GEO/OC 103
Exploring the Deep…

Lab 8

Reading 4.3

Resources for productivity

Mean, green food-making machines

With few exceptions, life on Earth depends on **photosynthesis**, the biological process that converts solar energy and inorganic compounds into food. Only autotrophs or "producers," including green plants and phytoplankton, are capable of photosynthesis. They contain the pigment **chlorophyll**, which uses solar energy to convert carbon dioxide and water into carbohydrates (Figure 1 at left). The amount of carbon converted to food by autotrophs is referred to as **primary productivity**. Autotrophs use some of this food immediately, and store the remainder for later use, to be converted back to energy through the process of **respiration**. Phytoplankton are consumed by other organisms which are, in turn, consumed by other organisms up the food chain. Collectively, these consumer organisms are called **heterotrophs**.

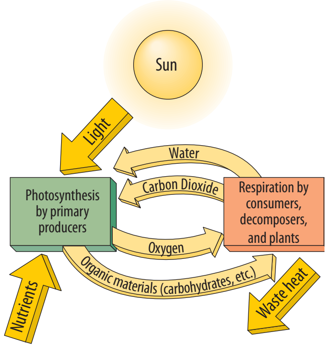

Figure 1. Photosynthesis and respiration.

Exceptions to the rule

Green plants and phytoplankton are not the only organisms capable of synthesizing their own food. In the last 40 years, scientists have discovered biological communities that are not based on the sun's energy. The autotrophs in these communities are microbes that convert carbon dioxide and water into food using chemicals rather than sunlight. This process is called **chemosynthesis** (Figure 2 at left). Chemosynthetic bacteria thrive in the high temperatures and pressures of environments like deep-sea volcanic vents. They synthesize food using the chemical energy of sulfur compounds emerging from the vents. Chemosynthesis supports a diverse community of organisms (Figure 3 bottom left).

NOAA

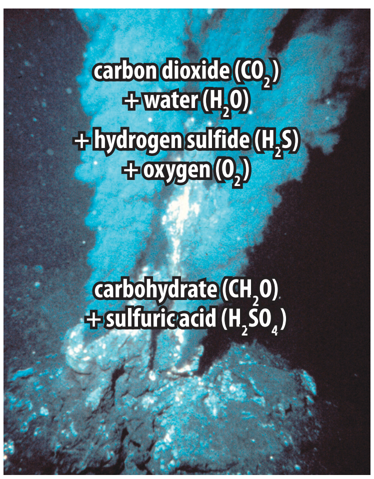

Figure 2. Process of chemosynthesis.

NOAA

Figure 3. Tube worms at hydrothermal vents consume chemosynthetic bacteria.

Food for thought—bottoms up!

Food webs illustrate the feeding relationships among organisms in a biotic community. The arrows represent the transfer of energy from one organism to another through consumption (Figure 4 at right). Autotrophs produce most of Earth's atmospheric oxygen as a by-product of photosynthesis, and are the foundation of nearly all terrestrial and aquatic food chains. Thus, primary productivity in terrestrial and marine environments is a key indicator of the overall health of the environment. Our ability to monitor primary productivity has profound economic and environmental importance.

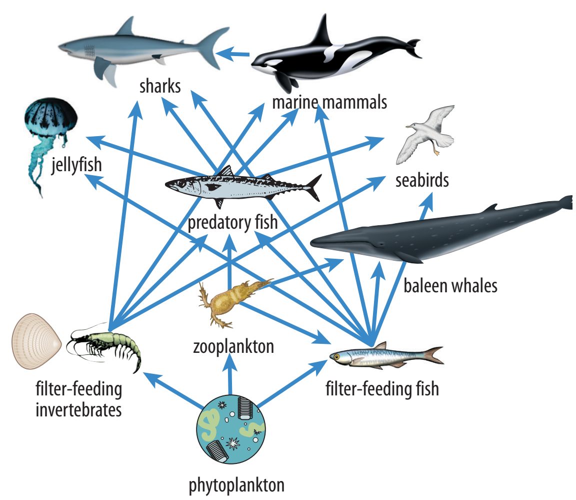

Figure 4. Marine food web.

1. Compare and contrast the two processes that autotrophs use to synthesize food.

2. What does the number of arrows leading *from* one organism to others suggest about that organism's importance in the food web?

3. What does the number of arrows leading *to* an organism suggest about that organism's likelihood of becoming endangered or extinct?

Resources for photosynthesis

Primary productivity levels vary with season and geographic location. You have identified and examined regions of extremely high and low productivity on land and in the ocean. These patterns of productivity are dictated by the availability of the resources necessary for photosynthesis. Autotrophs require carbon dioxide, water, sunlight, and nutrients to photosynthesize (Figure 1). When these resources are not present in adequate amounts for photosynthesis, they are referred to as limiting factors. Below, you will examine the likelihood of each resource being a limiting factor in productivity.

Carbon dioxide

Carbon dioxide is not likely to be a limiting factor in terrestrial or marine photosynthesis because it is plentiful in the atmosphere, as a result of respiration and human activities. As organisms convert food into energy, they release carbon dioxide (Figure 1). When humans burn fossil fuels like petroleum, coal, and natural gas, huge quantities of carbon dioxide are released into the atmosphere. Carbon dioxide is readily absorbed into the ocean from the atmosphere, so it is in good supply there as well.

Water

Water can often be a limiting factor for productivity in terrestrial environments. Productivity in deserts is typically very low because deserts lack the water needed to sustain all but the hardiest plants. In the ocean, obviously, water is never a limiting factor.

Sunlight

In the context of productivity, the sun's most important role is providing the light energy that drives photosynthesis. The availability of light to autotrophs varies, depending on latitude, season, and time of day. Therefore, there are places and times where sunlight is a limiting factor.

Nutrients

Organic or inorganic?

The terms **organic** and **inorganic** originally came from the idea that chemical compounds could be divided into two categories: those coming from or composed of plants or animals (organic), and those extracted from minerals and ores (inorganic).

Chemists now think of organic compounds as those that contain carbon. This definition works well for most compounds, but there are exceptions. For example, carbon dioxide is a carbon-based compound, but it is not considered organic.

Autotrophs use inorganic compounds containing nitrogen, phosphorus, potassium, calcium, silicon, and iron to build organic molecules. The concentrations of these **nutrients** vary throughout the environment. Nitrogen and phosphorus are particularly important because they are required in large quantities and play a critical role in growth and reproduction. Inorganic forms of nitrogen are the building blocks for amino acids, proteins, and genetic material (DNA, RNA). Similarly, phosphorus is an essential component of energy transport molecules (ATP), genetic material, and structural materials (bone, teeth, shell).

Despite the abundance of nitrogen gas in the atmosphere, it is often a limiting resource because it can be utilized by autotrophs only in certain forms. In the **nitrogen cycle**, nitrogen gas is converted to its most useful form, nitrate, through a series of reactions carried out by bacteria and fungi in the soil (Figure 5). Nitrates may be utilized by land plants, or may be carried to the ocean in groundwater or runoff and used by phytoplankton.

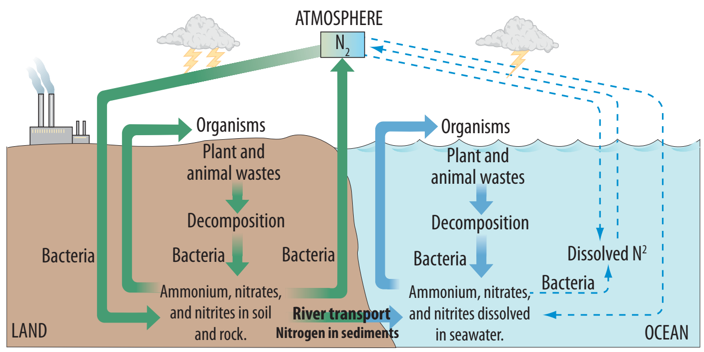

Figure 5. The nitrogen cycle.

Unlike nitrogen, phosphorus never exists as a gas. Phosphorus originates in rocks in Earth's crust in the form of phosphate salts, which are liberated from rocks by weathering (Figure 6). Phosphates are also an ingredient in some detergents and fertilizers. Precipitation carries phosphates into the soil, and runoff and ground water transport them to the ocean.

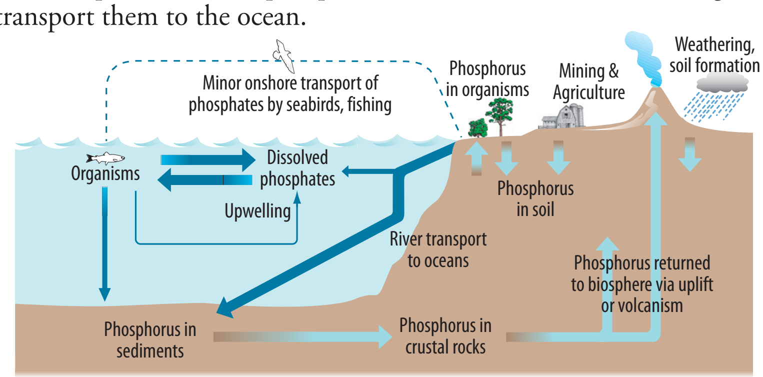

Figure 6. The phosphorus cycle.

4. Various human activities contribute additional nutrients to the ocean ecosystem. How might these additions influence marine productivity?

Sources of nutrients

Most of the nutrients utilized by phytoplankton in surface waters originate on land. Nitrates and phosphates in the soil dissolve easily in water. These nutrients are easily leached or removed from the soil by precipitation and runoff, and are carried by groundwater, streams, and rivers to the ocean. Near the coasts, phytoplankton thrive on the nutrients entering the ocean from land, resulting in high productivity. However, large portions of the nutrients entering the ocean are not utilized and eventually sink to the ocean floor, accumulating in the sediment.

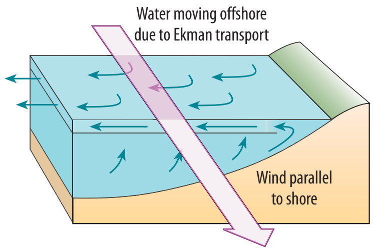

Figure 7. Coastal upwelling.

Not all nutrients enter the ocean from land. When marine plants and animals die they sink to the bottom, where decomposition liberates the nutrients, making them available for use again. However, except in shallow waters over the continental shelf, the nutrients on the ocean bottom can be utilized only when they are brought from the depths to the surface via **upwelling**, the upward movement of deep, cold bottom water to the surface. Coastal upwelling occurs in nearshore environments where strong winds blow parallel to the shore (Figure 7). **Ekman transport** causes the surface currents to deflect away from the shore, which pulls deep, cold, nutrient-rich water toward the surface. As you learned in Investigation 2.2 and Reading 2.3, Ekman transport is an offset between a current direction and its associated wind. In the Northern Hemisphere Ekman transport is deflected to the right, and in the Southern Hemisphere Ekman transport is deflected to the left. This phenomenon is caused by the Coriolis effect and by the slowing and deflection of water due to friction among successively deeper layers of water.

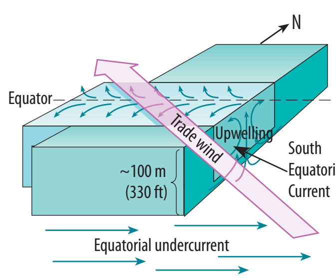

Figure 8. Equatorial upwelling.

Upwelling also occurs in the open ocean, near the equator. Equatorial upwelling is controlled by ocean currents—water moving westward on either side of the equator is deflected toward the poles and is replaced by cold, nutrient-rich water from below (Figure 8).

In the previous examples, upwelling is characterized by either winds or currents that move surface water and allow deeper water to "well up" in its place. The action of the wind or current is especially important in regions where there is a strong **thermocline**, a region where the water temperature changes rapidly with depth (Figure 9). Waters near the equator typically have a strong thermocline that traps nutrients in the cold, deep waters below, where they eventually sink to the ocean floor. At low latitudes, the mechanical action of strong winds or currents is necessary for nutrient-rich waters to penetrate the thermocline and rise to the surface.

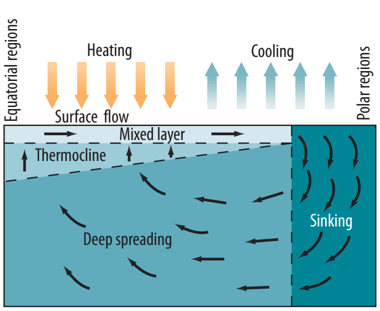

Figure 9. Schematic cross section of the ocean from equatorial to polar regions, showing change of depth to thermocline with changing latitude.

In contrast, in high-latitude regions, upwelling can occur without the help of strong winds. These regions receive little or no sunlight, resulting in a weak or nonexistent thermocline. As dense water sinks, it is replaced by an equal volume of nutrient-rich water rising from the adjacent depths.

5. What process makes nutrients in deep-ocean sediments accessible to marine phytoplankton drifting near the ocean surface?

6. Explain how the strength of the thermocline affects the availability of nutrients to primary producers.

7. Human activities can increase levels of nutrients in the ocean. Describe how human activities could influence the levels of *other resources* important in photosynthesis.

Too much of a good thing?

Previously, you observed that a shortage of one or more resources can decrease productivity. It may surprise you to learn that there can also be too much of a good thing when it comes to photosynthesis. For example, if the amount of solar energy received by the ocean were to intensify dramatically, tropical oceans could become too warm for photosynthesis to proceed properly.

Similarly, nutrients can be present in quantities so high that they become harmful. High levels of nutrients in coastal waters may cause a sharp increase in phytoplankton, which reduces light penetration, clogs the gills of marine organisms, and pollutes the water with waste products, some of which are toxic to other marine life. This may lead to **hypoxia**, a dramatic decrease in dissolved oxygen, or even **anoxia**, a total absence of dissolved oxygen, which can drive away mobile organisms and kill **sedentary organisms**.

sedentary organisms — organisms that are attached to a surface and cannot move freely.

Two conditions contribute to hypoxia in subsurface waters.

- **Stratification** or layering of the water column. Nutrient-laden runoff flowing into the ocean is less dense than salt water and floats on the surface. In summer, warm weather and calm seas inhibit mixing of the shallow, warm water with deeper, colder water. As a result, the oxygen from photosynthesis remains at the surface.

- **Increased decomposition** at depth, due to higher surface productivity. Phytoplankton die or are eaten by other organisms, creating large amounts of organic waste that sinks to the ocean floor. As the waste decomposes, nutrients are recycled but oxygen is also consumed, creating hypoxic conditions.

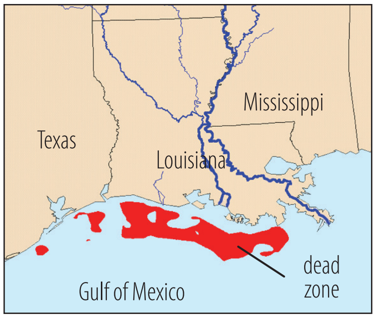

Figure 10. Location and extent of the 1993 Mississippi River dead zone.

The Gulf of Mexico is an important U.S. commercial fishery. In 2002, the Gulf accounted for 16.9 percent by weight (771,000 metric tons [850,000 U.S. tons]) and 24.7 percent by dollar value ($693 million) of the entire U.S. fish and shellfish catch. Each summer, a large hypoxic region known as the **Mississippi River dead zone** forms off the coast of Louisiana (Figure 10). The lack of dissolved oxygen in this region causes both the quantity and the diversity of economically important marine life to decrease dramatically, with potentially dire economic consequences.

8. Describe how an increase in nutrient levels can actually *lower* marine productivity in the marine ecosystem.

Is the Mississippi River dead zone unique?

In the United States alone, more than half of the estuaries experience hypoxia during the summer; up to a third experience anoxia.

9. Name two human activities that could result in an overabundance of nutrients being delivered to coastal waters. Explain your answer.

10. How might reduced light penetration affect primary producers as well as other animals higher up the food chain?

In the next investigation, you will examine changes in the Mississippi River dead zone from 1986 to 1993, and investigate patterns in the distribution of dead zones around the world.

Wrap-up 4.5

Searching for solutions

The Gulf of Mexico is suffering from the effects of industrial and agricultural pollution, population growth, and urban development. The Gulf receives 1.1 trillion m^3 (300 trillion gallons) of runoff each year that contains a vast collection of pollutants originating from factories, hog-waste ponds, heavily fertilized farms, golf courses, and residential lawns, as well as oily grime from urban runoff.

Although these chemicals pose serious health hazards, the added nutrients pose the biggest problem, triggering a series of events leading to the formation of the Mississippi River dead zone. Excess nutrients have also been implicated in the deaths of coral reefs, decline of sea-grass beds, occurrence of red tides, and declining health of *estuaries* around the Gulf of Mexico.

estuary — body of water where a river meets the ocean, mixing fresh river water with ocean water.

What are red tides?

Red tides are caused by seasonal reproductive surges, or blooms, of certain species of marine algae. During a bloom, colored pigments in these tiny one-celled plants discolor the ocean surface, giving it a reddish-brown appearance.

Most of these algae species are harmless, but a few produce potent chemical neurotoxins (poisons that affect the nervous system). These toxins cause widespread fish kills, contaminate shellfish, and can be deadly to humans and other animals that eat contaminated seafood.

1. Describe the cascade of events that leads to the formation of a dead zone, beginning with the addition of excess nutrients. Be sure to discuss how the presence of excess nutrients affects primary producers and other consumers in the food web.

Although the Mississippi River dead zone is the largest in the United States, it is not the only one. Next you will determine the effect your community has on dead zones off the U.S. coasts.

- Launch ArcMap, and locate and open the **etoe_unit_4.mxd** file.

Refer to the tear-out Quick Reference Sheet located in the Introduction to this module for GIS definitions and instructions on how to perform tasks.

- In the Table of Contents, right-click the **U.S. Dead Zones** data frame and choose Activate.
- Expand the **U.S. Dead Zones** data frame.

This data frame shows the major rivers and watersheds in the contiguous United States. Find the approximate location of your city or town on the map.

- Using the Zoom In tool, locate and zoom in on the region you live in.
- Click the Identify tool.
- In the Identify Results window, select the **Major Rivers** layer from the drop-down menu.
- Next, click on the major river nearest to your town.

2. What major river carries runoff from your region to the ocean?

- In the Identify Results window, select the **Major Watersheds** layer from the drop-down menu.
- Click on the watershed in which your town is located.

3. What is the name of the major watershed in which your town is located?

- Close the Identify Results window.

Science can tell us a lot about how dead zones are created and their impact on the environment. However, cleaning up dead zones requires significant changes in our behavior as a society.

Search the Internet to learn more about the sources of pollution, the economic impact of dead zones, and the technological solutions to the problem; then answer the questions below. Some starting Web sites are provided on the next page.

4. Discuss how your city or town contributes to the formation of a dead zone. Think about local residential, commercial, agricultural, and industrial practices.

mitigate — to make less severe.

5. Discuss how you might mitigate the negative impact of some of these activities.

Media Viewer shortcuts

To open these Web pages from within ArcMap, click the Media Viewer button and choose the appropriate entry from the list of Web sites.

Web sites on the Gulf of Mexico dead zone

Exploring Solutions

Potential Solutions for Gulf of Mexico's "Dead Zone" Explored

Discusses the impact of the dead zone as well as ecological and technological approaches to reducing the nutrient flow into the ocean.

http://researchnews.osu.edu/archive/hypoxia.htm

Dead Zone Research

Environmental Literacy Council

Provides an overview of the problem and links to major government and research groups investigating the problem and solutions.

http://www.enviroliteracy.org/article.php/1128.html

Hypoxia

National Center for Appropriate Technology (NCAT)

Discusses causes of hypoxia and the human activities that contribute to it. Also discusses approaches to reducing nutrient flow to the ocean.

http://www.ncat.org/nutrients/map.html

Red Tides

The Gulf of Mexico Dead Zone and Red Tides

Discusses the effect of the dead zone on the quality and quantity of fish and seafood stocks in the Gulf of Mexico.

http://www.tulane.edu/~bfleury/envirobio/enviroweb/DeadZone.htm

Gulf in Peril

Deep Trouble — The Gulf in Peril

Series of articles in the Naples (Florida) *Daily News* outlining all the issues facing the Gulf of Mexico and potential solutions.

http://web.naplesnews.com/deeptrouble/index.html

Quit ArcMap and do not save changes.