Milestones 5 & 6 Review

Carbon Cycling & Ecosystem Stability (Level 2)

Overview

Milestone 5 focuses on developing models that show how photosynthesis and cellular respiration drive carbon cycling among the biosphere, atmosphere, hydrosphere, and geosphere. These two processes are complementary—photosynthesis captures carbon from the atmosphere and builds it into living tissue, while cellular respiration breaks down that tissue and returns carbon to the atmosphere.

Milestone 6 examines how complex interactions in ecosystems maintain relatively consistent populations and species compositions under stable conditions. However, when conditions change significantly—through climate shifts, species loss, or human activities—ecosystems can reorganize into entirely new stable states with different species and interaction patterns.

Foundational Concepts

Carbon is essential to life. All living organisms are built from carbon-based molecules. Carbon atoms cycle continuously between living things (biosphere), the air (atmosphere), water (hydrosphere), and rocks and soil (geosphere). Understanding how carbon moves between these spheres is fundamental to understanding ecosystem function.

Photosynthesis captures energy and carbon. Plants, algae, and some bacteria use light energy to convert carbon dioxide and water into glucose and oxygen. This process takes carbon from the atmosphere and incorporates it into living tissue:

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

Cellular respiration releases energy and carbon. All organisms (including plants) break down glucose to release stored energy, consuming oxygen and producing carbon dioxide and water. This returns carbon to the atmosphere:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{ATP (energy)}$$

Ecosystems involve complex interactions. Predator-prey relationships, competition for resources, mutualistic partnerships, and effects on habitat all create a web of connections. These interactions typically maintain population sizes within certain ranges, preventing any single species from completely dominating or disappearing.

Keystone species have outsized effects. Some species play roles that are disproportionately important to ecosystem stability. When keystone species are removed, cascading changes can affect many other species and alter the entire ecosystem structure.

Intermediate Relationships (Level 2 Focus)

Photosynthesis and respiration are complementary processes. Notice that the products of photosynthesis (glucose and oxygen) are exactly the reactants needed for cellular respiration, while the products of respiration (carbon dioxide and water) are the reactants for photosynthesis. This creates a cycle where carbon and oxygen continuously move between organisms and the atmosphere. During the day, plants perform both processes, but photosynthesis dominates. At night, only respiration occurs.

Carbon moves between all four Earth spheres. The atmosphere stores carbon as CO_2. The biosphere stores it in living and dead organic matter. The hydrosphere dissolves atmospheric carbon, creating carbonic acid in oceans and lakes. The geosphere stores enormous amounts of carbon in rocks (limestone), fossil fuels, and sediments formed from ancient organisms. Photosynthesis moves carbon from atmosphere to biosphere. Respiration and decomposition return it from biosphere to atmosphere. Ocean absorption transfers it to the hydrosphere. Over geological time, burial and fossilization move carbon into the geosphere.

Feedback loops maintain ecosystem stability. When a prey population increases, predators have more food and their population grows. As predator numbers rise, they consume more prey, causing prey numbers to decline. With less food available, predator populations then decrease, allowing prey to recover. This negative feedback loop prevents either population from reaching extremes and maintains both populations within a certain range over time.

Removing key interactions can destabilize entire ecosystems. Consider what happens when a top predator is removed. Herbivore populations may explode without predation pressure. These growing herbivore populations overgraze vegetation, reducing plant cover. Loss of vegetation affects soil stability, water retention, and habitat for other species. The ecosystem reorganizes into a new state dominated by different species—perhaps more invasive plants resistant to heavy grazing, and fewer species that required dense vegetation.

Changing conditions can create new stable states. Ecosystems don't simply return to their original state after disturbance. If conditions have changed significantly (through climate warming, species loss, altered fire regimes, etc.), the system may stabilize in a new configuration with different dominant species and interaction patterns. This new state can be just as stable as the original, but with very different characteristics.

Level 2 Thinking Questions

Comparison:

- How does photosynthesis differ from cellular respiration in terms of energy and carbon movement?
- How does carbon storage differ between the four Earth spheres (atmosphere, biosphere, hydrosphere, geosphere)?
- How does removing a keystone species differ from removing a species with less ecosystem influence?

Relationship:

- How does the rate of photosynthesis affect the amount of carbon in the atmosphere?
- Why do predator and prey populations tend to cycle together rather than changing independently?
- How does the carbon cycle connect the processes of photosynthesis, respiration, and decomposition?

Circumstance:

- What happens to ecosystem carbon storage when forests are converted to agricultural fields?
- What might happen if ocean temperatures rise and affect phytoplankton populations?
- Under what conditions might an ecosystem shift from one stable state to a completely different one?

Credibility:

- What evidence demonstrates that ecosystems can exist in multiple stable states?
- How do scientists measure carbon movement between Earth's spheres?
- What evidence shows that certain species are keystone species rather than simply common ones?

California Connections

Kelp forest ecosystems: Sea otters are a classic keystone species in California kelp forests. Otters eat sea urchins, which graze on kelp. When otters were hunted to near-extinction in the early 1900s, urchin populations exploded and consumed vast kelp forests, creating "urchin barrens"—a different stable state with minimal kelp, few fish, and reduced biodiversity. After otter protection and reintroduction, some areas returned to kelp-dominated systems, but others remained in the urchin barren state, showing how ecosystems can stabilize in multiple configurations.

California's carbon storage: California's forests, grasslands, and wetlands store significant amounts of carbon in living biomass and soil. When wildfires burn these ecosystems, carbon rapidly moves from the biosphere to the atmosphere as CO_2. The state's old-growth redwoods are particularly important carbon sinks, storing carbon for centuries. Agriculture converts natural ecosystems, typically reducing carbon storage capacity as annual crops store far less carbon than perennial native vegetation.

Chaparral fire regimes: California chaparral ecosystems evolved with periodic fire that maintained specific plant communities adapted to these conditions. Fire suppression changed the frequency and intensity of fires, allowing different species to dominate and fuel to accumulate. When fires now occur, they're often more intense, leading to ecosystem shifts toward grasslands rather than shrubland recovery—a new stable state resulting from altered fire conditions.

Connecting to Your Species of Special Concern

As you prepare your Ecosystem Web presentation, consider these questions about your species:

For carbon cycling (Milestone 5): Where does your species fit in the carbon cycle? Is it a producer performing photosynthesis, a consumer that relies on eating other organisms, or a decomposer that breaks down dead material? How does energy and carbon flow to and from your species?

For ecosystem stability (Milestone 6): What are the key interactions that historically kept your species' population stable? Which species does it eat or rely on? What eats it or competes with it? Which specific changing conditions are now threatening these key interactions? Is your species at risk because its food sources are declining, its predators are increasing, its habitat is changing, or competition has intensified?