11. Photosynthesis and Primary Productivity

Driving Questions

All life on earth is directly or indirectly reliant on the primary productivity of autotrophs, also known as primary producers.

- How do you determine the primary productivity of a plant?
- Why is primary productivity important?

Background

Primary productivity is principally the production of carbohydrates from carbon dioxide gas, electromagnetic radiation from the sun, and water, through the process of photosynthesis. All life on Earth is directly or indirectly reliant on primary production. The organisms responsible for primary production are known as primary producers, or autotrophs, organisms that can make their own food, usually through the process of photosynthesis. These primary producers form the base of the food chain, functioning at the first trophic level.

In terrestrial ecosystems, autotrophs are primarily vascular plants. In aquatic ecosystems, primary producers include photosynthetic bacteria, phytoplankton (single-celled photosynthetic aquatic organisms), multicellular algae, and vascular plants, such as *Elodea sp*. Most photosynthetic organisms contain chloroplasts, organelles that contain chlorophyll and in which photosynthesis takes place.

Primary productivity can be expressed as gross primary productivity (GPP) or net primary productivity (NPP). Net primary productivity is the total amount of carbohydrates produced in the ecosystem (the GPP) minus the carbohydrates consumed by the producers for their own aerobic cellular respiration (R). Net productivity reflects the carbohydrates available to other organisms in the ecosystem. Net primary production is the excess food produced by autotrophs that is available for consumption by other organisms in the food chain. The equation for calculating NPP is: NPP = GPP – R.

Materials and Equipment

For each student or group:

- Dissolved oxygen sensor
- Photosynthesis tank
- Rubber stopper, #3 (included with photosynthesis tank)
- *Elodea sp*. plant (several sprigs)
- Ice (recommended if using incandescent bulb)
- Magnetic stirrer and stir bar
- Black cloth, opaque, 50 cm x 50 cm
- Lamp, with 100W equivalent LED or CFL bulb
- Dechlorinated tap water, 1 L

Safety

Follow all standard laboratory procedures.

Procedure

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

1. ☐ Start a new experiment on the data collection system.

2. ☐ Connect the dissolved oxygen sensor (or water quality sensor) to the data collection system.

3. ☐ Display Dissolved oxygen concentration (mg/L) on the y-axis of a graph with Time on the x-axis.

4. ☐ Put a stir bar into the photosynthesis tank.

5. ☐ Put several sprigs of *Elodea* plant in the tank so that it is loosely full of the plant, and fill the tank to the top with dechlorinated tap water.

6. ☐ Put the large two-hole stopper into the top of the tank.

Note: Water will overflow into the outer chamber.

7. ☐ Fill the outer tank to within about 2 cm from the top with tap water.

8. ☐ Why are you putting water in the outer chamber?

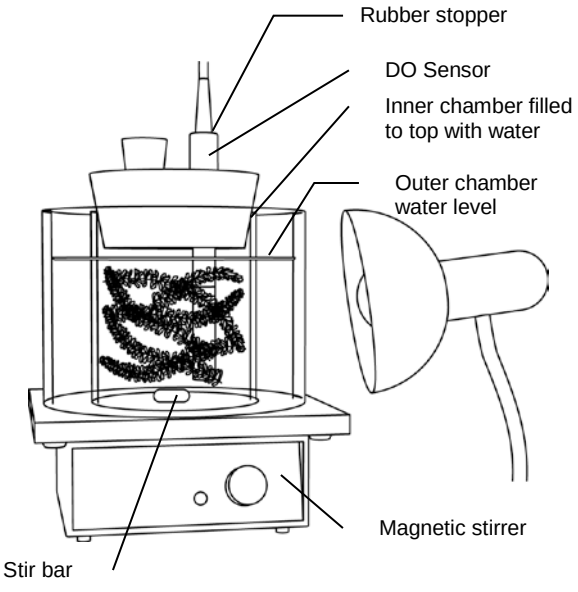
---

9. ☐ Place the photosynthesis tank on the magnetic stirrer.

10. ☐ Remove the dissolved oxygen sensor from the storage bottle.

    Be sure to remove the white cap from the sensor, being careful not to touch the membrane at the end of the sensor.

11. ☐ Insert the end of the dissolved oxygen probe carefully through the larger opening in the two-hole stopper. Push the probe down until the end is positioned just above the stir bar (within 1 cm of the stir bar) and so the end is not touching the plant.



Note: Positioning the end of the probe is important so that the vigorous motion of the water will knock any air bubbles off the end of the probe.

Note: If the plant obstructs the end of the probe, take the stopper out of the tank and rearrange the plant. You may need to add more water to ensure the tank stays completely full and to eliminate all air pockets.

12. ☐ Place the photosynthesis tank on the magnetic stirrer.

13. ☐ Put a #2 or #3 rubber stopper into the other hole of the large two-hole stopper.

14. ☐ Place the lamp very near the photosynthesis tank so the light will shine on the *Elodea* plant.

Collect Data

15. ☐ Turn on the magnetic stirrer to a high speed so that the water circulates in the tank.

16. ☐ Turn on the light to its brightest setting.

17. ☐ Why are you using a magnetic stirrer? *Hint:* Consult the user manual for the dissolved oxygen sensor.

_____

_____

18. ☐ Start data recording.

19. ☐ Adjust the scale of the graph so the data fills the graph vertically and you can better see the changes in concentration of DO while recording.

Note: The initial concentration of DO should be between 4 and 8 mg/L; if it is not in that range, check the DO sensor to be sure it is in good working order.

20. ☐ Continue to record data with the light on for 15 minutes. *Do not stop recording data!*

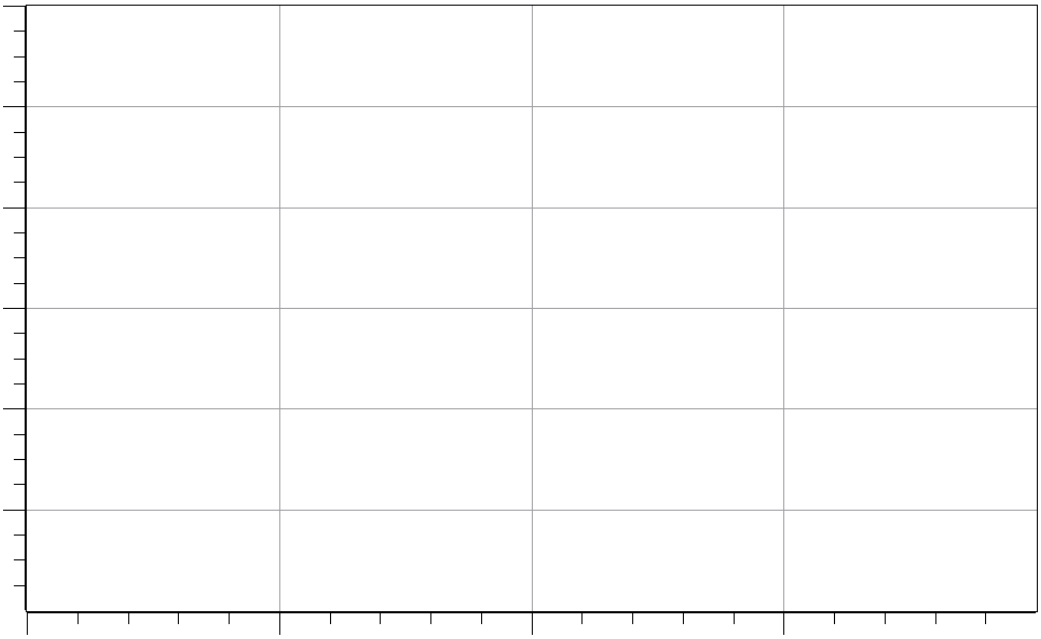
21. ☐ Turn the lamp off and carefully cover the setup with a black opaque cloth so the plant is in darkness.

22. ☐ Record data with the plant in darkness for 15 minutes, and then stop recording data.

23. ☐ Save your experiment.

Data Analysis

1. ☐ Draw a sketch of the Dissolved oxygen concentration versus Time graph. Label the x-axis and y-axis, including parameters and units as well as the point at which you turned off the light and covered the setup with the black opaque cloth.



2. ☐ Use your recorded data to find the rate of change in DO concentration when the light is shining on the plant and the rate of change in DO concentration when the plant is in darkness. Use 2 methods: 1) the slope of a linear fit line and 2) the 2-point method. Show your work.

3. ☐ Record these values in Table 1.

Note: The rate of change in [DO] in darkness correlates to the consumption of carbohydrates due to cell respiration. A negative slope, which indicates a decrease in the dissolved oxygen concentration, refers to a positive value of cell respiration (R). For example, if the rate of change in [DO] is -1.0×10^{-3} mg/(L·s), then R is 1.0×10^{-3} mg/(L·s).

Table 1: Rate of change of dissolved oxygen concentration comparison

Light Setup	Initial [DO] (mg/L)	Final [DO] (mg/L)	Total Change in [DO] (mg/L)	Rate of Change in [DO] (mg/(L·s) (Linear Fit)	Rate of Change in [DO] (mg/(L·s) (2-Point Method)
Bright light					
Darkness					

Analysis Questions

1. **Describe how you would find the GPP rate, and then perform the calculation.**

2. **Describe how you would calculate the net amount (in mg) of glucose produced (NPP) by the plant in 24 hours if the present conditions were maintained and the plant was in darkness for 12 of those hours. Then perform the calculation.**

3. **How did the rate of change calculated using the two-point method compare with the rate of change as determined by the slope at a linear region of the plotted data?**

4. **What does a negative slope (rate of change) value indicate?**

5. **What processes are causing the change in dissolved oxygen concentration under the conditions of bright light?**

6. **What process causes the change in dissolved oxygen concentration under the conditions of darkness?**

7. **Does the dissolved oxygen that you measured under lighted conditions represent the gross primary productivity (GPP) or the net primary productivity (NPP) rate? Explain.**

8. **In this exploration, which is the independent variable, which is the dependent variable, and which factors are controlled?**

Synthesis Questions

Use available resources to help you answer the following questions.

1. **What do you think would happen to this closed system if it were maintained for 2 weeks under these conditions?**

_____

_____

_____

2. **What are some of the methods currently used by scientists to determine primary production levels regionally and globally?**

_____

_____

_____

3. **What are some limitations to these methods of determining primary production?**

_____

_____

_____

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. **The first trophic level in an ecosystem refers to**

   A. Carnivores
   B. Consumers
   C. Herbivores
   D. All autotrophs
   E. B and D

2. **Autotrophs responsible for primary productivity in the oceans include**

   A. Kelp
   B. Zooplankton
   C. Photosynthetic bacteria
   D. Phytoplankton
   E. A, C, and D
   F. All of the above

3. **Most of the primary production in the oceans occurs in the**

   A. Euphotic zone
   B. Dysphotic zone
   C. Aphotic zone
   D. Abyssal zone
   E. Twilight zone

4. **Gross primary productivity is equivalent to net primary productivity plus**

   A. The amount of dead organic material that sinks to the bottom of a body of water or falls as litter to the ground
   B. The amount of organic material consumed in cellular respiration
   C. The amount of water transpired by plants
   D. None of these is true

5. **In this activity, the gross primary productivity was measured by**

   A. Determining the mass of the plant
   B. Determining the rate of oxygen gas consumption during cellular respiration
   C. Determining the rate of oxygen gas production during photosynthesis
   D. B and C
   E. All of the above