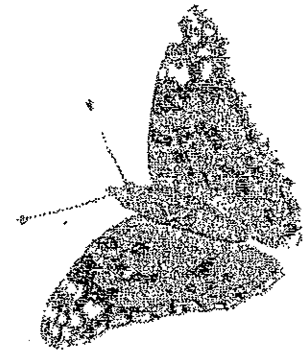


AP Biology Laboratory: Energy Dynamics

Objectives

- Observe the life cycle of the painted lady butterfly (*Vanessa cardui*).
- Construct a trophic level diagram depicting a typical North American food chain that includes the *V. cardui* species.
- Measure the efficiency of energy transfer from one trophic level to another.

Background

Energy moving through an ecosystem originates in the sun. Solar radiation is responsible for all primary productivity. Primary productivity relates to the amount of solar energy converted into chemical energy in a certain time frame. Thus, calculations of primary productivity are typically produced by measuring the amount of photosynthesis occurring in a given amount of time. Primary productivity is most often referred to in term of gross primary productivity (GPP) and net primary productivity (NPP). Gross primary productivity includes measurements of the amount of biomass (amount, or mass, of organic material in an ecosystem) produced and the amount of energy used in cellular respiration. Net primary productivity is a measure of the amount of biomass produced minus the amount of energy lost to cellular respiration.

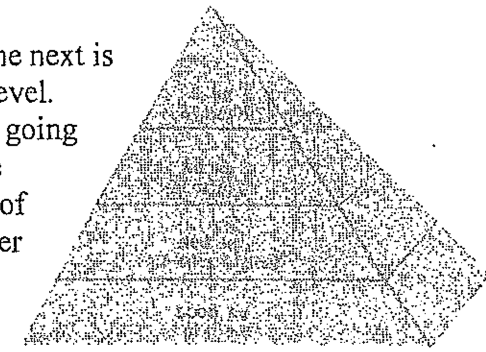
Energy that is stored in a primary producer biomass is transferred to a primary consumer, or herbivore, biomass when the herbivore consumes and digests the primary producer biomass. The energy captured in the herbivore biomass is then transferred to a primary carnivore when the primary carnivore consumes the herbivore. The chain continues as energy is transferred from primary carnivores to secondary carnivores and so forth.

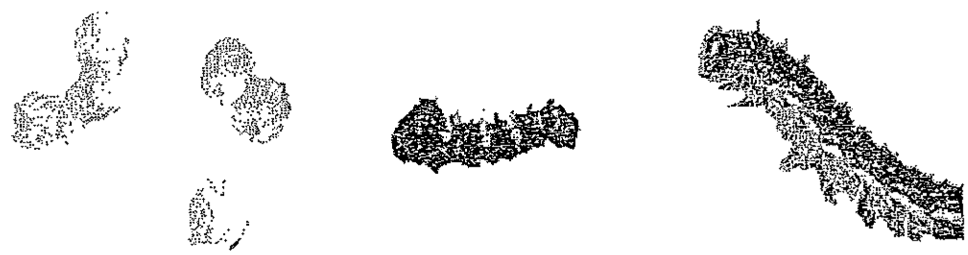
At each these levels of the food chain, referred to as trophic levels, much of the energy transferred from one trophic level to the next is lost for many reasons. One is the fact that not all of the biomass at one level is consumed by organisms of the next higher level. Of the biomass that is consumed, not all is digested and turned into biomass at the next level. Some becomes waste in the form of feces or frass. Also, processes such as cellular respiration require energy and thus transform some of the chemical energy of the biomass into heat.

The second law of thermodynamics, which states that entropy tends to increase in a given system, can describe this last situation. In other words, the energy of any form in a system tends toward chaos or heat. The loss of energy from one trophic level to the next typically limits the length of the food chains to four to six levels. The decrease in available energy at higher trophic levels means that there are fewer organisms at each successively higher trophic level as the amount of energy becomes successively smaller. This is exemplified by the fact that lions are at the top of their food chain. No organism exists that feeds on lions because it would not be energetically efficient for such a theoretical organism to do so. That organism would have to cover an extremely large hunting area and expend tremendous amounts of energy to obtain the small amount of energy left at such a high trophic level.

The efficiency of energy transfer varies greatly from one food chain to the next and is extremely dependent on environmental factors such as temperature, aquatic vs. terrestrial habitats, complexity of food web, etc. Generally, about 10% of the energy at one trophic level is transferred to the sent, but efficiencies range anywhere from less than 1% to 25% or higher.

In terrestrial systems, the loss of energy from one trophic level to the next is closely related to the amount of biomass transferred from level to level. This phenomenon occurs because all of the chemical energy that is going to move through the food chain is at one point living biomass. The ecological rule of thumb usually holds true in that only about 10% of the biomass in a certain trophic level is transferred to the next higher level. Both biomass transfer and energy flow between trophic levels are often represented graphically by what are referred to as biomass and energy pyramids, respectively.





images:
http://www.fcps.edu/islandcreekes/ecology/painted_lady.htm
http://www.carolina.com/butterfly-cultures/painted-lady-butterfly-life-stages-eggs/144078.pr
http://www.delta-education.com/productdetail.aspx?PartNo=270-4129
http://www.tutorvista.com/content/biology/biology-i/environment/types-ecosystem.php

Materials

Culture cup with Lid, tissue paper, Balance, Food Medium (artichokes), Sorting brush.

Introduction

The organism studied in this experiment is the painted lady butterfly, *Vanessa cardui*, found throughout the United States. It is a popular subject for study in the classroom for several reasons. The organisms are small, easy to care for, easily contained, and complete their life cycle in about 30 days. These aspects provide the unique experience of being able to closely monitor an organism's life stages in a controlled environment. As a result, we can closely monitor everything that goes into and out of the system, as well as observe everything that occurs within the system. Studying the long-term energy flow in organisms other than plants is often difficult because of the many variables found in the organisms' environments. With *V. cardui*, however, we have the unique opportunity to study energy flow at the trophic level of a consumer.

The life cycle of the painted lady butterfly consists of four distinct stages. The first stage is the egg. Eggs are laid by adults on the surfaces of leaves of certain types of plants. Favorite plant species of the painted ladies are mallow and thistle. The tiny, mint-green-colored eggs hatch into a small caterpillar in 5 to 10 days. During the second stage, or larval stage, the caterpillars feed on their host plant. The larvae experience a dramatic increase in body mass as they consume more and more food. The caterpillar's exoskeleton does not stretch with the growth of the body, and thus the larva must shed its exoskeleton in order to continue its growth. This shedding is referred to as molting, and the stages between molts are called instars.

The caterpillar usually has six instars. The last instar leads to the third stage of the painted lady's life, the chrysalis. In this stage, the caterpillar crawls to an appropriate location such as the underside of a leaf, attaches itself with a pad of silk, and molts one last time resulting in a sac-like chrysalis that is usually found hanging upside down. The chrysalis protects the organism as it makes its metamorphosis from caterpillar to butterfly. The time spent in the chrysalis varies, but is usually about one week. The end of the chrysalis stage is marked by the butterfly breaking open the chrysalis and crawling out into the fourth and final stage of its life as an adult.

Butterflies feed on nectar using a proboscis located on the anterior portion of the organism. Adult painted ladies do not excrete solid frass as the caterpillars do. Rather, they often release a drop of liquid waste that is generally red in color.

As adults, the sole purpose of the butterfly is to reproduce. After internal fertilization, females lay eggs, and both male and female organisms complete their life cycle in about 30 days.

Procedure

Set-up: Preparing Culture Cups for Larvae

1. Thoroughly wash your hands before handling the materials to set up your culture cups.
2. Obtain a culture cup with lid and a piece of tissue paper. Check your lid to be sure that there are adequate holes for ventilation.
3. Place your name on the lid and cup.
4. Measure and record the mass of your cup, lid, and tissue paper.
5. Place your cup on the scale, tare the balance, and fill your cup two-thirds full of artichoke leaves. Record this mass.
6. Empty your cup and place the artichokes on a paper towel.
7. Once again, place your cup on the balance, tare or zero the balance, and with a sorting brush, gently brush five butterfly larvae into the cup. Record this mass.
8. Gently remove your larvae from the cup, place the food into the cup and then place the larvae on top of the food.
9. Place the square of tissue paper on the opening of the cup. Snap the lid into place on the cup, securing the tissue paper over the opening of the cup.
10. Measure the final mass of the entire system and record the mass along with today's date on the data sheet.

Collecting Data

1. Measure and record the mass of your cup along with any observations about the experiment day until three days after the butterfly larvae attach to the tissue paper at the top of the culture cup and have formed their chrysalis.
2. If there are any days (i.e. weekends) where you do not have access to your experiment, simply divide the mass loss over the time period and assume a consistent loss of mass occurred each day during that time. For example, if you are unable to measure the cups on a Saturday and Sunday, do the following:
   a. Record the mass on Monday.
   b. Subtract Monday's measurement from Friday's measurement.
   c. Divide the difference by 3.
   d. Subtract the quotient from Friday's measurement, then record the difference as Saturday's mass measurement.
   e. Subtract the quotient from Saturday's measurement, then record the difference as Sunday's mass measurement.

Final Data Collection

1. On the last day of data collection, determine the mass of your larvae. If the larvae are hanging from the tissue paper at the top, do not disturb them. Find a way to calculate their mass using your previous masses of paper, cup, and lid.
2. Separate the frass from the uneaten food and determine the mass of all frass. Include in the mass of the frass all silk and shed exoskeletons.
3. Complete the attached data sheet.
4. Place your larvae into a clean cup with food and a piece of tissue paper across the top underneath the lid. In 2-3 days the larvae should form their chrysalis.
5. Two to three days after the chrysalis has formed, transfer it to the butterfly habitat by taping the tissue paper to the wall of the habitat.
6. Observe the chrysalis each day. It will darken and you will be able to see the butterfly developing inside. Occasionally you will see the chrysalis twitch.
7. Once the butterfly emerges, be sure there is a water/sugar solution in the habitat.

Data Sheet

Initial Measurements (Day 1)

Date:

Mass of Cup: ______________g

Mass of Lid: ______________g

Mass of Tissue Paper: ______________g

Mass of Food: ______________g

Mass of Larvae: ______________g

Mass of Complete System: ______________g

Observations:

Day 2 Mass ______________g

Day 3 Mass ______________g

Day 4 Mass ______________g

Day 5 Mass ______________g

Final Mass ______________g

Total Mass Loss ______________g

Observations:

Analysis of Results - Calculations

1	Wet mass plants (not eaten)	Initial mass 5.4 7.75	Final mass 4.76 2.55	Difference (mass of plants eaten) .64 5.2 g	
2	Plant % biomass (dry/wet)	Mass wet sample of artichokes: 26.68g Mass after 24 hrs in oven: 6.20g		0. 23238 or 23.238 %	
3	Plant biomass (dry) (wet x % biomass)			.1487256 g	1.21
4	Total plant energy consumed (dry biomass X 4.35 kcal/g)	Here we are converting biomass to energy by multiplying biomass with a known conversion factor.		.6469565 kcal	5.26
5	Plant energy consumed *per larvae*	Divide the plant energy value by the number of larvae you had.		12939 kcal/larvae	1.05
6	Wet mass of total larvae	Initial mass .04 .07	Final mass .13 1.4	Difference .09 g	1.33
7	Wet mass gained per individual			.018 g/larvae	.266
8	% biomass of larvae (provided)			0.15 or 15%	
9	Larvae biomass (dry) (wet x 0.15)	Somebody took many larvae and dried them out so you do not have to do this...		.0027 g/larvae	.0399
10	Total energy gained per individual larvae (dry biomass X 5.5 kcal/g)	Here we are again converting biomass to energy by multiplying biomass with a known conversion factor.		.01485 Kcal/larvae	.2194 5
11	% Energy transferred from producer → consumer	kcal gained per larvae/kcal plant consumed per larvae X 100		11.5% % efficiency	20.9%
	What happened to the lost energy...?				
12	Total dry mass of frass from all larvae (after 24 hrs in oven)			.0722 g	.361
13	Frass mass per individual larvae	Total dry mass/# larvae		.01444 g/larvae	.0722
14	Energy lost as frass	Frass mass per individual larvae X 4.76 kcal/g		.069 kcal/larvae	.343672
15	Energy lost in respiration	Per individual larvae: Total energy consumed – energy gained – energy lost as frass = energy consumed in cell respiration		kcal	

Adapted from C. Gray Mitchell

To summarize:

.12939 kcal food consumed → .01485 kcal biomass gained
→ .069 kcal lost as frass
→ .04554 kcal lost in respiration

.21945 kcal biomass gained

1.05 kcal consumed .343672 kcal lost as frass

.486878 kcal lost in respiration

Analysis of Results - Calculations				
1	Wet mass plants (not eaten)	Initial mass	Final mass	Difference (mass of plants eaten) g
2	Plant % biomass (dry/wet)	Mass wet sample of food: 46.88g Mass after 24 hrs in oven: 13.39g		0._____ or _____%
3	Plant biomass (dry) (wet x % biomass)			g
4	Total plant energy consumed (dry biomass X 4.35 kcal/g)	Here we are converting biomass to energy by multiplying biomass with a known conversion factor.		kcal
5	Plant energy consumed *per larvae*	Divide the plant energy value by the number of larvae you had.		kcal/larvae
6	Wet mass of total larvae	Initial mass	Final mass	Difference g
7	Wet mass gained per individual			g/larvae
8	% biomass of larvae (provided)			0.15 or 15%
9	Larvae biomass (dry) (wet x 0.15)	Somebody took many larvae and dried them out so you do not have to do this...		g/larvae
10	Total energy gained per individual larvae (dry biomass X 5.5 kcal/g)	Here we are again converting biomass to energy by multiplying biomass with a known conversion factor.		Kcal/larvae
11	% Energy transferred from producer → consumer	kcal gained per larvae/kcal plant consumed per larvae X 100		_____ % efficiency
	What happened to the lost energy...?			
12	Total dry mass of frass from all larvae (after 24 hrs in oven)			g
13	Frass mass per individual larvae	Total dry mass/# larvae		g/larvae
14	Energy lost as frass	Frass mass per individual larvae X 4.76 kcal/g		kcal/larvae
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Adapted from C. Gray Mitchell

To summarize:

________ kcal food consumed → ________ kcal biomass gained
→ ________ kcal lost as frass
→ ________ kcal lost in respiration

Analysis of Results – Discussion Questions

1. What is the purpose of having a control in this experiment?

2. How could you integrate the mass loss of the control into your calculations?

3. Why was there a greater mass loss in the culture cups with larvae than in the control cup with no larvae?

4. The painted lady butterfly can be part of the following food chain that is typically found in North America (mass of representative organisms follows in parentheses): mallow leaves (butterfly food medium constituent) (0.2 g per leaf), painted lady butterfly (0.5 g), American robin (77 g), domestic house cat (5,000 g). Assuming that 10% of the biomass from one trophic level is transferred to the next trophic level, calculate the number of robins, caterpillars, and mallow leaves that must be consumed to support one 5,000 g domestic house cat in this food chain.

5. Construct a biomass pyramid diagram depicting the food chain described in the previous question.

6. What was the experimental efficiency of biomass transfer in this experiment? Is this significantly close to the hypothetical efficiency delineated by the "ecological rule of thumb?" Explain why or why not (Hint: mammals tend to have lower rates of transfer than insects which can be upwards of 20% or more).