Chapter-wide learning goals:

1. Defend the assertion that the first law of thermodynamics (conservation of energy and matter) governs the flow of energy through and the cycling of matter within ecosystems.
2. Explain the key features of a biogeochemical nutrient cycle (i.e., the cycling of elements between organic and inorganic pools).
3. Contrast the processes that drive the cycling of key macronutrients (carbon, nitrogen, and phosphorus) within ecosystems.
4. Show how the relative magnitudes of the fluxes in and out of a pool determine the rate at which its size changes over time.

Section 1: Nutrient Cycling Fundamentals

1. Use an example to illustrate how the eutrophication of recipient water bodies is linked to land management practices in the broader watershed.
2. Explain why the 6 key macronutrients (C, N, P, H, O, and S) are essential for all biological organisms.
3. Provide examples to illustrate some of the different ways in which organisms use micronutrients.
4. Diagram the key pools and fluxes of ecosystem-level carbon and phosphorus cycles.
5. Identify nutrient transformations that are biologically mediated in the carbon and phosphorus cycles.
6. Contrast open and closed nutrient cycles.
7. Calculate the rate at which nutrients are being stored in a given pool, given the sizes of its inputs and outputs.
8. Calculate the average residence time of a nutrient in a given pool.
9. Describe how biochemical processes like photosynthesis and respiration couple the cycles of different nutrients.
10. Design a bioassay experiment that can be used to determine which nutrient is limiting primary production.
11. Distinguish between the cycling of nutrients within an ecosystem and the flow of energy through it.

Section 2: Ecosystem-level Nutrient Cycles

1. Diagram the key pools and fluxes of ecosystem-level nitrogen cycle.
2. Identify nutrient transformations that are biologically mediated in the nitrogen cycle.
3. Explain how clearcutting affected nitrogen cycling in Hubbard Brook.
4. Explain how the small watershed approach can be used to determine how humans are altering key nutrient cycles.
5. Summarize the studies at Hubbard Brook that have shown how acid rain affects forest nitrogen cycling.
6. Discuss how water movement, as driven by phenomena such as evapotranspiration and gravity, affect the cycling of nutrients in forest, stream, and lake ecosystems.

Section 3: Nutrient Budgets

1. Contrast how agriculture, fossil fuel combustion, and land-use change are altering the carbon, nitrogen, and phosphorus cycles at the ecosystem level.
2. Explain why different approaches are needed to limit fluxes of nitrogen and phosphorus from terrestrial ecosystems to recipient aquatic ecosystems.
3. Use a full nutrient budget to determine which nutrient pools are gaining or losing nutrients and why.
4. Show how modified nutrient budgets comparing watershed inputs to stream outputs can be used to determine nutrient retention.
5. Contrast nutrient retention and nutrient storage rate.

Section 4: Global Biogeochemical Cycles

1. Compare the key anthropogenic perturbations of carbon, nitrogen, and phosphorus cycles.
2. Use pre- and post-industrial global nutrient budgets to show how humans have altered the availability of nitrogen and phosphorus.
3. Show how analyzing the flux of materials between the four subsystems (atmospheric, geologic, oceanic and terrestrial) of a global biogeochemical cycle can help identify how fluxes are changing and where nutrients are accumulating.
4. Compare and contrast the expected impacts on the carbon cycle under different emission scenarios.
5. Describe some of the ways in which humans might limit their impacts on global nutrient cycles.
6. Compare and contrast the key active reservoirs of inorganic nutrients in the carbon, nitrogen and phosphorus cycles.
7. Analyze feedback loops to predict whether a perturbation will be amplified or dampened.
8. Summarize how changes in patterns of fossil fuel combustion over the past century caused acid deposition to first increase and then decrease.
9. Convince a lay audience that human-caused changes in the carbon, nitrogen, and phosphorus cycles are affecting the ability of ecosystems to provide key ecosystem services like nutrient retention and climate regulation.