Add to the above flowchart to show two reasons why the rate of biomass production was smaller for primary consumers than for producers. (Hint: See the figure on the top of this page.)

**29b.** There is another important reason why the primary consumers had a lower rate of biomass production. Most of the biomass produced by producers was not eaten by the primary consumers. Instead, most of this biomass became dead organic matter (e.g. dead leaves), which was consumed by decomposers (e.g. fungi and bacteria). Add these observations to the above flowchart.

The graph below shows that the rate of biomass production for the producers in the forest was five times bigger than the rate of biomass production for the primary consumers plus decomposers (1000 vs. 200 g/m²/year).

![Graph showing biomass production](image)

**30.** Draw a bar that shows the rate of biomass production that you would expect for secondary consumers, and explain your reasoning.
The information in the graph you just completed is often displayed in a trophic pyramid like this one. (Tertiary consumers eat secondary consumers. Each trophic omnivore is classified in a consumer level, based on the main type of food they eat.)

31a. Scientists sometimes use the general estimate that the rate of biomass production at one trophic level is ~10% of the rate of biomass production at the just lower trophic level. If the primary consumers have only 10% as much biomass production as the producers, what happened to the other 90% of biomass produced by the producers?

31b. Use the 10% estimate to calculate the rate of biomass production at each consumer trophic level in the above trophic pyramid.

32a. Some trophic pyramids show the relative numbers of organisms at each trophic level. Based on the trophic relationship between wolves and elk in Yellowstone, which would you expect?
   a. approximately 10 times as many elk as wolves
   b. approximately the same number of elk and wolves
   c. approximately 10 times as many wolves as elk

32b. In Yellowstone during the 21st century, there have been roughly 100 times as many elk as wolves. What is one possible reason why there is only one wolf for every 100 elk, instead of one wolf for every 10 elk? (Hint: Check your Yellowstone food web.)

33a. Erin and Pat each had a lunch with a similar amount of biomass. Erin had a hamburger and Pat had a baked potato, so they were consuming biomass from different trophic levels. In comparison to the amount of land required to produce Pat’s potato, how much land do you think is required to produce Erin’s hamburger?
   a. 10% as much land to produce the hamburger
   b. the same amount of land to produce the hamburger and the potato
   c. 10 times as much land to produce the hamburger

33b. Explain the reasoning that supports your answer.