Teacher Preparation Notes for "Food Webs –
How did the elimination and return of wolves affect other populations in Yellowstone?" [1]

To begin this hands-on, minds-on activity, students view a video about ecosystem changes that resulted when wolves were eliminated from Yellowstone National Park and later returned to Yellowstone. Then, students learn about food chains and food webs, and they construct and analyze a food web for Yellowstone. Finally, students use what they have learned to understand a trophic cascade caused by the elimination of wolves from Yellowstone.

This activity can be used for classroom instruction or remote learning. (See page 2. If you are providing your students with the cards for the food web, then you can omit pages 5-7 from the Student Handout.) This learning activity provides an introduction to the learning activities, Carbon Cycles and Energy Flow through Ecosystems and the Biosphere and Trophic Pyramids. All three of these activities are included in Food Webs, Energy Flow, Carbon Cycle and Trophic Pyramids, which is intended for classroom instruction.

Learning Goals

Learning Goals related to Next Generation Science Standards[2]

Students will gain understanding of Disciplinary Core Ideas

- LS2.B, Cycles of Matter and Energy Transfer in Ecosystems: "Food webs are models that demonstrate how matter and energy is transferred between producers, consumers and decomposers as the three groups interact within an ecosystem."
- LS2.C, Ecosystem Dynamics, Functioning, and Resilience: "A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions.… Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability."

Students will engage in Scientific Practices:

- "Constructing Explanations – Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena…"
- "Developing and Using Models – Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of the system."

This activity will help students understand the Crosscutting Concept, "Stability and Change: Much of science deals with constructing explanations of how things change and how they remain stable."

This activity will help to prepare students for the Performance Expectation, HS-LS2-2. "Use mathematical representations to support and revise explanations based on evidence about factors affecting… populations in ecosystems of different scales."

Additional Content Learning Goals

- A **producer** is an organism that produces all of its organic molecules from small inorganic molecules. A **consumer** is an organism that consumes organic molecules produced by other organisms. Consumers can be categorized as (1) **primary consumers** which eat producers, (2) **decomposers** which consume dead organic matter, (3) **secondary consumers** which eat

[1] By Drs. Ingrid Waldron and Lori Spindler, Department of Biology, University of Pennsylvania. © 2024. The Student Handouts and these Teacher Preparation Notes are available at https://serendipstudio.org/exchange/bioactivities/foodwebRR.
[2] Quotations are from http://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf

primary consumers and/or decomposers, or (4) **trophic omnivores** which eat organisms at more than one trophic level.

- In a **trophic relationship** one organism consumes organic molecules from another organism (or a decomposer consumes organic molecules from dead organic matter). A **food chain** shows a simple sequence of trophic relationships (e.g. producer → primary consumer → secondary consumer). A **food web** shows the multiple, complex trophic relationships among organisms in an ecosystem.
- Decomposers are crucial to prevent excessive accumulation of dead organic matter.
- Understanding a food web can help us to understand how changes in the population size of one organism can influence the population size of another organism in an ecosystem. For example, a **trophic cascade** can occur when a decrease in a predator population results in an increase in an herbivore population which in turn results in decreased plant growth.

Supplies for your students to make the Yellowstone food web

If your students are doing the activity in your classroom, you will need the following for each group of 2-4 students:

- a deck of 18 cards for a partial Yellowstone food web (to be reused in each class, so you will need a deck of cards for each student group in your largest class) Or students can use pages 5-7 of the Student Handout to cut out the cards themselves.
  - If you will supply the cards, then pages 5-7 can be omitted from the Student Handout.
  - We recommend that you print the cards on card stock and/or laminate these cards for durability. Before you laminate the cards, we recommend that you use markers to mark the edges of each deck with a different color stripe to help you keep track of which cards belong in which deck.
  - A PDF file suitable for professional printing and cutting of cards is available at https://serendipstudio.org/exchange/bioactivities/foodwebRR.[3]
- a lab table or other surface ~1.5 feet wide by 2 feet tall (~45 x 60 cm) which students can write on with chalk or dry erase marker as they create their food web or a large piece of paper (e.g. from an easel pad) or poster board.[4]
- if students are writing on lab tables, chalk or a dry erase marker to draw rectangles and arrows.

If your students are learning online, you can use either of the following options:

- If your students have printers at home, they can print pages 5-7 of the Student Handout and cut the cards.
- If your students do not have printers, you will want to use the "remote no printer" version of the Student Handout, available at https://serendipstudio.org/exchange/bioactivities/foodwebRR.

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[3] The corrected dimensions of beetles have not been incorporated in the PDF for printing (due to my technical limitations). We are grateful to Craig Douglas (http://www.douglasanimation.com/) for his help with preparing the cards and the PDF.

[4] If it is not feasible for you to provide such a large surface for students to write on, you can provide each student group with a reusable card stock or poster board set of the rectangles described in the chart on the bottom of page 3 of the Student Handout; if you are using this approach, we recommend that you provide masking tape or thin strips of paper of varying length that students can use to draw arrows (one set of 27 for each student group in your largest class, plus a few extras in case some are damaged).

Instructional Suggestions and Background Information

In the Student Handout, numbers in bold indicate questions for the students to answer and capital letters in bold indicate steps for students to do as they model the Yellowstone food web.

To maximize student learning, we recommend that you have your students work in groups of 2-4 students to answer a group of related questions or construct the food web.[5] After students have worked together to make the food web or answer a group of related questions, we recommend having a class discussion that probes student thinking and helps students to develop a sound understanding of the concepts and information covered.

If your students are learning online, we recommend that they use either of the Google Doc versions of the Student Handout, available at https://serendipstudio.org/exchange/bioactivities/foodwebRR. To answer questions 4, 8-9, and 12, students can either print the relevant pages, draw on those and send you pictures, or they will need to know how to modify a drawing online.[6] They can double-click on the relevant drawing in the Google Doc, which will open a drawing window. Then, they can use the editing tools to add shapes and text boxes.

You may want to revise the Word or GoogleDoc documents to prepare a version of the Student Handout that may be more suitable for your students. If you use the Word document, please check the format by viewing the PDF.

A key for this activity is available upon request to Ingrid Waldron (iwaldron@upenn.edu). The following paragraphs provide additional instructional suggestions and background biology information – some for inclusion in your class discussions and some to provide you with relevant background that may be useful for your understanding and/or for responding to student questions.

Wolves in Yellowstone National Park

The recommended part of the "Ecosystems Video" (https://www.learner.org/series/the-habitable-planet-a-systems-approach-to-environmental-science/ecosystems/ecosystems-video/) should engage student interest and introduce your students to the Yellowstone ecosystem.[7] The part on Yellowstone begins at 13 minutes and 40 seconds. We recommend that you end at 22 minutes because the rest of the video includes statements that have been contradicted by recent research. The speculation that the mere presence of wolves might discourage willow consumption has not been supported by empirical evidence (https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/08-2017.1). The reintroduction of wolves to Yellowstone has only resulted in increased willow growth in scattered spots, but not generally. One reason is that, as elk have become less numerous, bison have become more numerous, and bison also eat willows. Another reason appears to be that the earlier decrease in beaver colonies has lowered the water table in many places, and a lower water table is less

[5] Student learning is increased when students discuss scientific concepts to develop answers to challenging questions; students who actively contribute to the development of conceptual understanding and question answers gain the most (https://education.asu.edu/sites/default/files/the_role_of_collaborative_interactions_versus_individual_construction_on_students_learning_of_engineering_concepts.pdf).

[6] If you are using the "no printer" version of the Student Handout, then students will also need to be able to write on the chart in procedure A for making the food web.

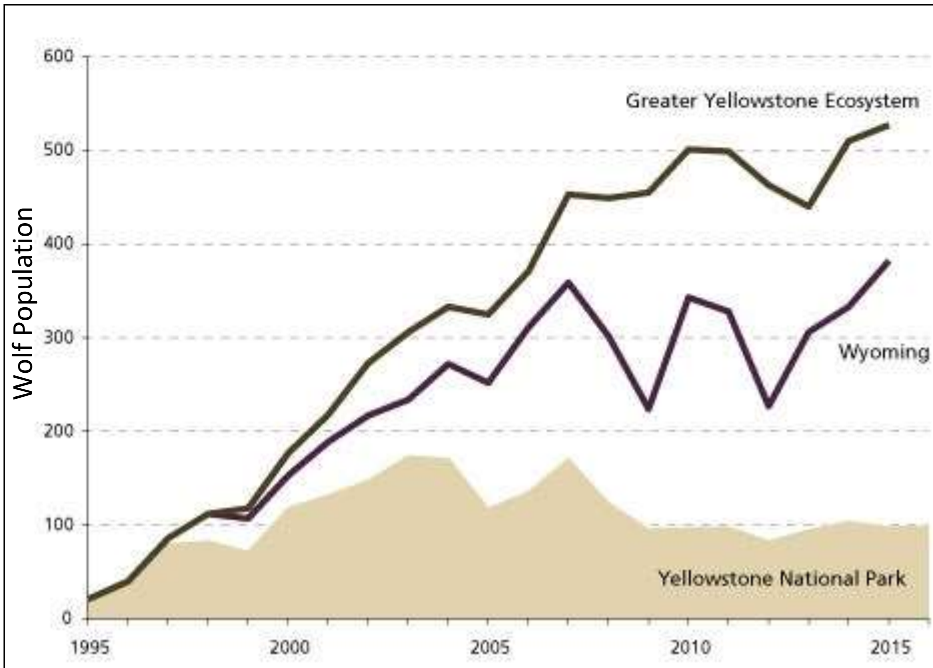
[7] You may be attracted to the video "Wolves of Yellowstone", but we recommend that you not use this video because many of the statements that are presented as fact in this video are actually quite speculative.

favorable for willow growth. It appears that there are two alternative stable states, one dominated by elk and grassland and the other with more beavers and willow, and the reintroduction of wolves has not been sufficient to cause the elk-grassland state to switch to the beaver-willow state. (https://esajournals.onlinelibrary.wiley.com/doi/epdf/10.1002/ecm.1598)

Yellowstone National Park includes ~3500 square miles, mainly in Wyoming. The park includes a variety of habitats, including forests, grasslands, and aquatic habitats.

Questions 1-3 are intended to start students thinking about phenomena that will be revisited in the rest of the activity. As your students discuss their answers to these questions, you can guide them to ask questions and formulate hypotheses that will set the stage for what follows.

The graph on page 1 of the Student Handout shows trends in wolf and elk populations in the Northern Range in Yellowstone National Park where many elk and wolves spend the winter. This graph shows trends in number of wolves for Yellowstone National Park and for larger areas.



(https://www.nps.gov/yell/learn/nature/wolves.htm)

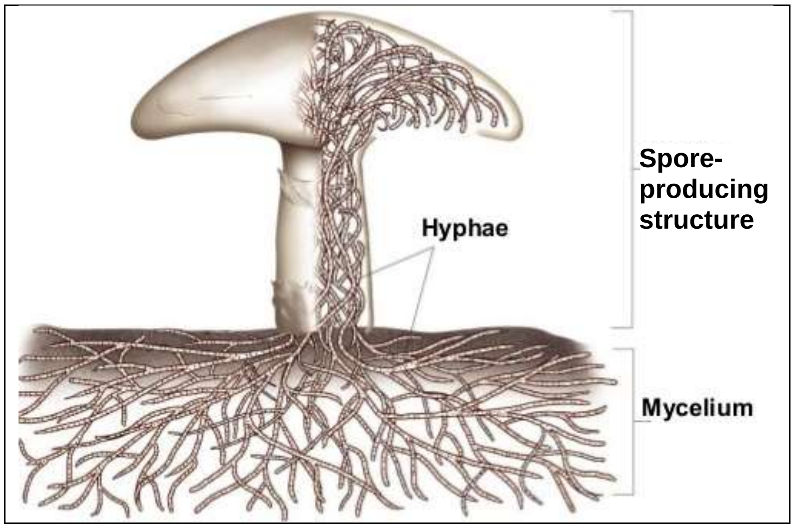
Food Chains and Food Webs

Your students should understand that, in food chains and food webs, the arrows point from the organism that is consumed to the organism that consumes. In other words, the arrows show the direction of flow of nutrition.

We use the term producer for organisms that use energy from sunlight to make their organic molecules (e.g. plants).[8] We use the term consumer for organisms that eat other organisms.

Scavengers such as coyotes, bears, ravens, and eagles feed on carrion such as the remains of an elk killed by a wolf pack. Detritivores such as earthworms and termites ingest dead organic matter, extract nutrition, and excrete smaller particles which decomposers can more readily digest. Decomposers such as bacteria and fungi release enzymes into dead organic matter; these enzymes digest complex organic molecules into smaller soluble molecules that are absorbed by the decomposers. Dead stuff doesn't accumulate on the forest floor because scavengers, detritivores, and decomposers consume the dead organic matter and ultimately the digested molecules return to the soil or air (see https://serendipstudio.org/exchange/bioactivities/carboncycle). An entertaining and informative 4-minute video, "Dead Stuff: The Secret Ingredient in Our Food Chain" (https://www.youtube.com/watch?v=KI7u_pcfAQE), summarizes some of this information and introduces food chains and food webs. You may want to show this video during your discussion of student answers to question 5.

If your students are not familiar with fungi, you may want to introduce them to the basic structure of the mycelium (a network of hyphae in the soil, rotting log, or other organic matter) and an above-ground structure that produces spores (e.g. a mushroom). The hyphae in the mycelium secrete digestive enzymes and absorb nutrients.



(http://image.slidesharecdn.com/funginotes-131009165742-phpapp02/95/fungi-notes-4-638.jpg?cb=1381337957)

The trophic omnivore category includes the more familiar category of omnivores (animals that eat both plants and animals).[9] The trophic omnivore category is broader and includes any organism that consumes organisms at more than one trophic level (e.g. a carnivore that consumes both primary and secondary consumers). An animal that eats a trophic omnivore is also a trophic omnivore. To understand why, consider a trophic omnivore that eats producers and primary consumers; this trophic omnivore can be considered to be both a primary consumer and a secondary consumer; therefore, an animal that consumes this trophic omnivore is consuming from two different trophic levels, so it is also considered to be a trophic omnivore. To stimulate your students to think about this issue, you can include the following question in the Student Handout.

9a. Why is an animal that eats trophic omnivores also categorized as a trophic omnivore?

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[8] In addition to producers that use sunlight as their energy source, there are producers in deep-sea hydrothermal vents and iron-rich rocks deep below the earth's surface that use chemical energy contained in compounds such as ammonia or hydrogen sulfide.
Producers are autotrophs. Consumers are heterotrophs. If you want, you can easily include the terms, autotroph and heterotroph, in the Student Handout.

[9] You are no doubt aware that, despite the name, an omnivore doesn't eat everything.

Trophic Relationships in Yellowstone

The Latin names for the animals and plants included in the Yellowstone National Park food web are as follows:

American Robin – *Turdus migratorius*
Beaver – *Castor canadensis*
Coyote – *Canis latrans*
Deer mice – *Peromyscus maniculatus*
Earthworm – *Lumbricina* spp.
Elk – *Cervus elaphus*
Gray Wolf – *Canis lupus*
Grizzly bear – *Ursus arctos*
Willow – *Salix* spp.

As your students begin to construct their Yellowstone food webs, you may want to point out that the cards include not only the trophic relationships for the organism, but also a general estimate of the size range (length) of the organism. We have used the more familiar term "eat" for most of the cards, but for bacteria and fungi we have used the term "consume" since these organisms do not ingest dead organic matter, but rather secrete enzymes into the environment and then absorb digested nutrient molecules.

To make an accurate food web in a reasonable amount of time, it is important for your students to complete each step in the procedure and check it off before proceeding to the next step. You may need to remind students that a primary consumer eats only producers and a secondary consumer eats only primary consumers and/or decomposers; consumers which consume food from more than one trophic level are trophic omnivores. The chart on the bottom of page 3 of the Student Handout provides both a helpful organization and hints for making the food web.

The Yellowstone food web includes both a green food web that begins with producers and a brown food web that begins with dead organic matter.[10] This is an example of the general principle that the Yellowstone food web is made up of many interrelated sub-webs. For example, sub-webs can be identified in different habitats, e.g., in the soil; above-ground in grassland or forest; in rivers, streams or ponds; or in the adjacent riparian ecosystems.

After your students have made their initial attempt to create the Yellowstone food web, if there are discrepancies between their food web and the food web shown in the key (available upon request to iwaldron@upenn.edu), you may want to ask questions that call your students' attention to information on the cards that they can use to make a more accurate food web.

To make a manageable food web for the students to construct, we have made multiple simplifications. As discussed on page 4 of the Student Handout, we have omitted most of the types of organisms found in Yellowstone National Park; we have omitted many of the trophic relationships for the organisms included in this activity; and we have not distinguished between more important and less important trophic relationships. Additional complexities include the following.

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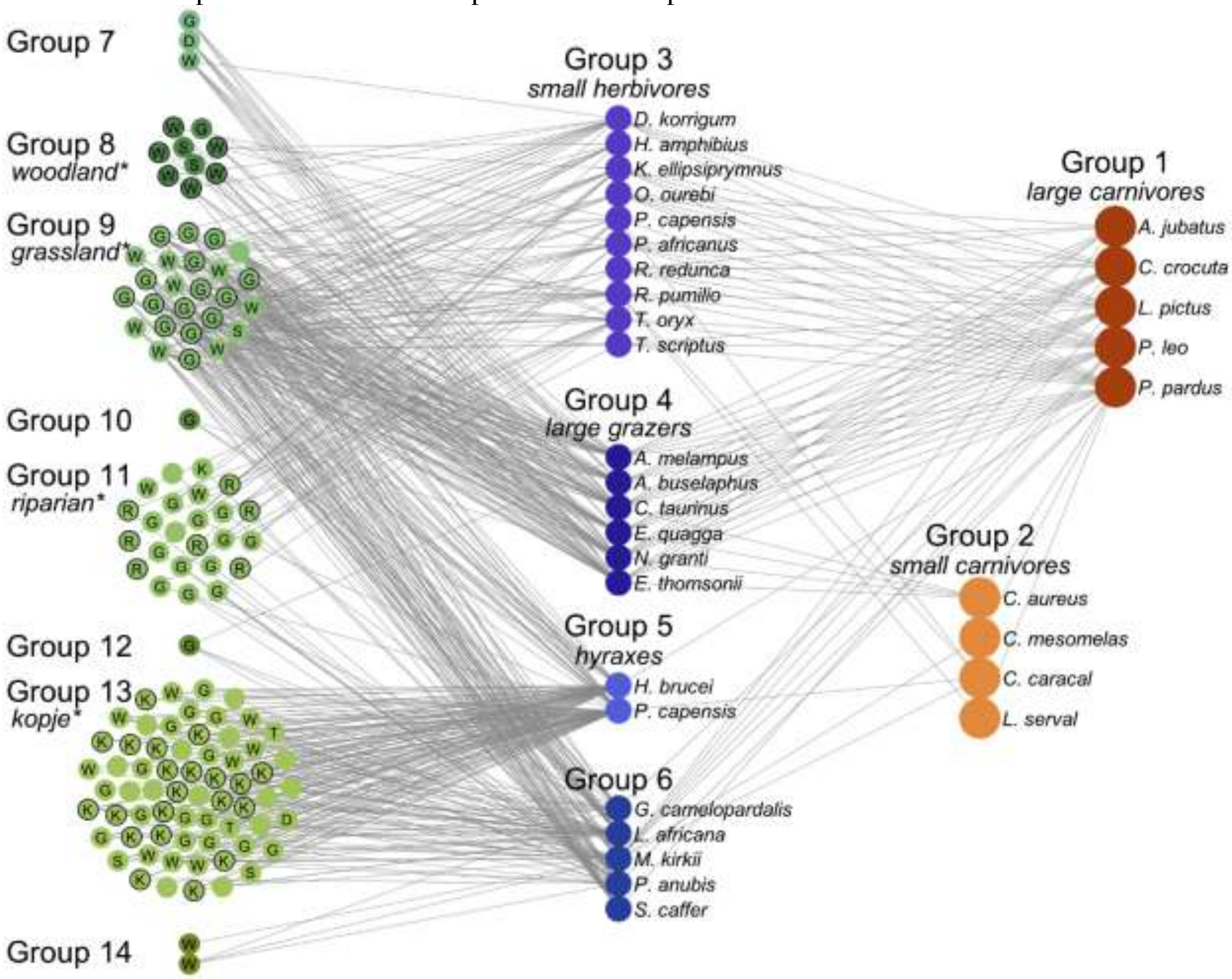
[10] American robins belong to both the green and brown food webs. Your students should notice the tiny size of most of the organisms in the brown food web.

- We have not distinguished between the many different types of fungi, Protista, nematodes, mites, grasses, or "other flowering plants" in Yellowstone. Consequently, we have omitted mention of the different trophic relationships for different species within each of these groups.
- Many types of animals consume different types of food at different times of year and/or at different life stages.
- None of the many parasites present in any biological community have been included.
- Humans are an important part of the Yellowstone food web. Although hunting is not permitted in Yellowstone National Park, many Yellowstone elk are killed by human hunters when they migrate out of the park during the winter. Human hunters killed roughly 25,000 elk per year in Wyoming, compared to roughly 10,000 elk per year killed by the ~500 wolves living in the greater Yellowstone ecosystem (https://www.wyofile.com/many-elk-yellowstone-wolves-eat/).

All or almost all published food webs are incomplete, since it is virtually impossible to research and describe all the many species and trophic relationships in real biological food webs. For example, one analysis of a plant-mammal food web for the Serengeti ecosystem included 129 species of plants and 32 species of mammals, but excluded many other mammals, reptiles, amphibians, birds, invertebrates and decomposers. The Serengeti food web in the figure below illustrates one way to organize complex food web data by grouping species according to similarities in spatial location and trophic relationships.



(http://journals.plos.org/ploscompbiol/article/figure/image?size=large&id=info:doi/10.1371/journal.pcbi.1002321.g003)

Top-down control occurs when population size at a higher trophic level influences population size at a lower trophic level. An example of top-down control of population size is the trophic cascade from wolves to elk to willows (see pages 1 and 4 of the Student Handout). Bottom-up control occurs when the population size at a trophic level is influenced by the rate of production of its food source (or the producers' population size is influenced by the availability of resources needed for growth). An example of bottom-up control is the effect of willow availability on beaver population size.[11]

For question 13, the changing availability of taller willows is believed to be one important reason for the mid-twentieth century decrease and recent increase in number of beaver colonies (http://www.bioone.org/doi/abs/10.3955/046.086.0404). The presence of a beaver colony often fosters greater willow growth by raising the water table. Thus, beavers and willows have a mutually beneficial relationship, known as mutualism. The recovery of willows in some parts of Yellowstone, but not in others, appears to be due in part to insufficient soil moisture in many places in the absence of beaver dams. Thus, in order to recover, willows need beavers and beavers need willows; this creates a "catch 22" that appears to have slowed recovery of both willows and beavers after wolves were reintroduced to Yellowstone. If you want your students to learn more about trophic cascades and keystone predators, we recommend the video "Some Animals Are More Equal Than Others: Keystone Species and Trophic Cascades" (http://www.hhmi.org/biointeractive/some-animals-are-more-equal-others-keystone-species-and-trophic-cascades).

Recommended Follow-Up Activities

Carbon Cycles and Energy Flow through Ecosystems and the Biosphere
https://serendipstudio.org/exchange/bioactivities/carboncycle
In this analysis and discussion activity, students learn that the biosphere requires a continuous inflow of energy, but does not need an inflow of carbon atoms. To understand why, students apply fundamental principles of physics to photosynthesis, biosynthesis, and cellular respiration, the processes which are responsible for carbon cycles and energy flow through ecosystems. Thus, students learn how ecological phenomena result from processes at the molecular, cellular and organismal levels. (This activity supports the NGSS.)

Trophic Pyramids
https://serendipstudio.org/exchange/bioactivities/trophicpyr
In this analysis and discussion activity, students discover the reasons why (in many ecosystems) plants are more common than primary consumers, which in turn are more common than secondary consumers. To begin, they learn about net rate of biomass production and the factors that influence it. Then, they figure out why the net rate of biomass production is lower for each higher trophic level in an ecosystem. Then, students construct and analyze trophic pyramids. Finally, they apply what they have learned to understanding why more resources are needed to produce meat than to produce an equivalent amount of plant food. (This activity supports the NGSS.)

You may also want to encourage your students to research related topics such as:

- aquatic food webs
- eutrophication as an example of bottom-up regulation

[11] Another example of bottom-up control occurred when the very severe winter of 1996-97 (when ice over snow prevented access to grass and other forage for elk) resulted in high elk mortality.

- other topics that students may ask about during the activity.

These research projects can be used to engage your students in the NGSS-recommended science practice of "Obtaining, Evaluating, and Communicating Information" (https://www.nextgenscience.org/sites/default/files/Appendix%20F%20%20Science%20and%20Engineering%20Practices%20in%20the%20NGSS%20-%20FINAL%20060513.pdf). To help your students evaluate which sources to use, you can distribute the last page of these Teacher Notes and ask students to follow the listed procedures to evaluate each source.

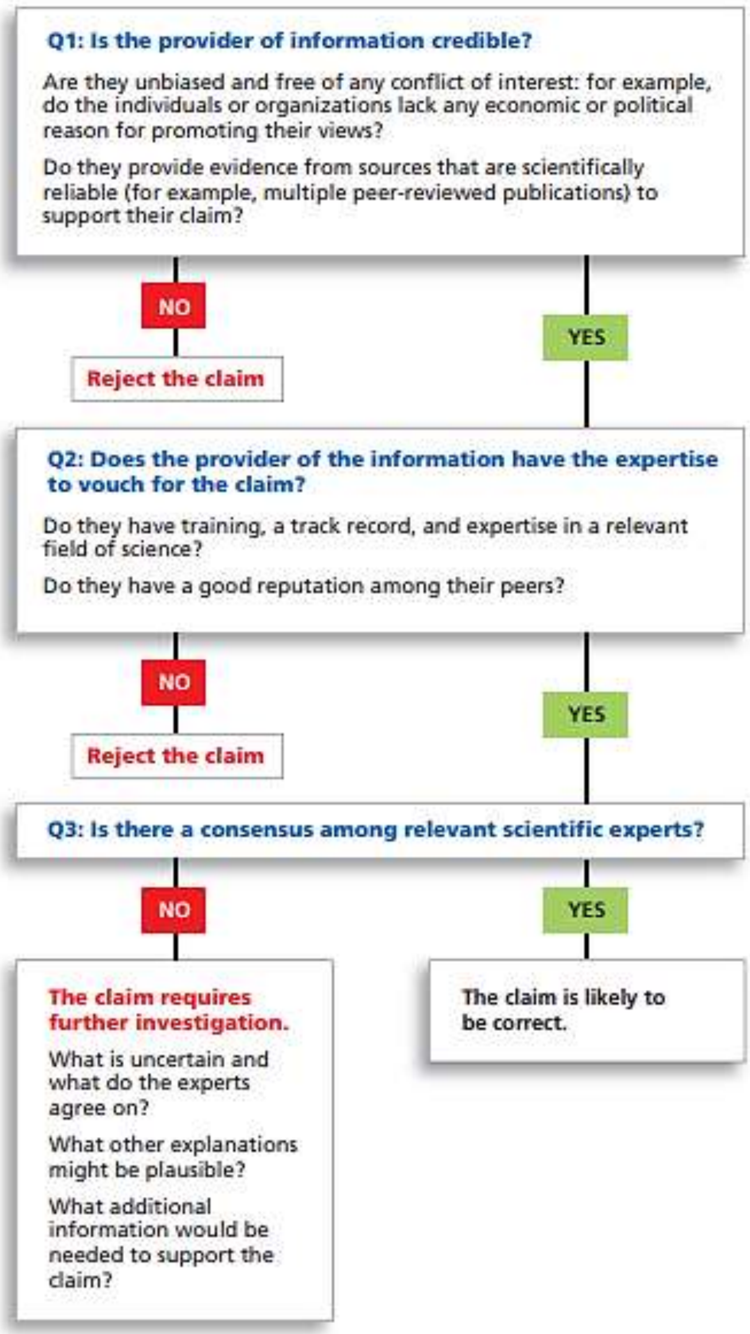
One problem that we have encountered is that some students tend to copy information from their sources without understanding the material well enough to put it in their own words. To avoid this problem, you can encourage your students to follow these guidelines.

1. Use online dictionaries to find the meaning of any unfamiliar technical terms. Reread the original passage until you understand its full meaning.
2. Put the original where you can't see it, and write the main points you remember in a document in a word processing program or on a note card.
3. Check your version with the original to make sure that your version accurately expresses all the essential information in your own words.
4. Use quotation marks to identify any unique term or phraseology you have borrowed exactly from the source.
5. Record the source (including the page number) in your document or note card so that you can credit it easily if you decide to incorporate the material in your paper.

Sources for Figures in Student Handout (Other figures were made by the first author.)

- Trends in wolf and elk populations on page 1 – modified from "Riparian vegetation recovery in Yellowstone: The first two decades after wolf reintroduction" Biological Conservation 198: 93-103, 2016
- Food web on page 3 – http://www.biorewind.com/ecology/

Instructions for Evaluating Each Source

<table>
<tr><th>Rubric for Evaluating Sources[12]</th><th>Additional Points</th></tr>
<tr><td>


</td><td>
To find out whether sources may have a conflict of interest, use Wikipedia or fact-checking sources such as Snopes. Do not use “.org” as a sign of reliability. Be cautious about any source that uses emotional language.

Experts in one subject are often unreliable when they write about another subject.

What are the risks of accepting a claim that is ultimately proven to be wrong? What are the risks of not accepting a claim that is ultimately proven to be correct?
</td></tr>
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[12] This rubric is from https://sciedandmisinfo.stanford.edu/sites/g/files/sbiybj25316/files/media/file/why_trust_science-ecb.pdf.