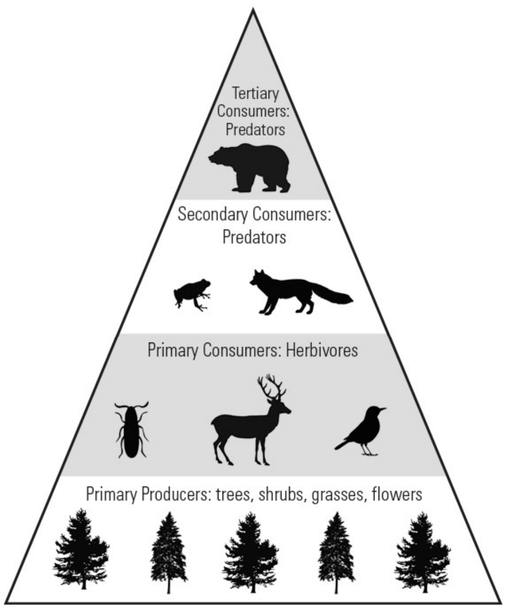
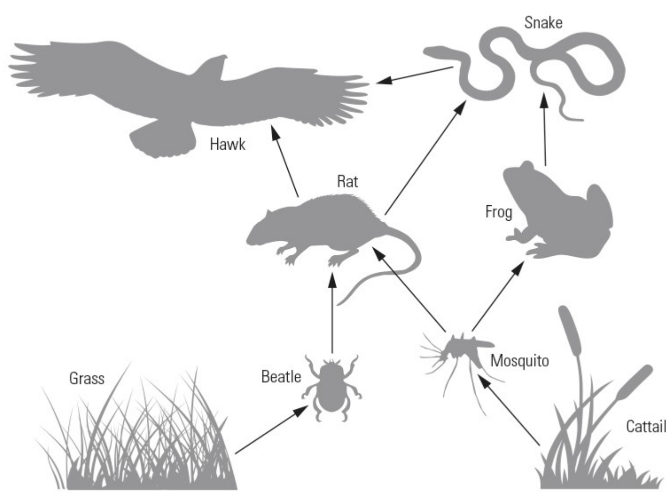
ENERGY DYNAMICS

Background

Energy flow and material cycling is a central theme in ecosystem science. Generally speaking, energy flows through ecosystems while material is cycled within ecosystems. Energy is first captured by producers that carry out photosynthesis, converting light energy to chemical potential energy stored in organic compounds. Producers use much of the energy for their own needs, but some of the energy captured by producers is transferred through successive trophic levels as herbivores consume producers and carnivores consume herbivores. Food webs and trophic level diagrams summarize these energy transfers.



Trophic levels



Food web

What is not typically shown in these diagrams is that much of the energy from the trophic levels is transferred to the detrital pool rather than to a higher trophic level. Organisms often die and decompose, instead of being consumed. Additionally, wastes excreted by animals in an ecosystem contain organic material. The energy contained within the detritus of an ecosystem is an important food source for decomposers and detritivores.

As with other organisms, decomposers and detritivores use cellular respiration to break down these compounds and extract the energy contained within them. Energy transfers are not 100% efficient however, and eventually the majority of the energy that was initially present in the organic compounds manufactured by an ecosystem's producers is lost to the environment as heat. Although it is almost impossible to measure heat loss from an ecosystem, ecologists can estimate energy dynamics by measuring the biomass of successive trophic levels or by measuring the change in mass of detritus over time.

Driving Question

How quickly does organic matter decompose in an ecosystem, and how much energy is transferred from detritus to the organisms that feed upon it?

Materials and Equipment

Use the following materials to complete the initial investigation. For conducting an experiment of your own design, check with your teacher to see what materials and equipment are available.

- Carbon dioxide gas sensor
- EcoChamber™ container, with lid and stoppers
- Yeast suspension or water, 5 mL
- Mealworms, 20
- Electronic balance, centigram (at least 1 per class)
- Detritus (organic material such as apples and banana peels), approximately 60 g
- Weigh boat
- Small knife (for cutting fruit)
- Filter paper or coffee filter (9 cm diameter)
- Plastic pipet, 1-mL
- Disposable gloves

Safety

Follow these important safety precautions in addition to your regular classroom procedures:

- Wear safety goggles at all times
- Use caution while handling decomposing organic matter and detritivores. Wear disposable gloves while handling ecosystem components and wash your hands immediately following ecosystem setup and measuring the mass of materials.
- Handle living organisms with care.

Initial Investigation

Complete the following investigation before designing and conducting your own experiment. Record all observations, data, explanations, and answers in your lab notebook.

Part 1 – System setup and carbon dioxide gas concentration monitoring

1. Put on your safety goggles and disposable gloves.

2. Copy Table 1 into your lab notebook and determine which of the following systems your group is responsible for.

   NOTE: At the end of the four-day investigation, you will need to gather data from other groups and your teacher to complete the table and make comparisons between all of the systems.

Table 1: Gravimetric analysis of EcoChamber container components

System Components		Initial Mass (g) of Detritus Components and Detritivore Population			Final Mass (g) of Detritus Components and Detritivore Population		
		Apple	Banana Peels	*T. molitor* larvae	Apple	Banana Peels	*T. molitor* larvae
A	Detritus + yeast						
B	Detritus + T. molitor larvae						
C	Detritus + yeast + T. molitor larvae						
Ctrl 1	Unwrapped detritus						
Ctrl 2	Wrapped detritus						

3. Place a piece of filter paper flat on the bottom of an EcoChamber container. Soak the paper with 5 mL of water or yeast suspension depending on the setup your group has been assigned.

4. Obtain the detritus material for the EcoChamber container and measure the initial mass of each component (record the number of the balance you use and always make your measurements on this balance):

   a. Place a weigh boat on the electronic balance and tare the balance. Add apple pieces to the weigh boat until you have approximately 30 grams of material. Record the collective mass of the apple pieces in your lab notebook.

   b. Add the apple pieces to the EcoChamber container on top of the filter paper.

   c. Obtain approximately 30 grams of cut banana peels. Record the collective mass of the material in your notebook and add the banana peels to the EcoChamber container.

5. Obtain the detritivore population for the chamber—20 mealworms is an adequate population. Measure and record the collective mass of the detritivore population before placing the worms in the chamber.

   NOTE: Add mealworms only to systems B and C.

6. Connect to the carbon dioxide gas sensor. Open the Energy Dynamics lab file from the experimental menu in SPARKvue under High School > Advanced Biology.

If a configuration file is not available , create a display of the sensor measurement in ppm versus time in hours, and adjust the sample rate to one sample every 5 minutes for 4 hours.

7. Place the sensor into one of the openings of the lid of the EcoChamber container.

8. Secure the lid on the chamber and seal all openings with rubber stoppers. Place the chamber and data collection system in a location where it will not be disturbed and is away from direct sunlight. Begin recording data.

9. Describe aspects of the carbon cycle present within the model system. Name carbon storages as well as carbon fluxes (or movement) within the system. Do you expect the carbon dioxide gas concentration to change in the chamber? Why or why not?

10. After 4 hours, stop data recording and save the data. Remove the carbon dioxide gas sensor and place a stopper in the open hole. Alternatively, if an auto-stop condition has been set, the gas sensor can remain in the lid until you return to the classroom after 24 hours.

11. Draw or print a record of the change in carbon dioxide concentration within the EcoChamber container.

Part 2 – Gravimetric Analysis and Estimation of Energy Transfers

12. After 24 hours, record observations of the components of your EcoChamber container.

    NOTE: If you have not already done so, disconnect the carbon dioxide gas sensor from the data collection system. For the next part of the investigation, keep the lid off the chamber; the chamber will remain open to the air.

13. Leave the chamber in a location away from direct sunlight for three additional days. Re-wet the filter paper with 5 mL of water each day.

14. Ecologists differentiate between “fresh” mass (total mass of material) and *biomass* (the mass of tissue present in an organism). The biomass is the collective mass of the organic compounds found in an organism's tissues: carbohydrates, proteins, and fats. These molecules store a certain amount of energy (measured as kilocalories, or kcal) and ecologists attempt to determine energy transfers by monitoring changes in biomass and relating these changes to the energy contained in that biomass.

    a. In general, if the apple pieces have a mass of 30 grams, the biomass of the apple pieces is approximately 5 grams. Explain why the total mass of apple pieces is not the same as the biomass of the sample.

    b. Carbohydrates and proteins contain 4 kcal per gram and fats contain 9 kcal per gram. Which of these organic compounds is the primary component of apples? Estimate the energy, in kcal, contained in 30 g of apple pieces.

    c. Mealworm larvae contain more kcal per gram of biomass than apples. Why would larvae biomass contain more energy than apple biomass?

15. Copy Table 2 into your lab notebook.

Table 2: Determining the energy content of detritus materials and detritivores

System C Components	Dry Matter (DM)[1] (%)	Gross Energy[1] (MJ/kg DM)	Energy Content per Gram of Fresh Mass (kcal/g)[2]	Total Energy Content of the Initial Mass of Each Sample (kcal)
Apple pieces			0.52	
Banana peels				

RECORD ANSWERS & DATA IN YOUR NOTEBOOK.

Mealworms[3]				

[1]If the website www.feedipedia.org becomes unavailable, use a similar resource to obtain these values.

[2]There are 238 kilocalories in every megajoule (MJ).

[3]If you set up Chamber A, this sample is not applicable to your setup. However, you will use the Energy Content per Gram of Fresh Mass for mealworms in a later question, so you should calculate that value here.

a. Use the information provided in the table for apple pieces to determine the energy content of the apples placed in the EcoChamber container on the first day of the investigation.

b. The website www.feedipedia.org provides nutritional information for a number of animal feed samples, including banana peels and mealworms. The energy content, in megajoules per kilogram (MJ/kg), is reported for the biomass (the dry matter) of the sample. The biomass can be determined by knowing the percentage of dry matter (DM) in the fresh sample. Use the information from the website to complete the table and then use dimensional analysis to determine the energy content per gram (kcal per gram of fresh mass) and the total energy content of banana peels and mealworms.

16. On Day 4 of the investigation, record observations of the chamber and measure the final mass of the detritus components and mealworms (if applicable). Record the data in Table 1.

17. For each item measured, calculate the percent change in mass that occurred over 4 days. Share this data with the class.

18. Create a table to organize class data from the three different experimental systems (A–C), as well as the two controls set up by your teacher. Record the average percent change in mass for each component, and the rate of change in carbon dioxide during the first 4 hours of the investigation.

❓ 19. Which contributes more to decomposition, decomposers (such as yeast) or detritivores (such as mealworms)? What evidence do you have to support your claim?

❓ 20. What purpose do the controls serve in this investigation? What can be concluded from a comparison of the controls and the experimental setups?

❓ 21. Do the results of System C indicate that decomposers affect detritivores? What evidence supports your answer?

22. Use data from one group's setup of System C (or an average from multiple setups of System C) and the conversion factors established in Table 2 to calculate the energy transfer in the system over the four days.

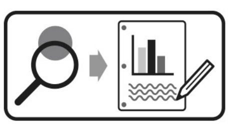
Table 3: Estimate of energy transfer in a model system containing detritus, decomposers, and detritivores

System C Ecosystem Component	Energy Content per Gram of Fresh Mass (kcal/g)	Change in Mass over 4 Days (g)	Change in Energy Content (kcal)
Detritus 1: Apple	0.52		
Detritus 2: Banana skin	RECORD ANSWERS & DATA IN YOUR NOTEBOOK.		
Detritivore: *T. monitor* larvae			

23. Calculate the ecological efficiency of the mealworms in System C during the Initial Investigation. Ecological efficiency can be calculated from the ratio of energy gained in the detritivore pool over energy lost from the detrital pool.

Design and Conduct an Experiment

The Initial Investigation offers insight into the processing of detritus within a simple ecosystem. In actual ecosystems, a significant amount of biomass and energy from primary production is transferred to the detrital pool. This detritus serves as a trophic base for both detritivores and decomposers. A number of biotic or abiotic factors can affect this trophic level. How can you change a component or condition of the model system to test factors that affect decomposition in ecosystems?



Design and carry out your experiment using either the Design and Conduct an Experiment Worksheet or the Experiment Design Plan. Then complete the Data Analysis and Synthesis Questions.

Design and Conduct an Experiment: Data Analysis

1. From your observations and your data:

   a. Describe how the independent variable you manipulated affected decomposition. Does the data support your hypothesis? Justify your claim with evidence from your experiment.

   b. Based on the evidence you collected, explain why the results occurred.

2. Is there any evidence in your data or from your observations that experimental error or other uncontrolled variables affected your results? If yes, is the data reliable enough to determine if your hypothesis was supported?

3. Identify any new questions that have arisen as a result of your research.

Synthesis Questions

1. How do the Laws of Thermodynamics relate to the model decomposition systems that were set up in the Initial Investigation?

2. With regard to measuring energy dynamics, describe at least three limitations of the model systems used in the Initial Investigation.

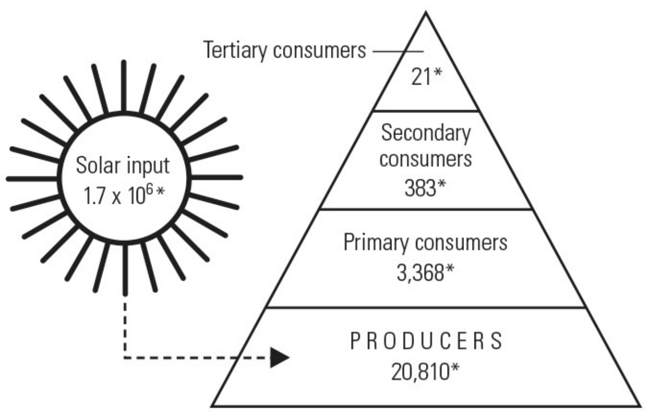
3. Movement of matter and energy occurs in all ecosystems. Often a model of this transfer is presented as a diagram, a food web for example.

   a. Describe the movement of matter and energy in ecosystems. Include in your description how different types of organisms acquire the free energy they need to sustain life, and why an ecosystem requires a constant input of free energy.

   b. Food webs and trophic level pyramids typically do not include decomposers or detritivores in the illustration. Propose an explanation for why this is the case.

4. The diagram below provides information about the amount of solar energy entering an ecosystem, the net primary productivity of the ecosystem's producers, and the amount of energy at each successive trophic level.

   a. Calculate the ecological efficiency of energy transfer between each successive trophic level and explain why ecological efficiency is often less than 10%.

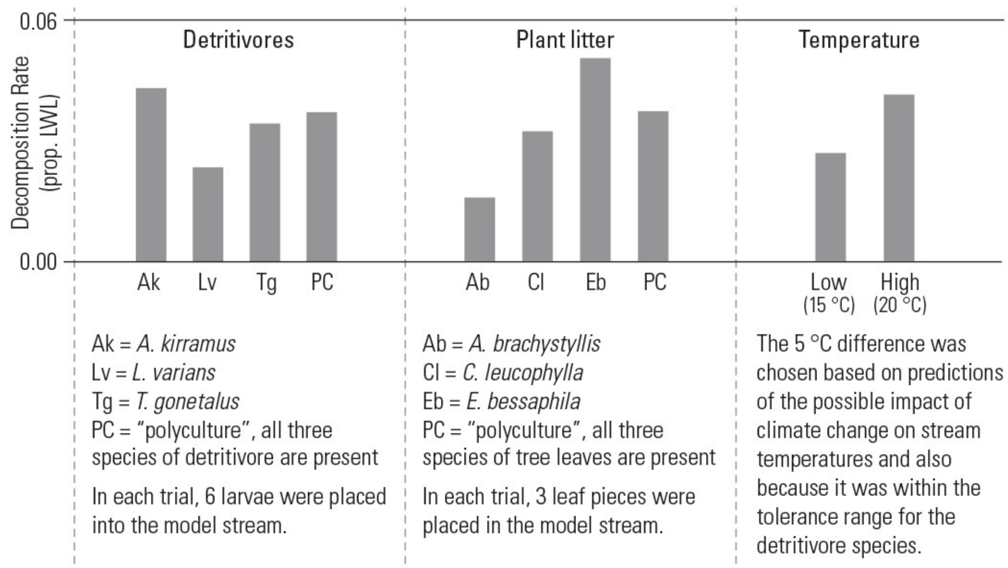


Temperate grassland ecosystem
(*Kcal/m^2 per year)

   b. Identify a biome that would have a higher net primary productivity (NPP) than a grassland ecosystem and a biome that would have a lower NPP. For each of your choices, explain biotic or abiotic aspects of the biome that affect its NPP. How would decomposition rates compare for these biomes?

5. Researchers carried out numerous experiments designed to study decomposition rates under a variety of conditions.[1] The experiments were designed to model the decomposition that occurs in an Australian stream. Three different leaf-shredding detritivore species were taken from the stream for use in the study, leaves from three native riparian tree species were collected for use as plant litter, and the researchers carried out experiments in model stream habitats at two different temperatures (typical stream temperature and 5 °C warmer). In total, almost 200 experiments were performed by the researchers.

   The following diagram illustrates the results of these experiments. The bars show the mean detritivore-mediated decomposition rates measured as a proportion of leaf weight loss per detritivore (prop. LWL). Detritivores were present in all trials; the species identity or richness of detritivores was manipulated for some trials, as was the species identity or richness of plant litter. Each manipulation of detritivores or plant litter species was tested at two temperatures. Researchers performed a variety of statistical analyses to the data and the resulting probability values p are provided below each graph.



[1] Boyero, L.; Bradley, J.C.; Bastian, M; Pearson, R.G. Biotic vs. Abiotic Control of Decomposition: A Comparison of the Effects of Simulated Extinctions and Changes in Temperature. *PLoS ONE* (Impact Factor: 3.73). 01/2014; 9(1):e87426. DOI:10.1371/journal.pone.0087426 http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0087426 (accessed July 3, 2014).

Table 4: Statistical analysis of decomposition rates under different conditions of detritivore, leaf litter, and temperature

	Statistical Comparisons	
	Species Identity: ***compared decomposition rate by Ak, Lv, and Tg and compared rates of decomposition of Ab, Cl, and Eb***	**Species Richness:** ***compared the polyculture decomposition rates to the single-species decomposition rates***
Detritivores	$p < 0.001$	$p = 0.79$
Plant litter	$p < 0.001$	$p = 0.83$
	Compared decomposition rates in low temperature and high temperature stream water	
Temperature	$p < 0.001$	

a. Identify two scientific questions that the researchers were likely investigating with these experiments.

b. For one of the scientific questions you describe, propose an experimental design for the experiment used to test the question. Be sure to make clear the independent and dependent variables, as well as the constant variables for the proposed experimental design.

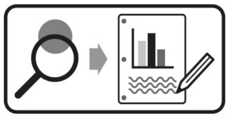
c. What can be concluded from the provided probability values?

d. For either detritivores or plant litter, identify a characteristic of the organism or leaves that may contribute to faster or slower decomposition.

NAME PERIOD DATE

Design and Conduct an Experiment Worksheet

The Initial Investigation offers insight into the processing of detritus within a simple ecosystem. In actual ecosystems, a significant amount of biomass and energy from primary production is transferred to the detrital pool. This detritus serves as a trophic base for both detritivores and decomposers. A number of biotic or abiotic factors can affect this trophic level. How can you change a component or condition of the model system to test factors that affect decomposition in ecosystems?



Develop and conduct your experiment using the following guide.

1. Based on your knowledge of energy dynamics and decomposition, what environmental factors (abiotic or biotic) could affect this process?

2. Create a driving question: choose one of the factors you've identified that can be controlled in the lab and develop a testable question for your experiment.

3. What is the justification for your question? That is, why is it biologically significant, relevant, or interesting?

4. What will be the independent variable of the experiment? Describe how this variable will be manipulated in your experiment.

5. What is the dependent variable of the experiment? Describe how the data will be collected and processed in the experiment.

6. Write a testable hypothesis (If…then…).

7. What conditions will need to be held constant in the experiment? Quantify these values where possible.

8. How many trials will be run for each experimental group? Justify your choice.

9. What will you compare or calculate? What analysis will you perform to evaluate your results and hypothesis?

10. Describe at least 3 potential sources of error that could affect the accuracy or reliability of data.

11. Use the space below to create an outline of the experiment. In your lab notebook, write the steps for the procedure of the lab. (Another student or group should be able to repeat the procedure and obtain similar results.)

12. Have your teacher approve your answers to these questions and your plan before beginning the experiment.