Investigating Energy Flow in an Ecosystem

Introduction

Energy flows from one organism to another as food. Energy enters into a food web either as solar energy captured as part of photosynthesis or as chemical energy captured by chemosynthetic bacteria in specialized ecosystems. No matter the source, this energy is used to create complex energy rich macromolecules which are either used immediately to maintain homeostasis or are stored for later use. Consumers feed on organisms in order to acquire complex energy rich macromolecules for their own needs. This investigation demonstrates how ecologists determine the flow of energy along a simple food chain.

Concepts

- Community modeling
- Ecological pyramid
- Net primary productivity

Background

Food chains and food webs are pictorial representations of the flow of energy from one organism to another (see Figure 1). Most often these diagrams focus on a food chain based on the Sun's energy being captured by photosynthesis. A similar chain forms in some of the deepest areas on Earth where chemosynthetic bacteria capture energy from sulfur vents on the sea floor and other harsh environments. Since the Sun food chain is the most common, that is the one we will focus on in this investigation.

In order to determine the actual amount of solar energy captured by producers, scientists measure the dry mass of all life within that ecosystem. The mass is converted to energy using calories per gram, a known constant for each organism. Since ecosystems are complex, scientists harvest part of the ecosystem or use a simplified model system to make an estimate of the whole.

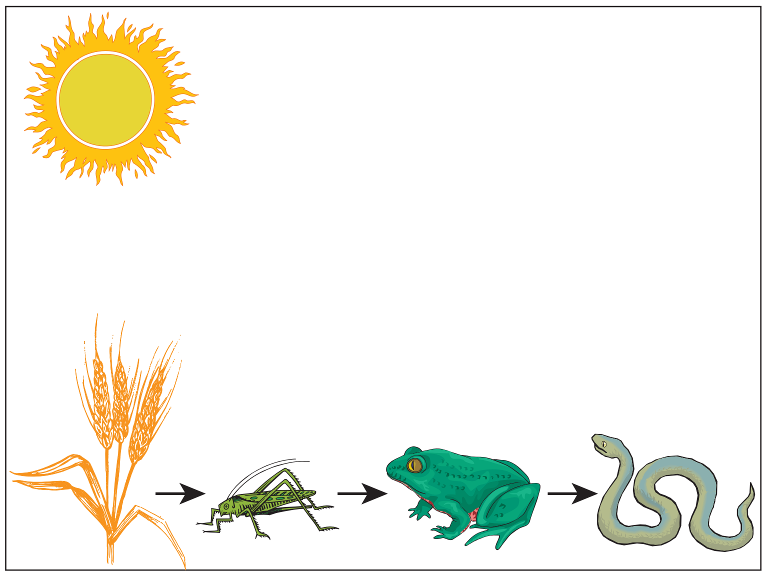

Figure 1. Food Chain

Plants use water, carbon dioxide, trace nutrients, and light to grow and carry out metabolic functions. Plants convert these raw materials into macromolecules, which have mass and store energy. *Gross primary productivity* is a measure of the total amount of energy converted by plants during photosynthesis and includes accounting for the energy in the waste products of photosynthesis and respiration. This is not easily measured because the waste products are oxygen and carbon dioxide. Scientists are generally interested in the amount of energy available to the next trophic level, or net primary productivity. The total mass of all the plants in an ecosystem at a given time is the biomass of the ecosystem. The added dry biomass that grows within a measured area over a specific amount of time is the *net primary productivity*. This is reported in grams per square meter per week, or as kilograms per square meter per year, depending on the type of ecosystem and nature of the study.

When plants grow from tiny seeds to large organisms, it may seem that they create mass from nothing. However, the law of conservation of mass states that mass cannot be created or destroyed, simply rearranged into different molecules. Where does the dry mass come from? Living things are carbon-based organisms; fats, carbohydrates, and proteins are primarily carbon, hydrogen, and oxygen. Therefore, the mass of the plant mainly comes from carbon dioxide and, to a lesser extent, water.

Primary consumers, those that eat plants, are not able to capture 100% of the plant's biomass for growth. They use most of the energy they acquire from plants just to maintain homeostasis. In addition, not all of the plant is digestible and a large fraction is lost as fecal waste, heat, and waste gases. Only a fraction of the energy acquired is used to make more cells (growth). By massing the animal over time, the *net secondary productivity* can be determined.

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The productivity loss at each level determines the total number of trophic levels that are able to exist in that ecosystem. This is represented by an ecological pyramid (Figure 2). A primary consumer assimilates plants and uses most of the plant's biomass for metabolism. On average, 5–20% of the primary consumer's biomass is converted to growth. A predator (secondary consumer) then eats the primary consumer. Again, much of the herbivore is used to maintain homeostasis in the predator leaving less biomass for growth. This means that the predator must consume numerous herbivores to maintain itself and to grow. When this predator is consumed by another predator, the amount of biomass available for the next animal on the food chain is once again reduced. A population study would show very few top predators in an ecosystem but thousands of plants.

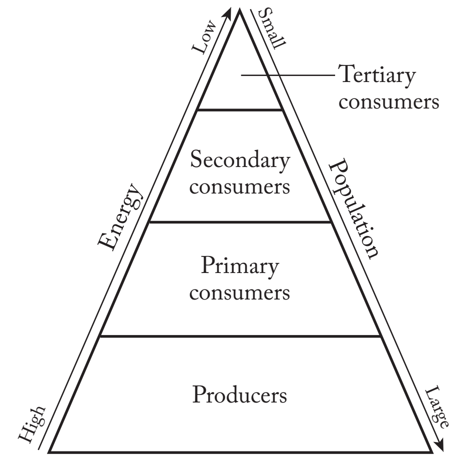

Figure 2.

Biomass is typically reported as a *dry mass* because water content can vary greatly and does not contribute energy. Consider the differences in the mass of the prairie grass in a one square meter area of prairie in a drought year versus a rainy year. By drying the prairie grasses the mass of the macromolecules from one year to the next can be compared. Therefore, calculations must be done on dried plants and animals. The percent dry weight can be calculated by massing the plants when they are harvested then drying them in a controlled environment and reweighing the same plants.

In this activity, the plant used is wheat, which is a monocot cereal grain and an important food crop. The type used in this experiment is a hard red winter wheat. The grain seeds are harvested for bread and other foodstuffs. Young blades of wheat, called wheatgrass, can also be used as food. Wheatgrass has an overall dry weight energy value of about 4 kcal per gram. The wheat seed contains the endosperm, the embryo called the wheat germ, and the hard outer layers called the wheat bran. In this activity, wheat bran will be used as the food source for mealworms. Wheat bran has an overall dry weight energy value of about 4 kcal per gram.

Mealworms are the larval form of the *Tenebrio molitor* beetle. The mealworm is easily cultivated in wheat bran and water to survive. The larvae have an overall energy value of 6.5 kcal/g and are 36% dry weight. The pupae have an overall energy value of 6.4 kcal/g and are 35% dry weight. The adult beetles have an overall energy value of 5.8 kcal/g and are 34% dry weight.

Experimental Overview

The *Baseline Activity* explores the net productivity for wheat and one of its predators, the mealworm. Daily observations allow for the study of the life cycle of a metamorphic animal and the growth of a monocot plant. The results of this baseline activity provide a procedure and model for open-inquiry and student-designed experiments .

Materials

- Mealworm diet, 10–20 g
- Mealworms, 10–15
- Wheat seeds, approx. 200
- Aluminum foil
- Apples
- Camera (shared)
- Containers, 3
- Dissection needle or pin
- Fertilizer solution, 0.1% solution in aged tap water
- Heat-resistant gloves
- Laboratory oven (shared)
- Lid
- Marker
- Paper towels
- Planting trays
- Plastic wrap
- Ruler
- Spoon, plastic (reused)
- Weighing dish (reused)
- Vermiculite

Safety Precautions

No parts of this laboratory are considered hazardous. Do not handle living animals unnecessarily. Wash hands thoroughly with soap and water before leaving the laboratory. Please follow all laboratory safety guidelines.

Baseline Activity Setup

Part A. Wheat

1. Use a dissecting needle or a dissection pin to poke at least 30 holes into the bottom of two of the containers. Move the dissection needle or pin around when forming each hole to ensure each hole remains open.
2. Label the container as instructed so it can be identified later.
3. Measure the area of the container in square meters.
4. Fill the two containers about halfway with vermiculite.
5. Thoroughly wet the vermiculite with the dilute fertilizer solution.
6. In each container, distribute 100 wheat seeds evenly on top of the wet vermiculite.
7. Cover the seeds with a light layer of vermiculite.
8. Place a piece of plastic wrap over the top of the container while the wheat plants sprout.
9. Place the containers in the planting trays in the grow area. The grow lights should be raised as the plants grow so they are always about 6 inches above the wheat plants.

Part B. Mealworms

1. Use a dissection needle or a dissection pin to poke at least 30 holes into the lid of the container. Move the dissection needle or pin around when forming each hole to ensure each hole remains open for air exchange.
2. Measure the area of the container in square meters.
3. Mass the container and write this on the side of the container.
4. Mass 10–20 g of mealworm diet (wheat bran) in a weighing dish. Record the mass. Transfer to the empty container. Wipe out the weighing dish with a paper towel.
5. In the weighing dish, mass 10–15 mealworms; record the mass. Transfer to the container with the wheat bran. Keep the weighing dish for future measurements.
6. Record the combined mass of the container, wheat bran, and mealworms.
7. Label the container as instructed so it can be identified later.
8. Place the aerated lid onto the container and place the mealworm culture in a designated area.

Baseline Activity

1. Make daily observations and maintain the wheat and mealworms for 2–3 weeks.
    a. Plant maintenance:
        i. Water the wheat as necessary.
        ii. Add vermiculite as needed to the wheat containers. The vermiculite holds water but compresses over time. This is especially important over the weekend when plants may dehydrate and die.
        iii. Remove the plastic wrap once the wheat seeds have grown enough to touch it.
    b. Animal care:
        i. Once adults emerge add small pieces of apple to the culture. The adult *Tenebrio* do not eat wheat bran and will cannibalize the pupa instead.
        ii. As the culture progresses it may be necessary to add more wheat bran and to collect deceased animals and sheds. Keep track of the mass of any added wheat bran and anything removed from the culture.
2. Once a week:
    a. mass the entire mealworm container, wheat bran, and *Tenebrio*.
    b. gently collect all of the *Tenebrio* (mealworms. pupae, and beetles) into a weighing dish and mass them.
    c. determine the mass of the solids within the container, including wheat bran, fecal matter, and eggs (if adults are present).

3. Once the wheat reaches a height of 4 inches, harvest the entire wheat crop from one of the two containers:
   a. Record the number of days since planting.
   b. Gently remove all of the vermiculite from the roots. *Note:* This can be a time consuming process. Remove as much vermiculite as possible, then use a tub of water to rinse off most of the remaining vermiculite. Use gently running water to completely remove the vermiculite. *Note:* Do not rinse large amounts of vermiculite down the drain. It will clog the pipes.
   c. Pat the wheatgrass dry and mass.
   d. Calculate the average mass per plant.
   e. Create an aluminum tray using the aluminum foil (see Figure 3).
   f. Mass the aluminum tray.
   g. Place the wheatgrass onto the tray and place into a 105 °C laboratory oven. Allow the wheatgrass to dry for 24–48 hours.
   h. After the wheatgrass has dried, mass again to determine the dry weight.
   i. Calculate the average dry mass per plant.

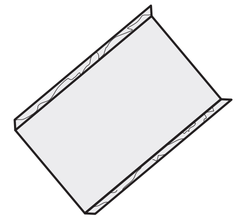

Figure 3.

4. Allow the remaining container of wheatgrass to grow one or two more weeks, and then harvest the remaining wheat crop using the same procedure as in step 3.
5. Calculate the net primary productivity and net secondary productivity of this model ecosystem.
6. Evaluate the model and make adjustments as necessary to determine how productivity is affected by various factors.

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School
MS-LS2 Ecosystems: Interactions, Energy, and Dynamics
LS2.A: Interdependent Relationships in Ecosystems
LS2.B: Cycle of Matter and Energy Transfer in Ecosystems

Disciplinary Core Ideas: High School
HS-LS2 Ecosystems: Interactions, Energy, and Dynamics
LS2.A: Interdependent Relationships in Ecosystems
LS2.B: Cycle of Matter and Energy Transfer in Ecosystems
LS2.C: Ecosystem Dynamics, Functioning, and Resilience

Science and Engineering Practices
Asking questions and defining problems
Planning and carrying out investigations
Constructing explanations and designing solutions

Crosscutting Concepts
Patterns
Cause and effect
Scale, proportion, and quantity
Energy and matter
Stability and change

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. Never release living specimens into the local ecosystem. Mealworms make excellent food for many amphibians, birds, fish, and reptiles. Otherwise the mealworms or adult beetles must be euthanized prior to disposal. The wheat can be considered Type VI Biological Waste and disposed of in the normal garbage.

Lab Hints

- This activity was adopted from *Energy Dynamics—Advanced Inquiry Laboratory Kit* (Flinn Catalog No. FB2049).
- This lab will last for several weeks. Most days only a few minutes are needed to maintain the plants and animals. Setup, harvesting, drying and planing days will take most or all of a 60-minute lab period.

The Materials for *Investigating Energy Flow in an Ecosystem* and supporting supplies are available from Flinn Scientific, Inc.

Catalog No.	Description
FB2049	Energy Dynamics Advanced Inquiry Lab
LM1113	Mealworms, Tenebrio larvae, pkg. 100
FB0582	Monocot Seeds, Wheat, 1 oz, pkg. 700
FB0674	Vermiculite, 8-qt bag
FB1617	Flinn Mealworm Diet, 800 g
FB0676	Plant Fertilizer, Liquid, 32 oz
AB1456	Planting Tray, Plastic, 11″ × 22″

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.