

Teacher Notes for “Trophic Pyramids”¹

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 the factors that influence the net rate of biomass production. 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.

As background for this activity, we recommend these activities:

- “Food Webs –What effects did the elimination and return of wolves have on other populations in Yellowstone?” (https://serendipstudio.org/sci_edu/waldron/#foodweb)
- “Carbon Cycle and Energy Flow through Ecosystems and the Biosphere” (<https://serendipstudio.org/exchange/bioactivities/carboncycle>)

Learning Goals

Learning Goals related to Next Generation Science Standards²

Students will gain understanding of Disciplinary Core Idea LS2.B, Cycles of Matter and Energy Transfer in Ecosystems:

“Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web.³ Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.”

Students 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.”

Students will gain better understanding of the Crosscutting Concept, “Energy and Matter: Flows, Cycles and Conservation. Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of and within that system.”

This activity helps to prepare students for the Performance Expectation, HS-LS2-4. “Use a mathematical representation to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.”

¹ By Drs. Ingrid Waldron and Lori Spindler, Department of Biology, University of Pennsylvania. © 2024. The Student Handout and these Teacher Notes are available at <https://serendipstudio.org/exchange/bioactivities/trophicpyr>.

² Quotations are from <https://www.nextgenscience.org/> and <http://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf>

³ As discussed on page 3 of the Student Handout and page 4 of these Teacher Notes, the total biomass at each trophic level and the numbers of organisms at each trophic level often do not show a pyramid shape. However, the net rate of biomass production at each trophic level does consistently show a pyramid shape.

Additional Content Learning Goals

- The **biomass** of an organism is the mass of the organic molecules in the organism.
- The **net rate of biomass production** is highest for the producers in an ecosystem and smaller for each higher trophic level in the ecosystem. One major reason why is that many of the organic molecules that an animal eats are used for cellular respiration and thus are not available for biomass production.
- The reduction in the net rate of biomass production at higher trophic levels results in a **trophic pyramid**.
- One practical implication is that the amount of land needed to produce meat is about ten times greater than the amount of land needed to produce an equivalent biomass of plant food.

Instructional Suggestions and Background Information

To maximize student learning, we recommend that you have your students work in pairs to complete groups of related questions. 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). After students have worked together to 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 the Google Doc version of the Student Handout available at <https://serendipstudio.org/exchange/bioactivities/trophicpyr>. To answer questions 3-4, 5c and 6a, 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. 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 lines, shapes, and text boxes.

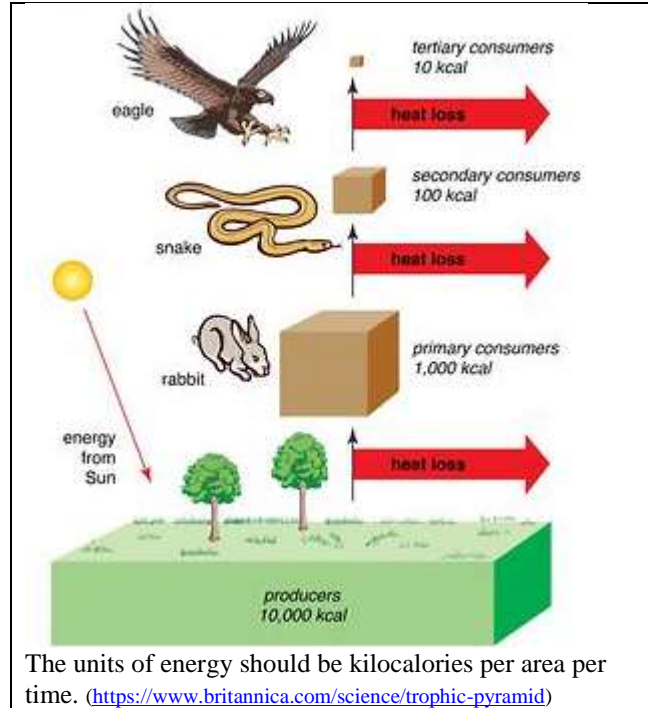
You may want to revise the Google Doc or Word document to prepare a version of the Student Handout that may be more suitable for your students. If you use the Word document, please check the format by viewing the PDF.

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.

Biomass is the mass of the organic molecules in an organism. Organic molecules and water are the main types of matter in most organisms, so biomass is often estimated by weighing a dried specimen.⁴

Trophic pyramids are also known as ecological pyramids. A trophic pyramid can be converted to an energy pyramid (see figure). Less energy is available at each higher trophic level, because each energy transformation or transfer results in heat, which is lost from the ecosystem and ultimately from the biosphere.

The flowcharts on page 1 of the Student Handout show how cellular respiration reduces the net rate of biomass production for producers and consumers. For consumers, the loss of indigestible food molecules in feces also reduces the net rate of biomass production.



Page 2 of the Student Handout discusses the net rate of biomass production at different trophic levels in a forest in New Hampshire (see table below).⁵ (Each trophic omnivore is classified in the consumer level of the main type of food they eat.)

Trophic Level	Net Rate of Biomass Production
Producers	1000 g/m ² /year
Primary Consumers and Decomposers	200 g/m ² /year
Secondary Consumers	30 g/m ² /year
Tertiary Consumers	3 g/m ² /year

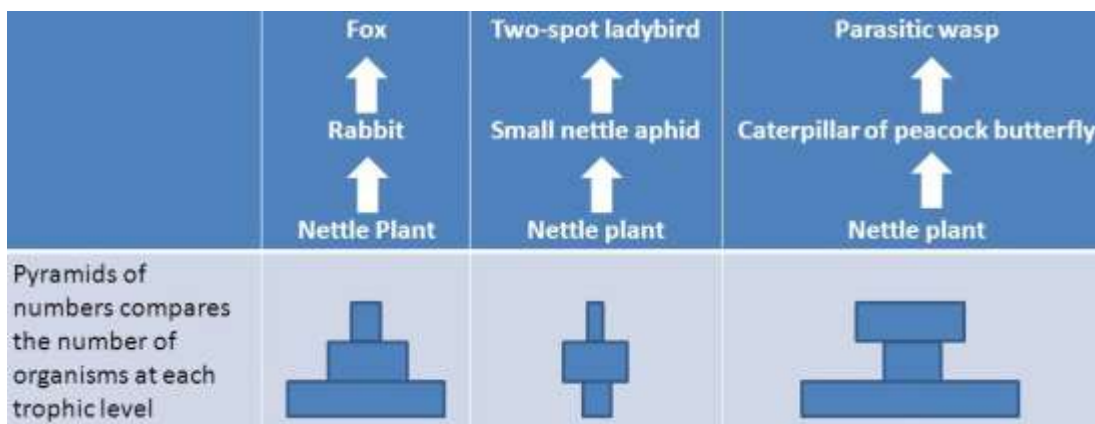
Student answers to question 4 should include the loss of CO₂ and H₂O produced by cellular respiration for primary consumers and decomposers, plus the loss of indigestible food molecules in feces for primary consumers. The relative importance of these different processes varies for different types of organisms. For example, one study found that the proportion of consumed biomass that is used for cellular respiration is ~80% for chipmunks vs. 33% for herbivorous insects. (This difference reflects the fact that chipmunks are homeotherms, whereas herbivorous insects are poikilotherms; homeothermy is metabolically expensive.) The proportion of the biomass consumed that is lost as feces is ~18% for chipmunks vs. ~50% for herbivorous insects that eat leaves. (Leaves have more cellulose and other relatively indigestible molecules than the nuts, seeds and fruits eaten by chipmunks). As a result of these differences, biomass production for chipmunks is ~2% of the biomass consumed, whereas biomass production for herbivorous insects is ~17% of the biomass consumed.

⁴ A proxy measure of biomass is the mass of carbon in an organism; the mass of carbon is approximately half of the dry weight. Unfortunately, biomass is sometimes used to refer to the total weight of an organism; this definition is *not* used in this learning activity.

⁵ Information about the ecology of the Hubbard Brook Experimental Forest in New Hampshire is available in pages 1151-2 in Freeman et al., *Biological Science*, 2014; *Scientific American*, March 1978, pages 93-102; and <https://hubbardbrook.org/online-book/online-book>.

The quantitative results in student answers to question 6a should help students understand why food chains are generally limited to 4 or 5 trophic levels. Question 6b helps students to understand that generalizations such as the “10% rule” often do not apply in specific cases. For example, the forest primary consumers plus decomposers had a net rate of biomass production that was 20% of the rate for producers. One reason for this relatively high percent may be that the researchers included decomposers, which are often ignored in simplified trophic pyramids.

You should be aware that the shape of trophic pyramids is highly dependent on the specific methodology used. Trophic pyramids for the net rate of biomass production always show the classic pyramid shape with each trophic level smaller than the previous trophic level. However, this is not true for trophic pyramids for number of organisms or for total biomass of organisms at each trophic level. For example, a trophic pyramid for the number of individuals may show more individuals at a higher trophic level, e.g. if the organisms at the higher trophic level are smaller, such as insects feeding on trees or other plants (see figure below and figure in question 7). Similarly, the amount of biomass may be greater at a higher trophic level, e.g. if the organisms at the higher trophic level are more long-lived, such as fish or whales feeding on plankton. This explains why, the biomass of marine consumers is roughly 5 times the biomass of marine producers (<https://www.pnas.org/content/pnas/115/25/6506.full.pdf>, pages 6508-6509). In conclusion, trophic pyramids for number of individuals or amount of biomass tend to show the classic pyramid shape only if organisms at different trophic levels have similar size and longevity (http://www.esa.org/history/Awards/papers/Brown_JH_MA.pdf, page 1785).



(<https://slideplayer.com/slide/3461369/12/images/20/Caterpillar+of+peacock+buttefly.jpg>)

In discussing student answers to question 8, you may want to mention that eating meat from primary consumers instead of eating plant foods not only requires ~10 times as much land, but also requires ~10 times as much water and other resources. The first follow-up activity recommended below explains why eating meat also contributes much more to global warming than eating plant foods.

Possible Follow-Up Activities

“Food and Climate Change – How can we feed a growing world population without increasing global warming?” (<https://serendipstudio.org/exchange/bioactivities/global-warming>)

In the first section of this activity, students analyze information about climate change, global warming and greenhouse gases. Students learn that correlation does not necessarily imply causation, and they analyze the types of evidence that establish causal relationships. In the next two sections, students analyze carbon cycles, how food production results in the release of

greenhouse gases, and the reasons why the production of different types of food results in the release of very different amounts of greenhouse gases. In the last section, students propose and research strategies to feed the world's growing population without increasing global warming. (This activity will help students meet the Next Generation Science Standards.)

The video, "Biomagnification and the Trouble with Toxins"

(<https://www.youtube.com/watch?v=TZk6vcmLcKw&vl=en>) shows how biomagnification arises from the same processes that produce trophic pyramids. To further student understanding of biomagnification, you can use the worksheet, "What is biological magnification?"

(https://www.biologycorner.com/worksheets/articles/biological_magnification.html). This worksheet also helps students develop reading skills.

Sources for Figures in Student Handout

- Trophic pyramid – modified from https://www2.nau.edu/lrm22/lessons/food_chain/energy_pyramid.jpg
- Temperate forest figure from <https://www.khanacademy.org/science/high-school-biology/hs-ecology/trophic-levels/a/energy-flow-and-primary-productivity>
- Other figures constructed by the first author