**Module 3**

**ENERGY FLOW AND BIOGEOCHEMICAL CYCLES**

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**3.1 INTRODUCTION**

Module 1 showed you different perspectives about living systems. More than that, it underscored why the biological perspective is important. In Module 2, the properties and principles of living systems were discussed and described that these systems are complex. Recall that it takes energy to make a living system more ordered. This module will focus on energy flow in living systems and how matter like elements or nutrients are used and reused. Think about this: where did the materials forming our body come from? Definitely, it was not just recently made but was formed so many years ago from dying stars when our planet evolved. Matter is recycled and we shall review about this as we discuss energy flows and biogeochemical cycles.

**3.2 LEARNING OUTCOMES:**

At the end of the module, the student should be able to:

1. define energy, describe energy sources and discuss how energy is acquired.
2. examine an ecosystem, categorize the organisms present and generate a food web to illustrate energy flow.
3. compare and contrast energy flow and biogeochemical cycles.
4. construct a biogeochemical cycle.
5. Discuss and assess environmental implications of these processes.

**3.3 LEARNING ACTIVITIES**

**3.3.1 ENERGY FLOW**

Almost every process important to life (living systems) depends on a steady flow of energy. In fact, the flow of energy is the essence of life, specifically, of living systems. Energy is the ability to do work and it is everywhere. What you need to do is to look for some motion, heat and light. Let us see if you can identify its many different forms.

By now you have some very good ideas of what energy is. We know that different forms of energy can be best recalled as MRS CHEN ….**M**echanical energy (kinetic energy) whose counterpart is potential energy (stored energy); **R**adiant energy (sun); **S**ound energy; **C**hemical energy; **H**eat energy; **E**lectrical energy and **N**uclear Energy. Energy can be possessed in two ways, either as kinetic or potential energy.

Energy may be sourced from renewable or non-renewable sources. Can you give examples of this?

Currently, non-renewable resources supply the bulk of our energy needs because of technologies that allow them to be harnessed on a large scale to meet consumer needs. Regardless of its source, energy contained in the source is changed into a more useful form. Do you now have a clear understanding of what energy is?

Good. Now that you know what energy is, let us consider how energy flows in living systems.

**Resource 1:**

**The Flow of Energy: Primary Production to Higher Trophic Levels** <https://globalchange.umich.edu/globalchange1/current/lectures/kling/energyflow/energyflow.html>

or

**Chapter 55 Ecosystems** pp 1218-1237 in N.A. Campbell, J.B. Reece, L.A. Urry, M.L. Cain, S.A. Wasserman, P.V. Minorsky and R.B. Jackson. 2008. Biology 9th edition

or

**Chapter 55 Ecosystems and Restoration Ecology** pp 1264-1283 in J.B. Reece, L.A. Urry, M.L. Cain, S.A. Wasswrman, P.V. Minorsky and R.B. Jackson. 2011. Campbell Biology 9th ed.

Based on your reading and understanding of the article and recall what you have learned in senior high school Science:

1. Give the significance of the following terms:

Autotrophs

Heterotrophs

primary producers

consumers

decomposers

photosynthesis

chemosynthesis

production

primary production

trophic level

food chains

food webs

1. Define gross primary productivity (GPP). How does this compare to net primary productivity (NPP)? Respiration (R)? Explain in your own words how these three terms are related.
2. Why do you think production rates vary with ecosystems?
3. How does energy flow in ecosystems?
4. How efficient is energy flow from one trophic level to another?
5. What do pyramids of biomass, energy and numbers show?

The flow of energy is based on two essential Laws of Thermodynamics. The first law concerns the amount of energy in the universe. It states that the amount of energy in the universe is constant. It may be changed from one form to another but cannot be created or destroyed. This is also known as the Law of Conservation of Energy. Moreover, energy cannot be changed without some conversion into heat energy. This is embodied in the second law of Thermodynamics. It states that disorder (entropy) in the universe is increasing. As energy is used, more and more of it is converted into heat, the energy of random molecular motion. Thus, as energy is changed from one form to another, part of that energy assumes waste form (heat energy). Consequently, after transformation, the capacity of energy to do work is decreased. Thus, energy flows from higher to lower level.

The main source of energy is the sun. How much of this is actually transformed to chemical energy? On the average, only 2% of the total light striking a leaf surface is used to make food through photosynthesis while most of it is transformed as heat. Yet that small amount of radiant energy goes a long way in providing energy not only for the plants but for other organisms as well!

Study Figure 2.1 below to recall how energy flows at different levels in an ecosystem.

 

 Fig. 2.1 Flow of energy at different levels of ecosystem

 [http://www.biologydiscussion.com/ecosystem/energy-flow-in-an- ecosystem-with-diagram/6740](http://www.biologydiscussion.com/ecosystem/energy-flow-in-an-%20ecosystem-with-diagram/6740)

How is energy acquired? There are many ways by which energy is acquired. If we focus on living systems, energy is acquired by living things in three ways through **photosynthesis**, **chemosynthesis**, or by eating and digesting other living or dead organisms by **heterotrophs**. Recall and review what you have learned in you high school Science. Remember **photoautotrophs** like algae, plants and photosynthetic bacteria that harness radiant energy and convert it to chemical energy in the form of ATPs (adenosine triphosphates) to be used to synthesize complex organic molecules like glucose. Autotrophs are the foundation of every ecosystem on earth. This may sound dramatic, but it's not an exaggeration! Autotrophs form the base of food chains and food webs, and the energy they capture from light or chemicals sustains all the other organisms in the community. **Chemoautotrophs** are organisms that create their own organic food from inorganic chemicals like  iron, nitrogen, sulfur and magnesium and in turn supply energy to the rest of the ecosystem. **Heterotrophs** cannot capture light or chemical energy to make food and thus, mainly rely on autotrophs.

By now you are familiar with the concept of **trophic levels**. It is a feeding level, often represented in a **food chain or food web**. Primary producers constitute the bottom trophic level, followed by primary consumers (herbivores), then secondary consumers, tertiary consumers and so on. Energy flows within these food chains and as it moves up the trophic levels, some of it is dissipated as heat because organisms carry out metabolic processes.

**3.3.1.1 Activity: WHO IS EATING WHOM?**

**Time allotment (20 minutes)**

Go on an adventure and explore the organisms that live in the ecosystem that has been assigned to your group. Build a food web that shows how food chains are connected in the system. Begin your adventure now!

Each group will be given a specific ecosystem to study. Examine this ecosystem and categorize the organisms present and generate a food web to illustrate energy flow.

Only about 10% of net energy production at one trophic level is passed on to the next level. This is so because there are processes like respiration, growth, reproduction, etc. that reduce energy flow. Even the nutritional quality of the consumed material affects how efficiently energy flows. Consumers often convert high-quality food sources into new tissue more efficiently that low quality food sources. The low rate of energy transfer between trophic levels makes decomposers generally more important than producers in terms of energy flow. Decomposers process large amounts of organic material and return nutrients to the ecosystem in inorganic form, which are then taken up again by primary producers.

**Ecological pyramids**, also referred to as trophic pyramids, are graphical representations designed to show relationships between energy and trophic levels in an ecosystem. Often, relationships are demonstrated through number of individuals, amount of biomass or the amount of energy at each given trophic level. Thus, there are pyramids of biomass, energy or numbers. Among these three types, the most useful is the pyramid of energy because it shows relationship between energy and trophic level.

Study Figure 3.2 to review the concept of ecological pyramids.

 

 **Fig. 3.2.** An example of Pyramids of numbers, biomass and energy.

 https://mrwallisscience.wikispaces.com/Class+notes

Energy is passed from one organism to another through food webs and their constituent food chains. As energy is passed from one trophic level to another, there is one important environmental consequence that we need to address. This is **biological magnification** or simply referred to as **biomagnification**. This refers to the increasing concentration of persistent, toxic substances at each trophic level, from the primary producers to the different consumer levels. Many substances have been shown to bioaccumulate and notable among them is the pesticide, dichlorodiphenyltrichloroethane (DDT), which has been shown to accumulate in eagles and raptors in the US causing detrimental effects on their reproduction where they formed thin-shelled eggs that broke in their nests. Fortunately, the pesticide has been banned and these bird populations have recovered. However, in many developing countries like ours, the bioaccumulation of pesticides and other toxic substances continue to occur and need to be addressed. In the Philippines, mussels have been reported to accumulate toxins from the dinoflagellates they have eaten which in turn cause diseases or death to the humans who later eat these mussels.

**Resource 2:**

Read these two articles which illustrate biomagnification in the Philippines. Discuss the lesson(s) you learned from these articles.

Contamination and bioaccumulation in fish

<https://www.sciencedirect.com/science/article/pii/S0045653511007119>

Lead bioaccumulation in gastropods

<http://www.fisheriessciences.com/fisheries-aqua/lead-bioaccumulation-and-the-imposex-effect-of-volemapugilina-cochlidium-in-bacoor-bay-philippines.php?aid=6677>

Energy flows in one direction through ecosystems, entering as sunlight (or inorganic molecules for chemoautotrophs) and leaving as heat during the many transfers between trophic levels. However, the matter that makes up living organisms is conserved and recycled. Like a wheel which has no beginning and no end, a cycle is a continual process of transformations. The basic components of a cycle may be used over and over again in slightly different forms. But they always return to the original form to begin the cycle again.

**Table 3.1**. Similarities and differences between energy flow and nutrient cycles.

|  |  |  |
| --- | --- | --- |
| **Criteria** | **Energy Flow** | **Nutrient Cycles** |
|  |  |  |
|  |  |  |
|  |  |  |

**3.3.2 BIOGEOCHEMICAL CYCLES**

Earth is a closed system for matter, thus, all elements needed for living systems came from what was present in the Earth’s crust so many billion years ago. This matter which are the building blocks of life, are continually recycled on time scales which can vary from a few days to millions of years. Just imagine, what constitutes us have been present since early times.

Elements are the key components of life and must be available for biological processes. Many geological processes like weathering and erosion play a role in this recycling of materials. Because geology and chemistry have major roles in the study of this processes, the recycling of inorganic matter between living organisms and their environment is called a **biogeochemical cycle**. These cycles, move chemicals through the biosphere, passing them through organisms and abiotic components of the biosphere like the atmosphere, marine and fresh waters, soils and rocks.

Biogeochemical cycles serve a variety of functions at the ecosystem level and in ensuring survival of various organisms including us. These cycles are important because they: 1) enable the transformation of matter from one form to another which enables the utilization of matter in a form specific for a particular organism; 2) enable the transfer of molecules from one locality to another; 3) facilitate the storage of elements; 4) assist in functioning of ecosystems; 5) link living organisms with living organisms and living organisms with abiotic factors; and 6) regulate the flow of substances. Let’s take a look at each of these and expound on why biogeochemical cycles are essential.

Each living organism is a part of many different biogeochemical cycles. The details of these cycles may differ but they follow similar patterns. First, these cycles are driven by radiant energy that powers processes like photosynthesis and evaporation. Second, these cycles involve reservoirs where chemicals are stored or concentrated for long periods of time. Third, these cycles function on both local and global levels, linking distant ecosystems. Earth has many biogeochemical cycles illustrating that our planet is a closed system. Elements are recycled and not replenished from outside sources.

There are five most common elements associated with organic molecules that are key components of life — hydrogen and oxygen (water), carbon, nitrogen and phosphorus. These elements take a variety of chemical forms and may exist for long periods in the atmosphere, on land, in water, or beneath the Earth’s surface.

**Resource 3:**

**Chapter 55 Ecosystems** pp 1222-1244 in N.A. Campbell, J.B. Reece, L.A. Urry, M.L. Cain, S.A. Wasserman, P.V. Minorsky and R.B. Jackson. 2008. Biology 8th edition

Or

**Chapter 55 Ecosystems and Restoration Ecology** pp 1264-1283 in J.B. Reece, L.A. Urry, M.L. Cain, S.A. Wasswrman, P.V. Minorsky and R.B. Jackson. 2011. Campbell Biology 9th ed.

# After reading the resource material to review about biogeochemical cycles, summarize the characteristics of these different biogeochemical cycles by completing the table below.

Table 3.2. Characteristics of Biogeochemical Cycles

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Element** | **Biological Importance** | **Biologically Available Forms** | **Key Processes** | **Reservoir** |
| **Water (Hydrogen & Oxygen)** |  |  |  |  |
| **Carbon** |  |  |  |  |
| **Nitrogen** |  |  |  |  |
| **Phosphorus** |  |  |  |  |

**3.3.2.1 Activity 3. MY OWN BIOGEOCHEMICAL CYCLE**

**Time Allotment (15 minutes)**

After completing the table, you have a good perspective and understanding of biogeochemical cycles. Create your own illustration of one biogeochemical cycle and write a short explanation to support your figure.

It is important to recognize that the cycling of these elements is interconnected. For instance, the leaching of nitrogen or phosphorus into bodies of water is affected by the hydrologic cycle. Thus, these elements are cycled at different timescales and extent through the biosphere, from one organism to another, and between the biotic and abiotic worlds.

Biogeochemical cycles are influenced by human activities. We hasten natural biogeochemical cycles when we cause disturbances like when elements are mined, when we continue to burn fossil fuels or even when we clear areas of vegetation that stores carbon. We have altered both nitrogen and phosphorus cycles when we over use fertlizers because the excess amounts are carried by runoff into waterways.

**Resource 4:**

Biogeochemical Cycles and Global Change

<https://nca2014.globalchange.gov/report/sectors/biogeochemical-cycles>

**Resource 5:**

Carbon Sequestration by Mangrove Forest written by Dr. Rex Sadaba

(see attached file)

1. How have human activities affected biogeochemical cycles?
2. Cite specific instances given in the reading material that illustrate how biogeochemical cycles have altered through the years due to anthropogenic causes.

**3.3.2.2 Activity 4. ALTERED BIOGEOCHEMICAL CYCLES**

**Time Allotment:** 30 minutes

The class will be divided into groups and assigned a particular cycle. Discuss why an altered biogeochemical cycle combined with climate change increase the vulnerability of biodiversity, food security, human health and water quality to a changing climate. As students, what could you do to alleviate these problems? Prepare a group report on this.

Alternatively, the class maybe given to chance to discuss and evaluate the situation in Boracay. In a recent decision from the Government, Boracay had to be closed down because of the continuous deterioration of the environment which has resulted to alga blooms which persisted year after year. What do you think happened in Boracay. Specifically, how have the biogeochemical cycles in Boracay been altered? What solutions were done to alleviate the problem?

**3.3.2.3 Activity 5. CALCULATING YOUR CARBON FOOTPRINT**

**Time Allotment:** 30 minutes

Another alternative activity will be to calculate the students’ carbon foot print. Check out this sites:

<https://www.carbonfootprint.com/calculator.aspx>

<http://calculator.carbonfootprint.com/calculator.aspx>

<http://waterfootprint.org/en/resources/interactive-tools/personal-water-footprint-calculator/>

**3.4 CONCLUSION**

From this module you should have a clear understanding of the flow of energy in living systems through food chains and webs and how elements or nutrients are cycled through biogeochemical pathways. Energy flow and biogeochemical cycles are interrelated. There are many issues related to the topics discussed in this module and to a certain extent you have been asked to discuss them. More importantly, as you become aware of these issues, do remember to do your own little actions to alleviate these problems. After all, taking all your small acts together, you are helping make Earth a better place to live in.

**3.5 SELF ASSESSMENT**:

After studying the module resources and the learning tasks of this module, the student can do a self-assessment by checking the following circles:

Identify the different forms of energy and how it flows in living systems through food chains and webs

Compare and contrast energy flow from biogeochemical cycles

distinguish the different biogeochemical cycles and create your own version of any of these biogeochemical cycles 

discuss the implications of energy flow and biogeochemical cycles particularly 

 when disturbances occur

*Both students and teacher will accomplish the rubrics.*

**Scoring Rubrics for WHO IS EATING WHOM?**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Criteria** | **Yes****(2)** | **Partly (1)** | **No (0)** | **Remarks** |
| Comprehension |  |  |  |  |
| 1. Output shows understanding of the key concepts on energy flow
 |  |  |  |  |
| 1. Information reflected in the output is accurate
 |  |  |  |  |
| Presentation of Ideas |  |  |  |  |
| 1. Ultimate source of energy is present
 |  |  |  |  |
| 1. There are at least 10 organisms in the ecosystem
 |  |  |  |  |
| 1. Organisms are properly labelled
 |  |  |  |  |
| 1. Food web is organized and effort is demonstrated
 |  |  |  |  |
| 1. Arrows show the flow of energy
 |  |  |  |  |
| Creativity |  |  |  |  |
| 1. Visually well executed
 |  |  |  |  |
| 1. Output reflects creative and unique
 |  |  |  |  |
| TOTAL |  |  |  |  |

**Scoring Rubrics for MY OWN BIOGEOCHEMICAL CYCLE**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Criteria** | **Yes****(2)** | **Partly (1)** | **No (0)** | **Remarks** |
| Comprehension |  |  |  |  |
| 1. Output shows understanding of the key concepts on biogeochemical cycles
 |  |  |  |  |
| 1. Information reflected in the output is accurate
 |  |  |  |  |
| Presentation of Ideas |  |  |  |  |
| 1. Illustration gives a correct reflection of the element being cycled.
 |  |  |  |  |
| 1. Illustration is properly labelled
 |  |  |  |  |
| 1. Arrows show how the element is cycled.
 |  |  |  |  |
| 1. Illustration is well crafted.
 |  |  |  |  |
| 1. Ideas presented are clear and easily understood.
 |  |  |  |  |
| Creativity |  |  |  |  |
| 1. Illustration gives a creative demonstration of the cycle with all of its parts.
 |  |  |  |  |
| 1. Visually well executed
 |  |  |  |  |
| 1. Output is creative and unique.
 |  |  |  |  |
| TOTAL |  |  |  |  |

**Scoring Rubrics for** **ALTERED BIOGEOCHEMICAL CYCLES**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Criteria** | **Yes****(2)** | **Partly (1)** | **No (0)** | **Remarks** |
| Comprehension |  |  |  |  |
| 1. Demonstrates knowledge and understanding of the key concepts
 |  |  |  |  |
| 1. Information reflected in the discussion is accurate
 |  |  |  |  |
| Presentation of Ideas |  |  |  |  |
| 1. Group shows clear grasp of the issue discussed and how the concepts in the module relate to the issue
 |  |  |  |  |
| 1. Group consistently posts insightful comments and questions that prompt on-topic discussion.
 |  |  |  |  |
| 1. The participants consistently help clarify or synthesize other group members' ideas.
 |  |  |  |  |
| 1. Group members actively participate in the discussion.
 |  |  |  |  |
| 1. Synthesis is done with a wrap up at the end of the discussion
 |  |  |  |  |
| Etiquette |  |  |  |  |
| 1. Group responds to their peer’s questions courteously.
 |  |  |  |  |
| 1. Group displays an openness to new ideas.
 |  |  |  |  |
| 1. If disagreeing with another group members' ideas, the participant stated his or her disagreement or objections clearly, yet politely.
 |  |  |  |  |
| TOTAL |  |  |  |  |

**Multimedia resources:**

<https://www.texasgateway.org/resource/food-chains-food-webs-and-energy-pyramids>

(with activities and videos)

<https://ocw.mit.edu/high-school/biology/exam-prep/ecology/communities-ecosystems/biogeochemical-cycles-overview/>

<https://www.khanacademy.org/science/biology/ecology/biogeochemical-cycles/v/biogeochemical-cycles>

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