Worksheet: Movement of Energy in Ecosystems

1. Primary production provides the energy that enters ecosystems. Answer the following questions on primary production.
   a. What is the definition of primary production? What units are used to measure primary production? The rate of conversion of solar energy by photosynthesis to organic compounds OR the rate of accumulation of carbon (or biomass) by autotrophic (photosynthetic) organisms. Units: kilojoules/m^2/yr, g carbon/m^2/yr, or g biomass/m^2/yr
   b. Explain the relationship between photosynthesis, respiration, and growth/maintenance in plants. Photosynthesis fixes CO₂ into carbohydrates (energy storage form) and in the process releases O₂; respiration breaks down carbohydrates (to release stored energy), thereby releasing CO₂ and consuming O₂. Growth and maintenance is possible as a result of respiratory breakdown of carbohydrates and photosynthetic fixation of CO₂ into carbohydrates.
   c. What is the difference between net primary production (NPP) and gross primary production (GPP)? GPP is the total energy or carbon fixed per m² per year, whereas NPP is the energy (carbon) gained minus energy (carbon) lost due to respiration.
   d. A scientist reported that the gross primary productivity of a grassland ecosystem was 55 g/m²/year. If the respiration loss was 33 g/m²/year, what was the NPP of the grassland ecosystem? Show your calculations. NPP = GPP - R NPP = 55 g/m²/yr - 33 g/m²/yr (more accurately, units should be g carbon/m²/yr)

2. What is secondary production? How does it differ from primary production? How does primary production affect secondary production? Secondary production is production of consumer biomass over time. It differs from primary production in that it is production by consumers (heterotrophs) that derive their energy from the consumption of primary producers. Because their energy is derived from primary producers, secondary production is dependent on primary production.

3. Primary production is measured differently in terrestrial versus aquatic ecosystems. For each method below, indicate whether it is a terrestrial or aquatic method (or both) and briefly explain how it is used to estimate primary production.
   a. Change in standing crop biomass (harvest technique) Terrestrial. The method relies on the harvest and measurement of aboveground dry biomass as an estimate of primary production. Unmeasured belowground biomass can also be estimated.
   b. EDDY analysis Terrestrial. The method measures primary production by calculating the difference in CO₂ concentration [CO₂] in the atmosphere above and below the canopy during the day and night. During the day, CO₂ is taken up by photosynthesis; though respiration is also occurring, [CO₂] below the canopy will be lower than above the canopy. At night, photosynthesis stops but respiration continues; this results in [CO₂] below the canopy being higher compared to above the canopy. The greater the decrease in [CO₂] between the atmosphere above and below the canopy during the day compared to at night, the higher the primary production.
   c. Chlorophyll method An aquatic method. It relies on the positive relationship between chlorophyll concentration and photosynthesis. Because phytoplankton require chlorophyll for photosynthesis, its concentration in a volume of water is a reliable measure of phytoplankton biomass in that body of water. Measurement of phytoplankton biomass based on chlorophyll concentrations can be estimated by measuring the wavelength of light reflected off chlorophyll in water samples with a spectrophotometer or in oceans and lakes by satellite remote sensing.
4. Primary production is controlled by different factors in terrestrial versus aquatic ecosystems. For each environmental factor below, indicate 1) whether it controls primary production in terrestrial or aquatic (or both) systems; and 2) how each factor acts to limit primary production.

Water: terrestrial (aquatic systems are not water limited); greater precipitation/soil moisture increases primary production.

Light: aquatic; production in aquatic systems is limited by light because light is quickly attenuated at depth; terrestrial systems are not as limited as aquatic systems by light, but since light and temperature are related, light plays an indirect role in terrestrial systems via temperature.

Temperature: terrestrial and aquatic; higher temperatures increase primary production (think about how temperature increases chemical reaction rates).

Nutrients: terrestrial and aquatic; increased nutrient availability results in greater primary production; productivity in terrestrial systems tends to be limited by nitrogen, whereas productivity in aquatic systems tends to be limited by phosphorus.

5. Terrestrial biomes differ in their productivity.
   a. Which biomes tend to have the highest primary production? Which the lowest? Tropical rainforests, swamps, and marshes have the highest productivities, whereas deserts and tundra have the lowest.
   b. For each of the high and low production biomes you listed above, explain why they have high or low productivity (i.e., what factors in their environment are responsible?). How does their geographic location affect these factors? Tropical rainforest: High temperature and precipitation are responsible for the high productivity of tropical rainforests; their equatorial location results in direct solar heating at these latitudes, which drives Hadley cells and resulting high precipitation. Desert: low rainfall is primarily responsible for low productivity in deserts; their location – around 30°N and 30°S latitude – results in dry descending air masses because of Hadley cell circulation.

6. In a typical grazing food chain (e.g., producers → herbivores → carnivores), energy moves up the different trophic levels from primary producers (autotrophs) to herbivores (primary consumers) to carnivores (secondary and tertiary consumers).
   a. On average, what percent of the energy is transferred from one trophic level to the next? \(10\%\) (ranges from 5 – 20%)
   b. Energy transfer from one trophic level to the next is subject to losses of energy along the way. Name the three efficiencies of energy as it is transferred from one trophic level to the next and how they are determined. Consumption efficiency is the proportion (or percentage) of energy in a trophic level that is consumed by the next higher trophic level. It is determined by dividing the amount of consumed energy by the net production energy of the next lower trophic level. Assimilation efficiency is the proportion (or percentage) of consumed energy that is assimilated into biomass. It is determined by dividing the assimilated energy by the consumed energy. Net production efficiency is the proportion (or percentage) of assimilated energy that is used for growth and reproduction. It is determined by dividing the net production energy by the assimilated energy.
   c. Although energy is lost at each step in a food chain, some elements and compounds can become more concentrated. What is this phenomenon called and what is an example? Biomagnification. An example is DDT. See page 556 in your text for a description of this example.