

## CHAPTER 3 MATTER, ENERGY, AND LIFE

### Chapter Overview

Knowledge of basic chemistry is necessary to understand chemical processes that occur in the environment. pH and its application to terrestrial and aquatic ecosystems is an important concept. The bulk of the chapter information, as it pertains to the AP exam, revolves around the biogeochemical cycles and species interactions.

### Topics and Key Concepts

#### Earth Systems and Resources

- Correlate pH and pOH to hydrogen and hydroxide ion concentration, and describe the role of buffers.
- Diagram the hydrologic, carbon, nitrogen, sulfur and phosphorus cycles.

#### The Living World

- Define and hierarchically organize the terms cell, organism, species, population, community, ecosystem, and biome.
- Summarize the ecological significance of trophic levels, and diagram examples of food chains, food webs, and ecological pyramids.
- Explain how energy is harnessed and transformed in photosynthesis and cellular respiration.
- Describe matter, atoms, molecules, ions, and isotopes, and give examples of the role of the four major kinds of organic compounds in living organisms.

#### Energy Resources and Consumption

- Paraphrase the laws of conservation of matter and thermodynamics, and correlate them to energy flow through an environment.
- Differentiate kinetic energy, potential energy, chemical energy, and thermal energy (heat).

### Key Terms

acids	chemical energy	food chain	omnivore
*aerobic respiration	chemosynthesis	food web	organic compounds
*ammonification	compounds	heat	pH
*anaerobic respiration	conservation of matter	herbivore	phosphorus cycle

*assimilation	consumer	hydrologic cycle	photosynthesis
*atomic number	decomposer	ions	population
atoms	deoxyribonucleic acid (DNA	*inorganic compounds	potential energy
bases	*denitrification	isotopes	producers
biological community	detritivores	kinetic energy	productivity
biomass	ecology	*lipid	*protein
*carbohydrate	ecosystem	matter	scavenger
carbon cycle	elements	metabolism	second law of thermodynamics
carbon sinks	energy	molecule	species
carnivores	entropy	nitrogen cycle	*thermal energy
cells	enzymes	*nitrification	trophic level
cellular respiration	first law of thermodynamics	*nitrogen fixation	

*\* These key terms are not boldfaced in the chapter text, but are still important for the AP Exam.*

## Pacing Guide

Since this chapter is the backbone for chapters to follow, it would be detrimental to not spend ample time on the concepts that are so vital to the foundation of environmental science. Spend 8-10 class days on this chapter with the bulk of the time spent on the latter half of the chapter.

## Approach and Tips

Begin with a quick review of the parts of the atom, atomic number and mass, and the difference between an element and a molecule or compound. Although the students have been exposed to this material for many years, it does not hurt to spend a moment now and determine if the information they remember is correct or if there are gaps in their knowledge. Many students that you are teaching may not have had chemistry, so you may need to spend additional time on this topic. When discussing ionic bonds, use  $MgCl_2$  rather than  $NaCl$  so the students understand the relationship between atoms when they are oxidized or reduced. Focus also on the conservation of matter and the laws of thermodynamics. Students need to understand these laws in order to understand how energy is moved around in an ecosystem. Also, it is important for the students to understand pH and how it applies to ecosystems. It is very helpful to conduct a titration lab so that students can understand the relationship between acids, bases,

and salts, and why environmental solutions are typically buffers to ameliorate chemicals in nature. It will reappear when the topic of acid precipitation is covered.

Be sure the students know the four basic elements that make up most of the mass of living organisms: carbon, hydrogen, oxygen, and nitrogen. Briefly describe the major macromolecules found in living cells: proteins, nucleic acids, lipids, and carbohydrates. Students need to know the elements which comprise these organic compounds. It is more important to know application of these compounds and the roles they play in the organism. DNA is the most important compound as it codes for heredity and is involved in evolution and natural selection.

The students need to know that most of all the energy on Earth originates from the Sun. The role that plants play in capturing this energy through the process of photosynthesis is a process that all AP students need to know. The processes involved in photosynthesis should be related to food chains and materials cycling, but the students do not need to focus on the specifics of the light and dark reactions during class time. But, they should know the basic chemical equation. Students need to know the difference between gross and net primary productivity (net productivity = gross productivity – respiration) in plants. GPP and NPP are both rates, so they will be given as mass/area/time, for example, kg/m<sup>3</sup>/day.

Move from the biochemical aspects of the chapter to the physical science aspects when you cover the section on energy. Another quick refresher on potential and kinetic energy and the difference between low quality energy versus high quality energy should take less than one class period. As you move into the study of energy and alternative energy supplies, this background information will be helpful.

Illustrate the concept of species connectedness by using food webs and food chains. The hierarchy of organisms from species to ecosystem can be explained by using specific examples. Review terminology such as herbivores, carnivores, omnivores, scavengers, decomposers, or detritivores. Be sure that students can differentiate between decomposers and detritivores.

The concept of ecological pyramids should be understood by all students. Emphasizing the levels of biomass and energy at each level are important for success. In addition, a student should be able to classify organisms as producers and consumers as well as herbivore, carnivore, omnivore. The students need to be able to draw a food web, food chain and an ecological pyramid or a trophic level diagram. The trophic level pyramid/diagram must indicate the energy or biomass at each level, knowing that anywhere from 5-20% is retained at each level, with the average being 10% if not expressed directly.

The five biogeochemical cycles need to be covered in detail, emphasizing the nitrogen and hydrologic cycles. The details of the nitrogen cycle are particularly important. The Dead Zone in the Gulf of Mexico is a good case study to explain the nitrogen cycle and how anthropogenic causes can create environmental problems. Eutrophication and its effects should be explained. Emphasize that the carbon cycle consists of two processes: photosynthesis and cellular respiration. Stress to the students that nutrients cycle and that all of the biogeochemical cycles are important. Also, the significance of the hydrologic cycle with reference to the other cycles should be learned. Specifically, how run-off of the other nutrients may alter the environment. Knowing how humans have altered the rate of materials cycling can have global consequences and can be explained using specific examples.

Finally, relate the potential energy and the food chain information to the life processes and materials cycling material presented in the chapter. Spend time discussing sources and sinks in both materials and energy cycling, as this topic will be discussed throughout the course. Also discuss how humans can impact each cycle by citing several examples. Along with the examples, remediation techniques are also helpful.

## Common Mistakes and Misconceptions

The most common mistake that students make is with reference to food webs. When asked to complete a food web, students need to make sure that the arrows are pointing in the correct direction -following the flow of energy. Students also forget to include decomposition as the reason for anoxia in eutrophication. The algae make oxygen, not deplete it. It is the decay of the dead plant matter which reduced the oxygen.

## Activities

### Biogeochemical Cycles Activity

Part 1: Tell the students to review the biogeochemical cycles listed below. Have them summarize each biogeochemical cycle in either paragraph or bullet form and write two multiple choice questions with five possible answers for each of the three cycles. Tell them to be sure to include the correct answer.

Carbon Cycle Tutorial—be sure to discuss the relationship of photosynthesis and respiration.

- The carbon cycle is well explained on the NOAA website: <http://noaa.gov/resource-collections/carbon-cycle> and by NASA:

<https://science.nasa.gov/earth-science/oceanography/ocean-earth-system/ocean-carbon-cycle>

Phosphorus Cycle Tutorial—be sure to include the fact that the phosphorus cycle has no gaseous component and therefore is the longest cycling of all the biogeochemical cycles.

- Cornell University has a series of fact sheets on soils; the phosphorus cycle is well explained in the following PDF:  
<http://nmsp.cals.cornell.edu/publications/factsheets/factsheet12.pdf>

Nitrogen Cycle Tutorial—be sure to explain nitrogen fixation, the role of nitrifying bacteria, ammonification, assimilation, and denitrification.

- A cheat sheet for the steps of the nitrogen cycle is included at the end of this chapter
- The NRCS has a nice explanation of the role of bacteria in the soil, which may be helpful for the students to understand the processes involved in the nitrogen cycle:  
<https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/biology/>

Part 2: Have students complete the following:

Sulfur Cycle —Investigate the sulfur cycle using the Cornell fact sheets (<http://nmsp.cals.cornell.edu/publications/factsheets/factsheet34.pdf>) and draw a diagram of the cycle. Be sure to explain the common sources and ecological importance of the following sulfur compounds/molecules/ions.  
 $\text{SO}_4^{2-}$ ,  $\text{SO}_2$ ,  $\text{CH}_3\text{SCH}$ ,  $\text{H}_2\text{SO}_4$ ,  $\text{S}^{2-}$

Hydrologic Cycle—Watch the animations provided by NOAA ([http://www.nwrfc.noaa.gov/info/water\\_cycle/hydrology.cgi](http://www.nwrfc.noaa.gov/info/water_cycle/hydrology.cgi)) Diagram the hydrologic cycle including the role of condensation, precipitation, infiltration, runoff, and evapotranspiration.

## Food Web Activity

Several food web activities can be found on the Internet. The activities that incorporate “what ifs” are effective when teaching this subject. When having students construct food webs, emphasis on the direction of the arrow is crucial. The arrow must point in the direction that the energy flows through the food chain or web. Therefore, it points towards the consumer.

### **Calculating for Gross and Net Primary Productivity Rates**

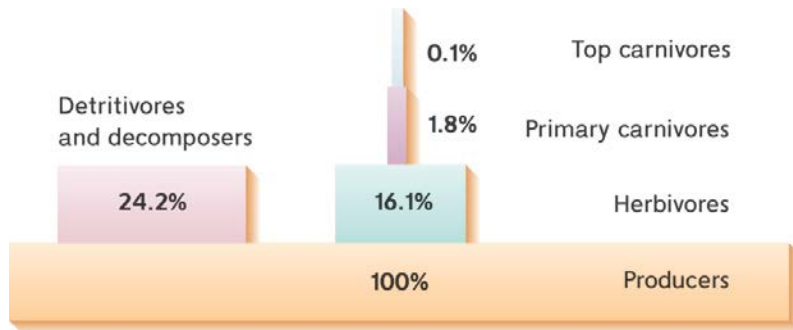
Visit College Board's AP Central website and use the Special Focus: Ecology pdf to help students work ecological calculations beginning on page 77.

[http://apcentral.collegeboard.com/apc/public/repository/Environmental\\_Science\\_Ecology\\_Special\\_Focus.pdf](http://apcentral.collegeboard.com/apc/public/repository/Environmental_Science_Ecology_Special_Focus.pdf)

### **Nitrogen Cycle Review**

Have students review the steps and importance of the nitrogen cycle using the worksheet attached at the end of this chapter.

## Questions for Review



1. Only about 10 percent of the energy in one consumer level is represented in the next higher level in an energy pyramid. Why is there so much less energy?  
*Energy transfer through the trophic levels is very inefficient. Most of the energy an organism gains through consumption of food is dissipated as heat.*
2. How have human activities altered the material cycling of nitrogen? What is meant when nitrogen is referred to as a limiting factor?  
*The nitrogen cycle has been altered primarily through the use of inorganic fertilizers in agricultural production. Fertilizers containing nitrates can run-off into waterways leading to eutrophication. Nitrogen in different ions and/or compounds is used by plants for growth. When nitrogen is a limiting factor, it means there is not enough nitrogen, and plants will not be able to grow at their maximum rate.*
3. What is the difference between a carbon sink and a carbon flux?  
*A carbon sink is a reservoir that accumulates carbon. Carbon flux is the difference between carbon removal and carbon addition.*
4. Why is it better to eat lower on the food pyramid? Think in terms of energy.  
*Since only 10% of energy is transferred from one trophic level to another, the lower levels have more energy available.*

## Practice Questions

### Multiple Choice:

*Directions for questions 1-5:* The lettered choices below correspond to the descriptions given in questions 1-5. Select the one lettered choice that best fits each statement. Each choice may be used once, more than once, or not at all.

- (A) Nitrogen fixation
- (B) Denitrification
- (C) Assimilation
- (D) Nitrification
- (E) Ammonification

1. Process carried out by cyanobacteria
2. Bacteria convert ammonia into nitrates
3. Decomposition of organic material into ammonia
4. Conversion of ammonia to molecular nitrogen
5. Process carried out in the root nodules of a legume

*Directions:* For each of the following questions, select the one lettered choice that best answers the question.

6. A pH of 2 corresponds to a  $[H^+]$  equal to
  - (A) 0.1 M
  - (B) 0.01 M
  - (C) 1.0 M
  - (D) 2.0 M
  - (E) 0.2 M
7. Which of the following is an example of potential energy?
  - (A) Water flowing in a river
  - (B) An insect flying from flower to flower
  - (C) A rock at the top of a cliff
  - (D) A car speeding down the highway
  - (E) A horse galloping



8. A complex interconnectedness of who eats what, including producers, consumers, and decomposers.
- (A) food chain
  - (B) food web
  - (C) ecosystem
  - (D) community
  - (E) biomass

Use the following scenario to answer questions 8 & 9.

In a meadow a student made several observations. She observed a mouse eating left over grain from a horse. The mouse was swiftly captured by an American kestrel. Butterflies were observed feeding on horse manure while the horses grazed in the meadow.

9. At which trophic level is the American kestrel feeding?
- (A) First
  - (B) Second
  - (C) Third
  - (D) Fourth
  - (E) First and fourth
10. The horse in the scenario is a \_\_\_\_\_.
- (A) decomposer
  - (B) top level carnivore
  - (C) producer
  - (D) tertiary consumer
  - (E) primary consumer

Free-Response Question:

*Directions:* Answer all parts of the following question. Where explanation or discussion is required, support your answers with relevant information and/or specific examples.

1.

There is a pond on Creekside Farm. This pond is surrounded by a cattle pasture and land that is used to raise hay. On the edges of the pond it has been observed that great blue herons feed on blue-gilled sunfish and minnows. Frogs jump about on the sides of the pond eating stonefly and crane fly larvae. The sunfish and minnows also eat both fly larvae. The stonefly and crane fly larvae feed off of the phytoplankton and algae. The blue-gilled sunfish also eat minnows. Occasionally, a snapping turtle eats frogs and both species of fish.

- (a) Diagram a food web for the scenario.
- (b) Describe one food chain of the food web that you diagrammed in part (a). A trophic level pyramid might be helpful. Be sure to label each level.
- (c) If the biomass of the phytoplankton is 1000 kg, what is the biomass of the great blue herons?
- (d) Where does the energy for this system originate? What process makes this energy useful to the ecosystem?
- (e) The owners of the farm have noticed an increase in algae during the summer months. What is one probable cause for this increase? What can happen if this situation goes unchecked? Explain one way that the owner could remedy this situation.

## Answers to Practice Questions

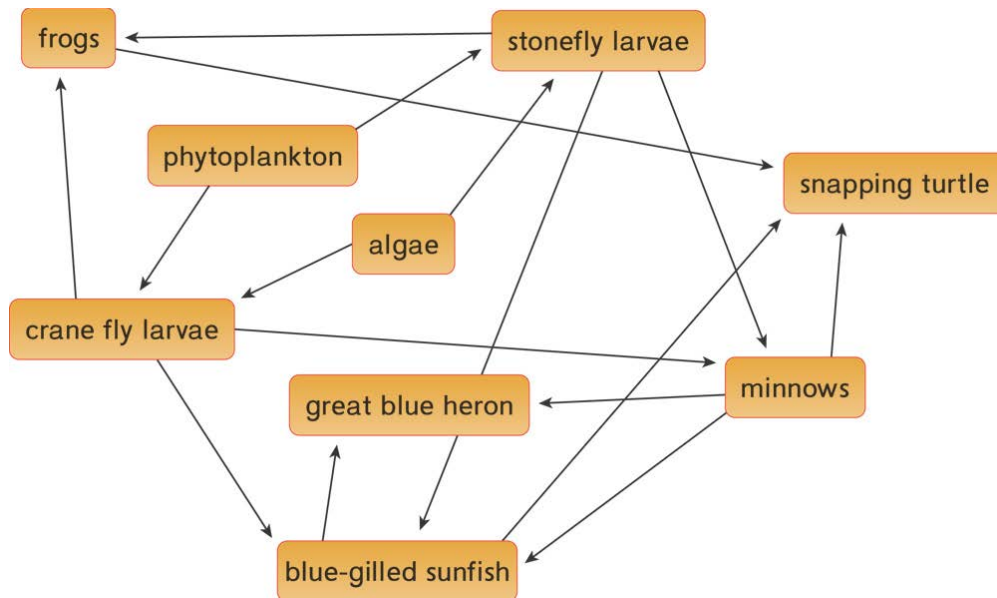
### Multiple Choice:

1. A
2. D
3. E
4. B
5. A
6. B
7. C
8. C
9. C
10. D

### Free-Response Question:

Most AP questions are 10 points. This question is based on 10 points.

1. (a) 2 points total: 1 point for all species connected properly and 1 point for arrows pointing in the correct direction.

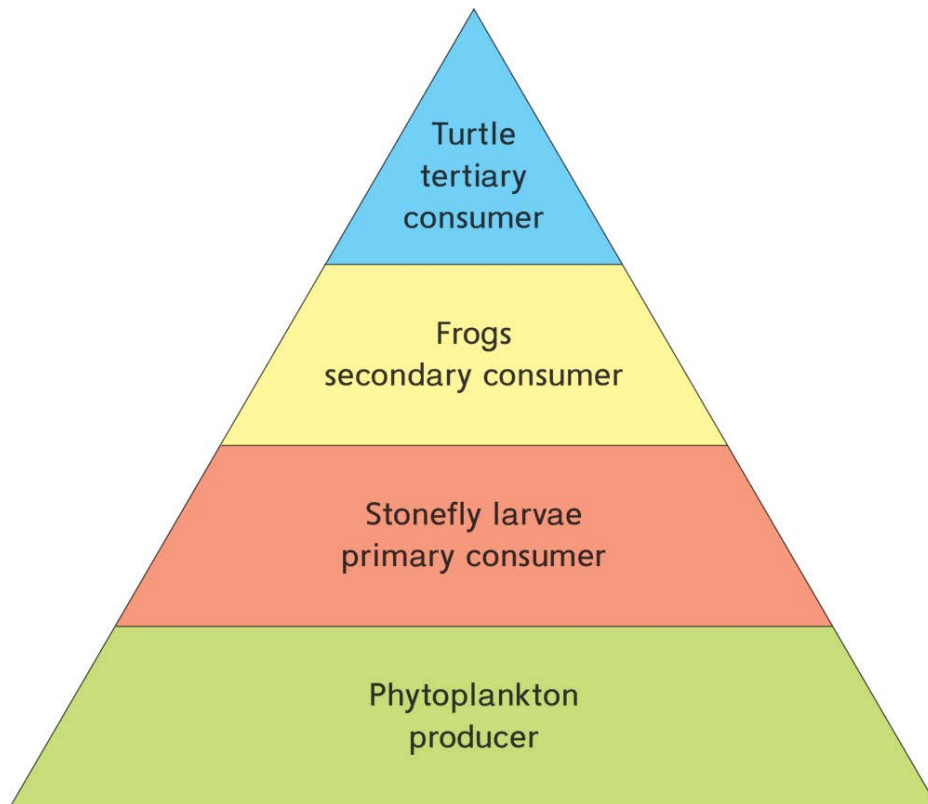


- (b) 2 points total. One point for the food chain/trophic level pyramid and one point for the correct labeling.

Food chain: Any one of the connections would be acceptable. For example:

phytoplankton → stonefly larvae → frogs → snapping turtle

or



- (c) 1 point for the correct answer. Remember 10% biomass is retained from 1 level to the next. Since the great blue heron is on the top level (fourth level) and only 10 % is retained, the correct answer is 1 kg.
- (d) 2 points for each part: 1 point for indicating that the Sun is the source of energy for this ecosystem, 1 point for indicating photosynthesis allows the energy from the sun to be converted into glucose for use by higher level organisms

- (e) 3 points total: 1 point for the cause of the algal bloom, 1 point for the problem caused if this goes unchecked, 1 point for the remedy.

There are two possible causes for the algal bloom. Both involve runoff. High nutrient input from either cow manure or fertilizer will produce eutrophication or nutrient overload, leading to an algal bloom. A clear explanation involving runoff of either component which in turn increases nutrients causing an algal bloom is acceptable.

The second response should include the concepts of eutrophication, algal bloom and possible death of fish.

The remedy for this problem should be simple since the students have not had more detailed instruction. Simply using less fertilizer or no fertilizer will reduce amount of runoff thus reducing possible algal blooms. The other solution is to simply move the cattle so that they are not in close proximity to the pond.

## Answers to Student Edition Questions

### Document-Based Question (p. 51)

- (A) Phytoplankton blooms can support growth of fish and invertebrates and can increase the dissolved oxygen in an area. However, large, dense blooms caused by large nutrient inputs cause blooms that are too big for plankton eaters to consume. Dense blooms of only one phytoplankton species can quickly use up all of the nutrients in an area. Once the nutrients are depleted the bloom quickly dies off and sinks to the bottom of the bay, where this large input of organic matter is decomposed by aerobic bacteria. The aerobic bacteria consume all of the oxygen in the area, creating a “dead zone” of very low or no oxygen. Dense blooms also block sunlight from reaching plants near the bottom, and without sunlight they cannot photosynthesize so these plants may die. Sedentary benthic organisms that cannot leave the dead zone to more oxygen-rich waters may die in the oxygen depleted areas.
- (B) TMDLs have been set, but many of the goals are set on a timeline, some of which are not until 2025. It can be difficult to get businesses and people that are accountable for the pollution to change their current practices to less wasteful practices, especially if the business or person has to use their own money to implement the change. Policies involving environmental change are often slowly implemented and it takes time to see results. In

addition, TMDLs are still set above levels that would naturally occur (sometimes 4-5 times higher), so even when all TMDLs are met, the bay may not reach 'A' status.

- (C) Reasons that make restoring the Chesapeake Bay difficult include: the bay is large and has a very large watershed that drains into it, the bay is home to several large ports with a large amount of ship traffic, the watershed that drains into the bay covers 7 states and implementing laws that include more than one state can be very difficult, and with such a large watershed it is difficult to identify accountable parties and who punishes the accountable parties if they are not following the policy.

### **Use the Math (p. 54)**

Normal rain (pH 5) has 100 times as many H<sup>+</sup> ions per unit volume than pure water (pH 7) has. (To find this number count the number of pH units and add that many 0s.) Soda pop (pH 3) has 10,000 times as many H<sup>+</sup> ions. Vinegar (pH 2) has 100,000 times as many H<sup>+</sup> ions. Sea water (pH 8) is more basic than pure water (pH 7).

### **Use the Math (p. 63)**

16.1% of primary production energy is captured by herbivores. 11.2% of energy from herbivores is captured by primary carnivores. 0.62% of energy from herbivores is captured by top carnivores.

### **Multiple-Choice Questions**

1: b. The algae have 10,000 kcal of energy. By assuming that 10 percent of the energy is available to subsequent trophic levels, the zooplankton have 1,000 kcal available and the minnow would have 100 kcal available.

2: b. Simple sugars, carbohydrates, and lipids contain the elements C, H, and O. In addition to those three elements, proteins also contain N. DNA is the only choice that has P as part of its structure.

3: a. Neither cellular respiration nor photosynthesis produces hydrogen, nitrogen, or methane gas. None of those gases were mentioned as a part of the life-sustaining energy conversions found in photosynthesis and respiration. The choices are between carbon dioxide and oxygen gas. Respiration uses oxygen and produces carbon dioxide as a by-product.

- 4: e. Water has a high heat of vaporization, expands as it freezes, and is polar. Cohesion is the tendency for water to stick to itself.
5. e, 1000. The pH scale is logarithmic; each step down in pH indicates a solution that is 10 times more acidic.
6. c. All other choices are examples of potential energy.
7. c. The hyenas are scavengers.
8. b, community.

### Data Analysis & Free-Response Questions

1a. The usual limiting factors for growth of phytoplankton in an aquatic ecosystem include nitrogen and phosphorus. When either increase (usually from man-made sources), populations can explode resulting in eutrophication.

1b. A simplified food web for a coastal ecosystem can be created by modifying the terrestrial example in Figure 3.14. It should include these categories and may include some of the following examples:

Primary Producers (autotrophs): phytoplankton, algae, seagrass

Primary Consumers (herbivores): zooplankton, sea turtles, fish

Secondary Consumers (carnivores): fish, birds

Tertiary Consumers (top carnivores): sharks, alligators

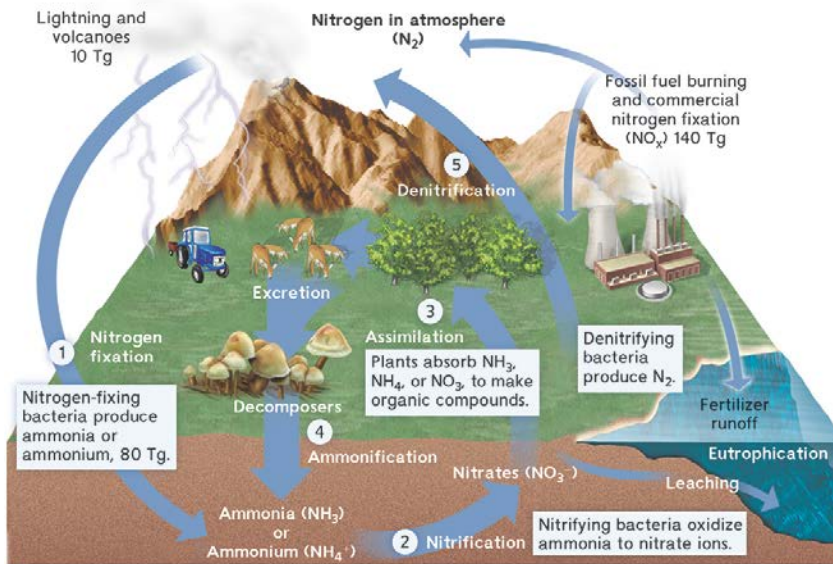
The phytoplankton's normal role is as a primary producer, or autotroph.

1c. The first law of thermodynamics states that energy is conserved (neither created nor destroyed). In energy transfer in a food web, the energy available in a consumed organism is taken by the consuming organism. The second law of thermodynamics states that with each successive transfer, less energy is available to do work (energy is degraded to lower-quality forms). Energy is used by each organism for maintenance – each time a cell does work, it takes energy, resulting in less energy available for higher trophic levels. Some of this energy is also “lost” in the form of heat.

2a. The largest dead zone was approximately 22,000 square kilometers in size, and the smallest dead zone was approximately 4,000 square kilometers in size.  $[(22,000 - 4,000)/4,000]*100 = 450\%$  increase.

2b. The highest moving average is for the year 2007.

## Nitrogen Cycle Analysis



**Assimilation**—process of the transformation of external substances and materials into substances and materials internal to the body.

**Nitrogen Fixation**—process by which nitrogen is taken from its ambient form ( $N_2$ ) in the atmosphere and converted into nitrogen compounds (such as, ammonia, nitrate and nitrogen dioxide) useful for other chemical processes. This is done by bacteria or lightning.

1. What are two ways nitrogen in the air ( $N_2$ ) may be converted to usable nitrogen compounds?
  
2. What are three nitrogen compounds produced in the nitrogen cycle? Name the three and write out the chemical formula.
  
3. What role do decomposers play in the nitrogen cycle?
  
4. Define nitrogen fixation.
  
5. Why is nitrogen important for plants and animals? (hint: assimilation)
  
6. How do animals obtain the major biomolecule necessary for their survival?



7. How does nitrogen re-enter the atmosphere?
  
8. Excess nitrogen in bodies of water can spur plant and algae growth. What can cause excess nitrogen to collect in a body of water?
  
9. Define *eutrophication*.
  
10. Place the following steps in order
  - \_\_\_1\_\_\_ Nutrients enter a pond
  - \_\_\_\_\_ Increased decomposition occurs
  - \_\_\_\_\_ Plants die
  - \_\_\_\_\_ Fish and other organisms die
  - \_\_\_\_\_ Oxygen is depleted
  - \_\_\_\_\_ Excessive algae growth occurs
  - \_\_\_\_\_ Sunlight is blocked

### Quick Cheat Sheet

PROCESSES	END PRODUCTS
<b>F</b> ix (Nitrogen Fixation)	<b>A</b> mmonia
<b>N</b> itrification	<b>N</b> itrates
<b>A</b> ssimilation	<b>P</b> rotein
<b>A</b> mmonification	<b>A</b> mmonia
<b>D</b> enitrification	<b>N</b> itrogen gas

Students have a difficult time remembering the processes of the nitrogen cycle and their products. This document provides a quick study tool to recall the end products of the major processes of the nitrogen cycle. The acronym FNAAD and ANPAN should be learned along with the outcome of each process.