Name: _____   Period: _____

AP Biology Lab 10: Energy Dynamics

Purpose:
What factors govern energy capture, allocation, storage, and transfer between producers and consumers in a terrestrial ecosystem?

Background:
Almost all life on this planet is powered, either directly or indirectly, by sunlight. Energy captured from sunlight drives the production of energy-rich organic compounds during the process of photosynthesis. These organic compounds create biomass. Gross productivity is a measure of the total energy captured. The net amount of energy captured and stored by the producers in a system is the system's net productivity.

In terrestrial systems, plants play the role of producer. Plants allocate that biomass (energy) to power processes or to be stored. Different plants have different strategies of energy allocation that reflect their role in various ecosystems. For example, annual weedy plants allocate a larger percentage of their annual biomass production to reproductive processes and seeds than do slower-growing perennials. As plants, the producers, are consumed or decomposed, the stored chemical energy powers additional individuals (the consumers) or trophic levels of the biotic community. Biotic systems run on energy much as economic systems run on money. Energy is generally in limited supply in most communities. Energy dynamics in a biotic community is fundamental to understanding ecological interactions.

Learning Objectives:
- To explain community/ecosystem energy dynamics, including energy transfer between the different trophic levels.
- To calculate biomass, net primary productivity (NPP), secondary productivity, and respiration use a model consisting of Brussels sprouts and butterfly larvae.

There are two parts to this lab:
1. In part 1, you will estimate the net primary productivity (NPP) of _____(your plant name) over several weeks.
2. In part 2, you will calculate the flow of energy from plants (producers) to butterfly larvae (primary consumers). These calculations will include an estimate of (a) secondary productivity, which would be the amount of biomass added to the larvae and therefore available to the next trophic level, and (b) the amount of energy lost to cellular respiration.

Part I: Estimating Net Primary Productivity (NPP) of _____(your plant name)

Primary productivity is a rate – energy captured by photosynthetic organisms in a given area per unit of time. Based on the second law of thermodynamics, when energy is converted from one form to another, some energy will be lost as heat. When light energy is converted to chemical energy in photosynthesis or transferred from one organism (a plant or producer) to its consumer (ex: an herbivorous insect), some energy will be lost from heat during each transfer.

In terrestrial ecosystems, productivity (or energy capture) is generally estimated by the change in biomass of plants produced over a specific time period. Measuring biomass or changes in biomass is relatively straightforward: simply mass the organism(s) on an appropriate balance and record the mass over various time intervals. The complicating factor is that a large percentage of the mass of a living organism is water – not the energy-rich organic compounds of biomass. Therefore, to determine the biomass at a particular point accurately, you must dry the organism. Obviously, this creates a problem if you wish to take multiple measurements on the same living organism. Another issue is that

different organic compounds store different amounts of energy; in proteins and carbohydrates it is about 4kcal/dry of weight and in fats it is 9kcal/dry of weight.
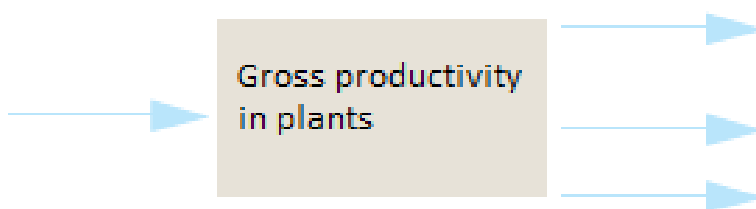
Define the following terms, and then fill in the diagram below showing energy transfer in plants. Use the word "biomass" where necessary.
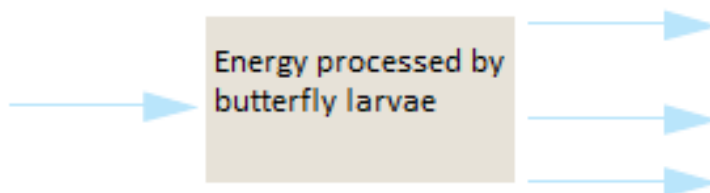
- Gross primary productivity: _____

  _____

- Net primary productivity: _____

  _____

- Secondary productivity: _____

  _____

*Review the energy transfer in plants by filling in the arrows below:*

Gross productivity in plants

Review the energy transfer in primary consumers (butterflies) by filling in the arrows below:

Energy processed by butterfly larvae

Procedure:
Day 1:
1. Plant 40 _____(your plant name) seeds according to your teacher's instructions. These seeds will be grown for 7 days under controlled conditions.
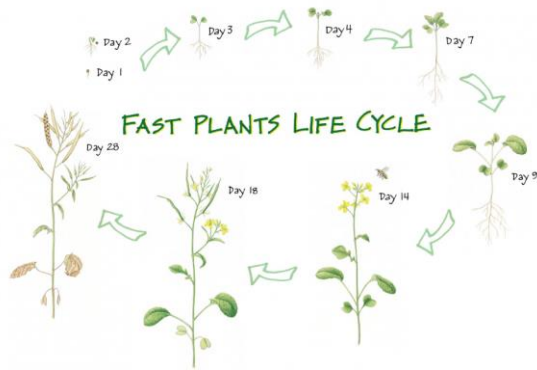
Sketch and label the life cycle of your plant in the space provided:

Day 7:

2. Randomly select 10 plants and remove them with their roots intact from the soil.
3. Carefully wash the soil from the roots and blot the roots dry.
4. Measure the wet mass of the 10 plants collectively. Record the mass in the data table provided.
5. Place the 10 plants in a drying bowl and place them in a drying oven at 200°C for 24 hours.

Day 8:

6. Measure the mass of the dry plants. Record the mass in the data table provided.
7. Use the following equation to calculate percent biomass:

$$\% \text{ biomass} = \frac{\text{mass of dry plants}}{\text{mass of wet plants}} \times 100$$

   Note how much of the plant's total mass is actually biomass (organic compounds) and how much is made up of water!

8. Each gram of a Plant's dry biomass is equivalent to 4.35 kcal of energy. *Note: throughout this lab, the energy equivalents of biomass in kcal (plant or animal) were obtained in a laboratory using a calorimeter that measures the amount of energy per gram of organism.*

   Use the following formula to calculate the amount of energy (in kcal) in the plants:

   $$\text{amount of energy (kcal)} = (\text{mass of dried plants (g)}) \times (4.35 \text{ kcal/g})$$

9. Record the amount of energy in 10 plants and in 1 plant in the data table.
10. Net primary productivity (NPP) is the amount of energy stored (added) as biomass per day by autotrophs in a ecosystem and is expressed in units of kcal/day.

    Use the following formula to calculate NPP per plant per day:

    $$\text{NPP} = \frac{\text{energy per plant (kcal)}}{\text{age of plant (days)}}$$

11. Record the NPP per plant per day in the data table.

Day 14:
    12. Repeat steps 2-11.

Day 21:
    13. Repeat steps 2-11.

Results & Data:

Part I: Estimating Net Primary Productivity (NPP) of _____(your plant name)
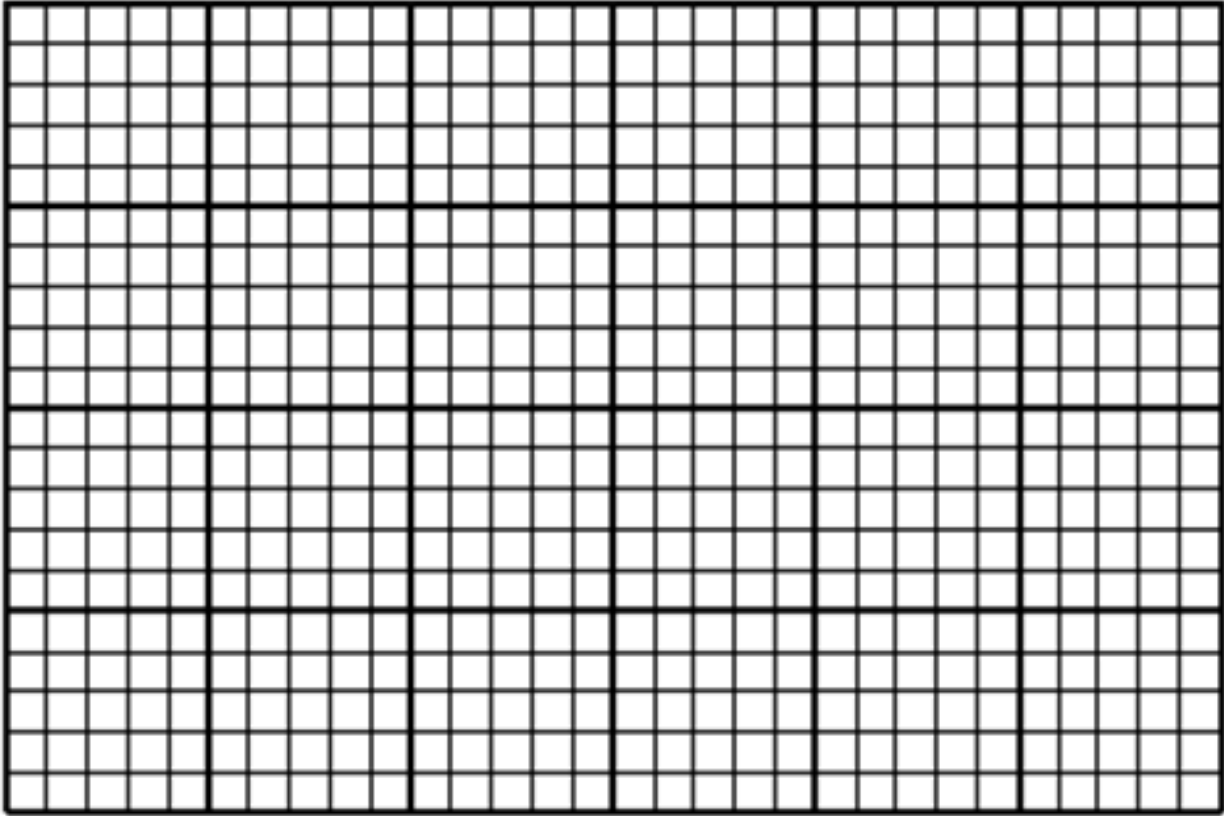
Group Data: NPP of _____(your plant name)

Age in Days	Wet Mass of 10 Plants (g)	Dry Mass of 10 Plants (g)	Percent Biomass	Energy in 10 Plants(kcal)	Energy in 1 Plant (kcal)	Net Primary Productivity per day per Plant
7						
14						
21						

Class Data: NPP of _____(your plant name)

Time (Days)	Group 1/ family of plant	Group 2/ family of plant	Group 3/ family of plant	Group 4/ family of plant	Group 5/ family of plant	Group 6/ family of plant	Average NPP
7							
14							
21							

Analysis:

1. Graph your group AND the class average NPP vs. time.

2. Why does the NPP increase over time (as the plants grow and mature)?

Part II: Estimating Energy Transfer from Producers to Primary Consumers

Read the article on Water Temperature by Fundamental of Environmental Measures at
http://www.fondriest.com/environmental-measurements/parameters/water-quality/water-temperature/#watertemp3

1. How could water temperature affect the energy transfer in your system by affecting metabolic rates and photosynthesis production? _____

_____

_____

_____

Use a representation to demonstrate the above relationship.

2. How could water temperature affect the energy transfer in your system by affecting compound toxicity? _____

_____

_____

_____

Use a representation to demonstrate the above relationship.

3. How could water temperature affect the energy transfer in your system by affecting dissolved oxygen? _____

_____

_____

_____

Use a representation to demonstrate the above relationship.

4. How could water temperature affect the energy transfer in your system by affecting pH? _____

_____

_____

_____

Use a representation to demonstrate the above relationship.

Ecological efficiency: the transfer of energy between trophic levels

Large amounts of energy are lost from the ecosystem between one trophic level and the next level as energy flows from the primary producers through the various trophic levels of consumers and decomposers. The main reason for this loss is the second law of thermodynamics, which states that whenever energy is converted from one form to another, there is a tendency toward disorder (entropy) in the system. In biologic systems, this means a great deal of energy is lost as metabolic heat when the organisms from one trophic level are consumed by the next level. The measurement of energy transfer efficiency between two successive trophic levels is termed the trophic level transfer efficiency (TLTE) and is defined by the formula:

TLTE=production at present trophic level production at previous trophic level x100

In Silver Springs, the TLTE between the first two trophic levels was approximately 14.8 percent. The low efficiency of energy transfer between trophic levels is usually the major factor that limits the length of food chains observed in a food web. The fact is, after four to six energy transfers, there is not enough energy left to support another trophic level. In the Lake Ontario ecosystem food web, only three energy transfers occurred between the primary producer (green algae) and the tertiary, or apex, consumer (Chinook salmon). **Food Web of Lake Ontario:**
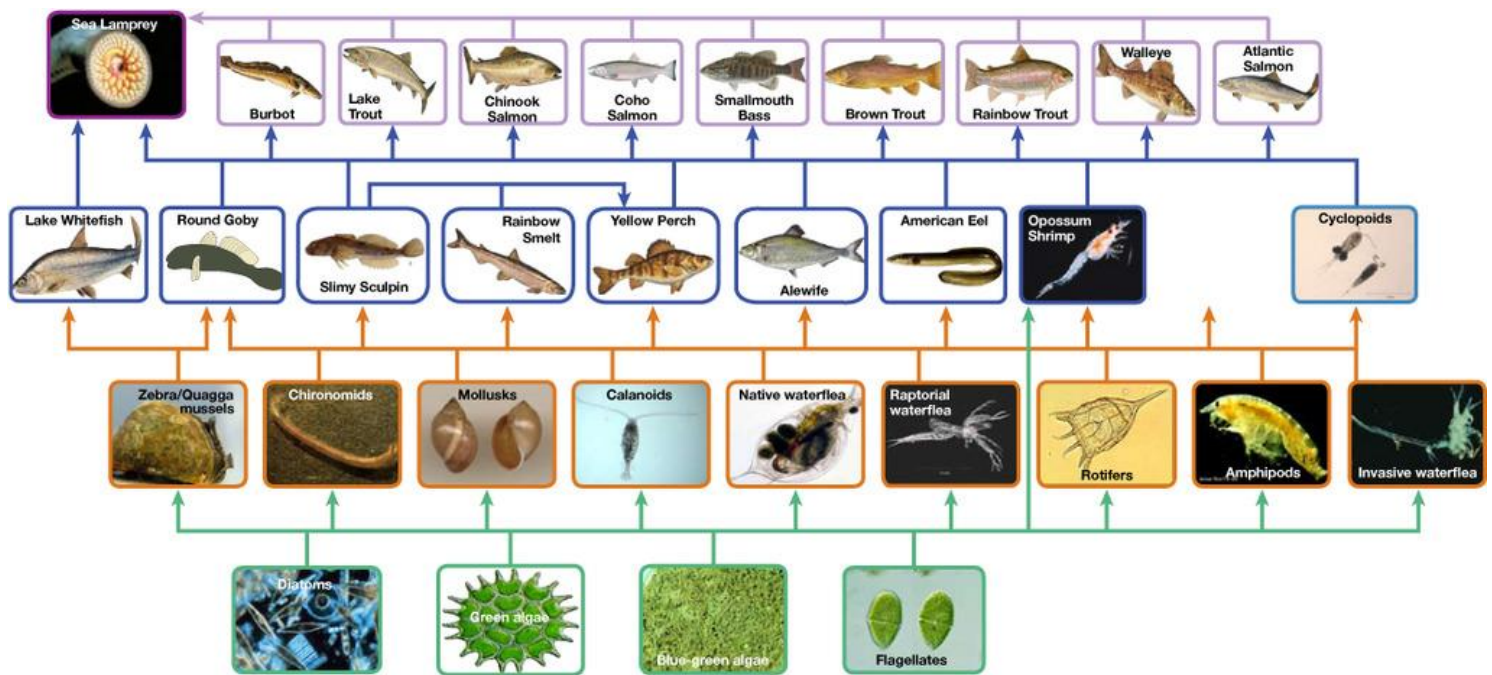
This food web shows the interactions between organisms across trophic levels in the Lake Ontario ecosystem. Primary producers are outlined in green, primary consumers in orange, secondary consumers in blue, and tertiary (apex) consumers in purple. Arrows point from an organism that is consumed to the organism that consumes it. Notice how some lines point to more than one trophic level. For example, the opossum shrimp eats both primary producers and primary consumers.

Ecologists have many different methods of measuring energy transfers within ecosystems. Some transfers are easier or more difficult to measure depending on the complexity of the ecosystem and how much access scientists have to observe the ecosystem. In other words, some ecosystems are more difficult to study than others; sometimes the quantification of energy transfers has to be estimated.

Another main parameter that is important in characterizing energy flow within an ecosystem is the net production efficiency. Net production efficiency (NPE) allows ecologists to quantify how efficiently organisms of a particular trophic level incorporate the energy they receive into biomass. It is calculated using the following formula:

*NPE=net consumer productivity assimilation x*100

Net consumer productivity is the energy content available to the organisms of the next trophic level. Assimilation is the biomass (energy content generated per unit area) of the present trophic level after accounting for the energy lost due to incomplete ingestion of food, energy used for respiration, and energy lost as waste. Incomplete ingestion refers to the fact that some consumers eat only a part of their food. For example, when a lion kills an antelope, it will eat everything except the hide and bones. The lion is missing the energy-rich bone marrow inside the bone, so the lion does not make use of all the calories its prey could provide.

Thus, NPE measures how efficiently each trophic level uses and incorporates the energy from its food into biomass to fuel the next trophic level. In general, cold-blooded animals (ectotherms), such as invertebrates, fish, amphibians, and reptiles, use less of the energy they obtain for respiration and heat than warm-blooded animals (endotherms), such as birds and mammals. The extra heat generated in endotherms, although an advantage in terms of the activity of these organisms in colder environments, is a major disadvantage in terms of NPE. Therefore, many endotherms have to eat more often than ectotherms to obtain the energy they need for survival. In general, NPE for ectotherms is an order of magnitude (10x) higher than for endotherms. For example, the NPE for a caterpillar eating leaves has been measured at 18 percent, whereas the NPE for a squirrel eating acorns may be as low as 1.6 percent.

The inefficiency of energy use by warm-blooded animals has broad implications for the world's food supply. It is widely accepted that the meat industry uses large amounts of crops to feed livestock. Because the NPE is low, much of the energy from animal feed is lost. For example, it costs about $0.01 to produce 1000 dietary calories (kcal) of corn or soybeans, but approximately $0.19 to produce a similar number of calories growing cattle for beef consumption. The same energy content of milk from cattle is also costly, at approximately $0.16 per 1000 kcal. Much of this difference is due to the low NPE of cattle. Thus, there has been a growing movement worldwide to promote the consumption of non-meat and non-dairy foods so that less energy is wasted feeding animals for the meat industry.

Source: Boundless. "Ecological Efficiency: The Transfer of Energy between Trophic Levels." *Boundless Biology*. Boundless, 03 Jul. 2014. Retrieved 23 Feb. 2015 from https://www.boundless.com/biology/textbooks/boundless-biology-textbook/ecosystems-46/energy-flow-through-ecosystems-257/ecological-efficiency-the-transfer-of-energy-between-trophic-levels-953-12213/

5. What type of fish are you using in your aquaponics unit? _____

6. In its natural food chain, where would you fish fit in the trophic web? _____

    Draw and label a picture of the natural food web in which your fish may be found.

7. What do you predict about the quantity of energy of a heterotroph takes in compared to the quantity of energy that goes out?_____

_____

_____

8. What do you think are various ways that an animal (or a number of animals) could lose energy, and how could you estimate the amount of energy lost through these various pathways? _____

_____

_____

9. Develop a procedure that will quantify the growth of your fish over three weeks:

Define the problem and select variables:

_____
_____
_____

Controlling variables:

_____
_____
_____

Develop a method for data collection:

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