

CHAPTER 15

PRODUCTION AND LIFE

Objectives

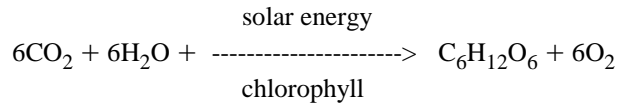
1. To examine the process of primary production in the oceans.
2. To learn what factors play a critical role in regulating primary production.
3. To look at patterns of primary production in the oceans and the ways in which we can measure rates of primary production.
4. To look at the total picture of production and consumption in the oceans.

Key Concepts

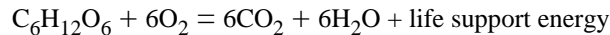
Major Concept (I) *Primary production can be divided into gross primary production and net primary production.*

Related or supporting concepts:

- Phytoplankton contain the pigment chlorophyll, which is used in photosynthesis to form new plant material.
- The production of new plant material through photosynthesis is called primary production. In this process, carbon dioxide and water are combined in the presence of sunlight to produce organic compounds (sugars) and oxygen.



- In primary productivity some of the complex organic compounds created by plants must be used by them to supply the necessary energy for life. This use occurs in the process called respiration, where sugars are broken down with the addition of oxygen to produce life support energy.



- The total mass of new plant material produced by photosynthesis is the gross primary productivity of the oceans.
- The ultimate gain of new organic material after some of the gross product has been consumed by the existing plant community is the net primary productivity.
- The total dry weight of organic carbon in the seas is called the biomass of the oceans.
- Primary production and biomass are typically reported as the mass of dry weight organic carbon in grams per unit area or volume.
- The term "primary productivity" is used to describe the rate at which biomass is produced by photosynthesis. It is usually expressed as grams of carbon per unit volume or surface area per day.
- The total plant biomass under one unit area of sea surface or in a volume of water is called the standing crop. The standing crop, at any given time, is determined by:
 - a. the growth of organisms,
 - b. the rate of reproduction,
 - c. the death of organisms, and
 - d. the amount of grazing by herbivores (fig. 15.1).

Major Concept (II) *Primary production is controlled by the ability of phytoplankton to remain in surface*

waters, which is often a function of the stability of the water column, and by the availability of both sunlight and nutrients. These factors vary seasonally and geographically.

Related or supporting concepts:

- At high latitudes:
 - a. There is a weakly stable surface layer during the summer months due to a slight warming of the water and the addition of low density fresh water to the surface from the melting of sea ice.
 - b. There is a dramatic change in the availability of sunlight seasonally. During winter months there is almost constant darkness and during summer months nearly constant light. The intensity of the light in the summer is very low, however, because the angle of the Sun's rays is low.
 - c. The abundance of nutrients is usually not a limiting factor because high levels of productivity are restricted to a short time period.
 - d. There is a short period of rapid growth in the midsummer (see fig. 15.2a) and the yearly productivity is controlled primarily by the availability of sunlight.
- At mid-latitudes:
 - a. The water column stability varies seasonally. Warm, low-density surface water in the summer creates a stable layer and organisms can remain near the surface easily. Surface cooling and storms in the winter result in vertical mixing.
 - b. The intensity and duration of sunlight vary seasonally, being greater in the summer than in the winter, but the change is not as dramatic as at high latitudes.
 - c. The abundance of nutrients also varies seasonally. Vertical mixing in the winter replenishes the nutrient supply near the surface after it has been lowered by higher levels of productivity over the spring and summer.
 - d. There are two growth spurts, one in the spring with the lengthening of the days and high levels of nutrients after the winter mixing, and a second in the midsummer. Productivity can be limited either by nutrient supply or sunlight (fig. 15.2b).
- At low latitudes:
 - a. The water column is quite stable throughout the year with warm, low-density surface water. Consequently, phytoplankton remain in the photic zone.
 - b. There is only a small change seasonally in the intensity of sunlight.
 - c. Because of the stability of the water column there is little vertical mixing to replenish nutrients in the photic zone.
 - d. Productivity is fairly constant with a slight increase during summer months. The level of productivity is limited primarily by the availability of nutrients (fig. 15.2c).

Major Concept (III) *Earth is essentially a closed system, so the nutrients necessary for life must come from recycled organic matter.*

Related or supporting concepts:

- Primary producers require nitrates and phosphates to grow and reproduce.
- In general, nitrogen and phosphorus must pass through a series of steps and organisms before they are in the form of nitrate and phosphate that can be used by plants. As an example, nitrogen gas is converted to ammonia, then to nitrite, and finally to nitrate.
- Nitrogen is essential in the formation of amino acids and proteins.
- Phosphorus is required in energy reactions, cell membranes, and nucleic acids.
- These nutrients are transported up the food chain into herbivores feeding on the phytoplankton and carnivores feeding on both herbivores and other carnivores.
- Nutrients are returned to seawater:
 - a. when organisms die and decomposers, such as bacteria and fungi, break down the tissue into basic molecules and nutrients, and
 - b. in the waste products of organisms.
- Human activities have approximately doubled the global rate of nitrogen fixation by terrestrial and

- aquatic bacteria between pre-industrial times (140×10^9 kg) and the present (280×10^9 kg).
- Excess nitrogen increases phytoplankton blooms. When this abundant biomass decomposes it consumes oxygen in the water. This can be harmful to other organisms in the environment.
- Some areas of the oceans have low primary productivity despite adequate amounts of nitrogen and phosphorus in the water. This is due to a lack of iron in surface waters.
- Iron is essential to marine organisms and can be a limiting factor for some populations. Low levels of iron have been shown to limit populations in subarctic and equatorial waters in the Pacific and southern oceans.
- The addition of soluble iron to surface water can cause a temporary increase in phytoplankton production until the iron reacts with other dissolved substances in the water and sinks.

Major Concept (IV) *The highest levels of primary productivity per square meter occur in the smallest geographical areas of the oceans near continents, while the lowest levels are found in the vast expanses of the open ocean.*

Related or supporting concepts:

- In discussing rates of primary productivity we can divide the marine environment into three regions. In order of decreasing productivity these are: zones of upwelling, coastal waters, and the open ocean.
- Zones of upwelling occur along the western coasts of continents in the Pacific and Atlantic oceans. Upwelling carries nutrient-rich water to the surface.
- Coastal waters are also very productive because nutrients are brought to the surface waters by tidal and wave turbulence as well as freshwater runoff from the land. Freshwater runoff also creates a low-density surface water layer that keeps phytoplankton near the surface.
- Relative rates of primary productivity in these three regions are (see fig. 15.7; table 15.1):

| <u>Region</u> | <u>Relative Rate of Productivity</u> |
|---------------|--------------------------------------|
| upwelling | 6.7 |
| coastal | 4 |
| open sea | 1 |

- The total area of each of these three regions is inversely related to its level of productivity. Relative areas are:

| <u>Region</u> | <u>Relative Area</u> |
|---------------|----------------------|
| upwelling | 1 |
| coastal | 10 |
| open sea | 89 |

- On average, upwelling areas are approximately two times more productive than coastal areas and about six times more productive than the open ocean.
- Total primary productivity is the product of the rate of primary productivity and the area over which it is taking place:

| <u>Region</u> | <u>Total Primary Productivity</u> |
|---------------|-----------------------------------|
| upwelling | 1 |
| coastal | 6 |
| open sea | 13.4 |

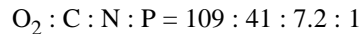
- Most of the organic material produced worldwide by phytoplankton is in low concentrations in the open-ocean waters because of the enormous area covered by open-ocean waters (89% of the ocean surface).
- Levels of gross primary productivity in the open ocean are similar to those in deserts on land. In coastal waters, it is similar to mid-latitude forests or pasture land, and in upwelling areas it is similar to

rain forests. (Compare the areas and magnitudes very carefully by studying table 15.2.)

Major Concept (V) *Absolute amounts of primary productivity in seawater samples may be measured by direct or indirect methods.*

Related or supporting concepts:

- There are a variety of direct ways to measure primary productivity including:
 - a. Phytoplankton can be filtered out a known volume of water and counted. The number of cells can then be multiplied by the average mass of an individual cell.
 - b. The chlorophyll can be extracted from a sample of phytoplankton and the concentration of pigment can be calculated. The chlorophyll concentration can then be used to estimate the biomass.
 - c. Chlorophyll pigment will fluoresce when exposed to certain wavelengths of light. If the intensity of fluorescence of a sample of plankton is measured it is possible to directly calculate the biomass. A fluorometer is used to measure fluorescence and can be attached to a CTD (conductivity-temperature-depth) sensor lowered through the water column, or carried by a robotic device such as SeaSoar (see chapter 6 in your text).
- Measurements of primary productivity often rely on the known ratios between the oxygen and carbon produced and the nitrogen and phosphorus consumed in photosynthesis. These ratios are:



- Knowing these constant ratios, the rate of primary productivity, as determined by carbon production, can be estimated simply by measuring one parameter, such as the rate of production of dissolved oxygen or the rate of uptake of a nutrient.
- Over seven times as much nitrogen is consumed in photosynthesis as phosphorus, thus the abundance of nitrogen is usually the limiting nutrient factor in rates of primary productivity. Our knowledge of this limiting process gives us tremendous predictive power for determining critical nutrients in oceanic ecosystems.
- The relationship between net and gross production in a given area can be determined with three water samples. One sample, the control bottle, is used to measure the concentration of dissolved oxygen in the water at the start of the experiment. The two other samples are returned to the depth at which they were obtained, one in a clear, or light bottle and the other in a dark bottle, shielded from light. Oxygen will be depleted from the dark bottle by respiration and produced in the clear bottle by photosynthesis. The net primary production can be determined by the difference in oxygen concentration in the clear bottle and the control bottle. The gross primary production can be measured by the difference in oxygen concentration between the clear and dark bottles (see experiment in fig. 15.8).
- Rates of primary production generally decrease with depth while rates of respiration remain nearly constant. At the compensation depth, net primary production is zero as the oxygen produced through photosynthesis equals that consumed by the phytoplankton in respiration.
- Global measurement and prediction of primary productivity can be enhanced by the use of satellite information on chlorophyll concentrations (assumed to be directly related to phytoplankton biomass). Satellite imagery can now be used to prepare maps of the global distribution of phytoplankton standing crop (see fig. 15.9).
- A series of satellite images taken over time can show changes in chlorophyll, or biomass, related to productivity.
- Changes in chlorophyll concentration are related to:
 - a. annual seasonal cycles of light intensity,
 - b. photic zone depth,
 - c. nutrients,
 - d. water temperature,
 - e. currents,
 - f. grazing by herbivores, and
 - g. population die-off.

- Plankton abundance is generally:
 - a. low in the centers of ocean gyres, and
 - b. high along coastal and upwelling areas.

Major Concept (VI) *Marine plants, herbivores, and carnivores are all linked in what are called food chains or more complex food webs. Together, they make up the total production of the sea.*

Related or supporting concepts:

- Each food chain or web usually has a broad base comprised of numerous organisms and plants and ends with a few or single organism as the top consumer.
- Towards the top end of a food chain or web we usually find larger, often more familiar, organisms. In the marine environment these may include the large fish such as tuna or swordfish, mammals such as seals and humans, and reptiles such as sea turtles.
- These larger organisms survive by eating smaller organisms lower in the food chain. At the lower levels are the microscopic plankton.
- The very base of the food chain, supporting all other organisms as an original food source, are the phytoplankton.
- Where primary productivity is high, there are generally large interlinked population of herbivores and carnivores.
- The largest and most numerous herbivorous biomass are the zooplankton. They are the primary consumers, or in other words, the first step in the conversion of plant tissue to animal tissue, as they feed off the phytoplankton.
- These systems are rarely so simple that there is a single path from plants to the top predator. As a result we generally see complicated interrelationships between plants, herbivores, and carnivores that we would term a food web (see figs. 15.11 and 15.13 in the text).
- To demonstrate the pathways followed by food and nutrient energy in a food chain or web, we construct a trophic pyramid (fig. 15.12).
 - a. Trophic pyramids are composed of successive feeding or trophic levels, where the large biomass is formed by the plants at the base of the pyramid and each higher level consists of less biomass and fewer (and often larger) organisms.
 - b. It is estimated that the overall energy transfer efficiency between trophic levels is approximately 10% in the open ocean, with 90% of the energy lost in serving the metabolic needs of the consuming organism at each level. Because of this, consumers at the highest levels are much less energy efficient than those at the lowest.
 - c. It is critical to have some understanding of trophic structure in the oceans because human actions often impact specific trophic levels.
 - d. Efficiency changes as the abundance of primary producers changes. It is highest in upwelling areas where food chains are short, and lowest in the open ocean where food chains are large.

Major Concept (VII) *There are unique areas of the ocean where total productivity is not tied to the primary productivity of oceanic phytoplankton.*

Related or supporting concepts:

- There are four areas where this is the case:
 - a. coral reef systems (see chap. 18),
 - b. shallow coastal areas with extensive benthic plant communities,
 - c. estuaries, especially broad, shallow estuaries with extensive bordering wetlands,
 - d. deep-sea communities where hot water vents rich in hydrogen sulfides and methane sources provide nutrients for bacterial primary producers (see chap. 18).
- At deep hydrothermal vent communities dense clouds of bacteria are the base for trophic pyramids.
- These bacteria use dissolved chemicals (especially hydrogen sulfide) in the vented water to obtain energy through a process called chemosynthesis.

Major Concept (VIII) *Human activities that directly overwhelm any single trophic level can cause disastrous imbalances in local and global ecosystems.*

Related or supporting concepts:

- An imbalance in the relationship between primary producers and herbivores is created when industrial and domestic wastes add excessive nutrients to estuaries or coastal regions. This can cause uncontrolled growth in the plant community along with massive oxygen demands from unconsumed plant decomposition.
- Human activities have led to an increase in the amount of chlorofluorocarbons (CFCs) in the atmosphere. This has led to a depletion of ozone and an increase in the size of the ozone hole over Antarctica.
- Ozone depletion allows more ultraviolet energy to reach the sea surface. Studies in 1990 discovered a reduction in primary productivity of about 2% to 4% in the Southern Ocean around Antarctica related to increased levels of ultraviolet radiation.
- Over harvesting organisms from any trophic level can upset the balance of the entire ecosystem. Knowing the energy transfer efficiency at each level and the accumulative losses in the trophic pyramid suggests that we should harvest food resources from the lowest possible trophic levels (fig. 15.14).
- We need to use the knowledge gained from an understanding of trophic systems and their interactions so that we can harvest food resources without depleting them, and manage these resources more effectively.

Matching Key Terms with Major Concepts

At the end of the chapter in the textbook is a list of key terms. You should be able to match each of these with one of the previously listed major concepts. To test your ability, try to match the following key terms with the number (I–VIII) of the appropriate major concept identified in this section:

| | | |
|---------------|------------------------|--------------------------|
| decomposer | respiration | trophic level |
| biomass | food chain | photosynthesis |
| zooplankton | net primary production | compensation depth |
| phytoplankton | chlorophyll | gross primary production |
| carnivore | food web | trophic pyramid |
| dark bottle | herbivore | nutrient |
| standing crop | light bottle | chemosynthesis |

Test Your Recall

Answer the following questions to test your understanding

FILL IN THE BLANK

1. The primary producers in the oceans are the _____.
2. The total mass of organic material produced by photosynthesis is _____ primary production.
3. Cell plants contain a pigment called _____.
4. _____ for marine plants are similar to fertilizers for land plants.
5. In photosynthesis _____ gas is consumed.
6. The opposite process of photosynthesis is _____.

7. The weight of organic matter produced in primary productivity is known as _____.
8. The difference between the organic material produced in photosynthesis and that consumed in respiration is the _____ primary productivity.
9. The total amount of plant material under any area of sea surface is called the _____ crop.
10. _____ are plant eaters.
11. _____ are meat eaters.
12. Bacteria and fungi are _____, or organisms of decay.
13. Highest rates of primary productivity occur in areas of _____.
14. The largest total mass of organic material is produced in the _____.
15. Net primary production is zero at the _____ depth.
16. Animal plankton are called _____.
17. Trophic levels are numbered from the _____ to the _____.
18. In general, as you move to higher trophic levels the size of the organisms will _____.
19. Nitrogen in the form _____ is an important nutrient.
20. Phosphorus in the form _____ is an important nutrient.

TRUE - FALSE

1. For every molecule of carbon dioxide consumed in photosynthesis, two molecules of oxygen are produced.
2. Photosynthesis produces molecules of sugar.
3. Net productivity is always greater than gross productivity.
4. Phytoplankton are multi-celled organisms.
5. Herbivores graze on phytoplankton.
6. Primary productivity peaks in the spring in polar latitudes.
7. Nitrogen gas is used as a nutrient by plants.
8. In polar regions the abundance of nutrients is not a limiting factor for primary productivity.
9. At mid-latitudes there are two periods of increased productivity annually.
10. Nitrogen is essential in the formation of proteins.
11. Zones of upwelling on the western sides of ocean basins are the areas of highest rates of primary productivity.
12. Upwelling areas are about four times more productive than coastal areas.
13. Gross primary production rates in the open ocean are similar to those in desert regions on land.
14. Over seven times as much nitrogen is consumed in photosynthesis than phosphorus.
15. Values for respiration remain nearly constant with depth while those for photosynthesis decrease.
16. The shark is a top predator in the oceans.
17. The efficiency of energy conversion increases at higher trophic levels.
18. Phytoplankton are not the only primary producers in the oceans.
19. Primary production can be reduced in unstable water columns.
20. Harvested food value is increased if the lower trophic levels are used.

MULTIPLE CHOICE

1. At high latitudes the primary productivity is controlled by
 - a. seasonal changes in nutrient supplies.
 - b. seasonal changes in sunlight.

- c. rates of convective overturn in the water.
 - d. grazing by herbivores.
 - e. none of the above.
2. Rates of primary productivity depend on
 - a. abundance of nutrients.
 - b. availability and intensity of sunlight.
 - c. stability of the water column.
 - d. a and b above.
 - e. all of the above.
 3. The stability of the water column in coastal areas is often increased
 - a. by constant temperature.
 - b. by tidal currents.
 - c. by freshwater runoff.
 - d. by wave activity.
 - e. all of the above.
 4. Phosphorus is required for
 - a. the formation of proteins.
 - b. cell membranes.
 - c. nucleic acids.
 - d. b and c above.
 - e. all of the above.
 5. The largest fraction of total biomass in the oceans comes from primary productivity in
 - a. the open ocean.
 - b. zones of upwelling.
 - c. coastal areas.
 - d. estuaries.
 - e. the benthic environment.
 6. The highest rates of primary productivity occur in
 - a. polar latitudes.
 - b. upwelling regions.
 - c. tropical regions.
 - d. coastal waters.
 - e. the open ocean.
 7. Zones of upwelling are found
 - a. in the centers of ocean basins.
 - b. beneath large mid-ocean gyres.
 - c. on the eastern sides of ocean basins.
 - d. on the western sides of ocean basins.
 - e. on the eastern sides of continents.
 8. The open oceans are productive because of
 - a. their well-mixed waters.
 - b. the scarcity of herbivores.
 - c. their sunlit waters.
 - d. their abundance of nutrients.
 - e. their vast size.
 9. Zones of upwelling have rates of gross primary productivity that are similar to those found on land in
 - a. deserts.
 - b. grasslands.
 - c. rain forests.
 - d. pastures.
 - e. none of the above.
 10. The ratio between mass of oxygen produced and mass of phosphorus consumed in photosynthesis is approximately
 - a. 100 : 1.
 - b. 1000 : 1.

- c. 50 : 1.
 - d. 40 : 1.
 - e. 7 : 1.
11. If 10 grams of phosphorus are consumed in photosynthesis, how many grams of nitrogen will be consumed?
 - a. 94
 - b. 109
 - c. 53
 - d. 72
 - e. 14
 12. The compensation depth is
 - a. where net primary production is zero.
 - b. where the gross primary production is zero.
 - c. where the biomass is zero.
 - d. where the standing crop is zero.
 - e. below the photic zone.
 13. The most numerous and the greatest biomass of herbivores are the
 - a. carnivores.
 - b. zooplankton.
 - c. phytoplankton.
 - d. predators.
 - e. crustaceans.
 14. The efficiency of energy transfer up each open ocean trophic level is about _____ %.
 - a. 25
 - b. 5
 - c. 10
 - d. 35
 - e. 15
 15. Decaying organic material consumes
 - a. nitrogen.
 - b. phosphorus.
 - c. carbon dioxide.
 - d. ammonia.
 - e. oxygen.
 16. Primary production can be estimated by
 - a. counting the increase in plant cells.
 - b. measuring the change in chlorophyll concentration.
 - c. measuring the rate of production of oxygen.
 - d. all of the above.
 - e. none of the above.
 17. There is roughly _____ times more coastal water area than upwelling area.
 - a. 150
 - b. 50
 - c. 1000
 - d. 250
 - e. 20
 18. Respiration consumes
 - a. carbon dioxide.
 - b. sugar.
 - c. oxygen.
 - d. a and b above.
 - e. b and c above.
 19. Primary production is usually given as the mass of dry weight organic _____ in grams per surface area per time.
 - a. nitrogen
 - b. carbon

- c. oxygen
 - d. phosphorus
 - e. hydrogen
20. Nutrients can be resupplied to surface waters by
- a. land drainage.
 - b. overturn.
 - c. mixing.
 - d. upwelling.
 - e. all of the above.

Visual Aids: Test Your Understanding of the Figures

1. A dramatic increase in the rate of primary productivity in an area does not necessarily mean that there will be a matching dramatic rise in the standing crop. Take a close look at figure 15.1 to see why.
2. Take a close look at figure 15.3. Notice how the year is divided into periods of time when the surface waters are heated and cooled. When are the two peaks in productivity and how are they related to the abundance of nutrients in the surface water? Is there a time lag?
3. What conclusions can you draw from figure 15.7 about the general relationship between primary productivity and proximity to the continents?
4. In figure 15.8 you can see that gross production varies as a function of depth. Why does it peak 30 m below the surface rather than at the surface? What does the fact that the two curves for net and gross production are parallel to one another tell you about rates of respiration with depth?
5. Why do you think there is a time lag between phytoplankton and zooplankton abundance as shown in figure 15.10?

Study Problems

1. Given the fact that the open ocean efficiency of energy conversion between trophic levels is about 10%, how many kilograms of phytoplankton would it take to increase the mass of a carnivore at the fourth trophic level by 2 kilograms?
2. If 27.8 grams of oxygen are produced in a water sample as a result of photosynthesis, how many grams of carbon have been produced and how many grams of nitrogen have been consumed?
3. A sample of water from a depth of 10 meters had 12 mg of dissolved oxygen per liter. Part of this water was placed in a clear bottle and part in a dark bottle and they were returned to a depth of 10 m where they remained for 8 hours. The bottles were then recovered and the concentration of dissolved oxygen in the clear and dark bottles was found to be 13.2 and 11.1 mg per liter respectively. Calculate the a.) respiration rate, b.) net primary production, and c.) gross primary production.

Answer Key for Key Terms and Test Your Recall

KEY TERMS

decomposer (III)
 biomass (I)
 zooplankton (VI)
 phytoplankton (I,VI)
 carnivore (III,VI)
 dark bottle (V)
 standing crop (I)

respiration (I)
 food chain (VI)
 net primary production (I)
 chlorophyll (I)
 food web (VI)
 herbivore (I,VI)
 light bottle (V)

trophic level (VI)
 photosynthesis (I)
 compensation depth (V)
 gross primary production (I)
 trophic pyramid (VI)
 nutrient (II)
 chemosynthesis (VII)

FILL IN THE BLANK

1. phytoplankton
 4. nutrients
 7. biomass

2. gross
 5. carbon dioxide
 8. net

3. chlorophyll
 6. respiration
 9. standing

10. herbivores
13. upwelling
16. zooplankton
19. nitrate

11. carnivores
14. open ocean
17. bottom, top
20. phosphate

12. decomposers
15. compensation
18. increase

TRUE - FALSE

1.F 2.T 3.F 4.F 5.T 6.F 7.F 8.T 9.T 10.T 11.F 12.T 13.T 14.T 15.T 16.T 17.F 18.T 19.T 20.T

MULTIPLE CHOICE

1.b 2.e 3.c 4.d 5.a 6.b 7.c 8.e 9.c 10.a 11.d 12.a 13.b 14.c 15.e 16.d 17.a 18.e 19.b 20.e

STUDY PROBLEMS

1. 2000 kg
2. 85.7, 15.1
3. a. 0.04 mg C/liter/hour
b. 0.06 mg C/liter/hour
c. 0.10 mg C/liter/hour