12.6: Stability and Equilibrium of the Biosphere

In order for an organism to survive and thrive, it must reach a state of stability and equilibrium with its environment. The term given to such a state is **homeostasis** (“same status”). In maintaining homeostasis, an organism must interact with its surroundings and other organisms in its surroundings and must balance flows and processing of matter (including nutrients) and energy. On an individual basis, organisms do a remarkably good job of keeping their internal levels of water, materials such as calcium in blood, and temperature within a range conducive to their well being. Mammals have developed extraordinary capabilities of homeostasis; a healthy individual maintains its internal temperature within a few tenths of a degree. The concept of homeostasis applies to entire groups of organisms living together in ecosystems and, ultimately, to the entire biosphere. Therefore, a major objective of environmental science, including the practice of green chemistry, is to maintain and enhance conditions of homeostasis in the biosphere.

Ecology describes the interaction of organisms with their surroundings and each other. An important consideration in ecology is the manner in which organisms process matter and energy. An **ecosystem** describes a segment of the environment and the organisms in it with all of the interactions and relationships that implies. An ecosystem has means of capturing energy, almost always by plants or algae that perform photosynthesis. Light, temperature, moisture, and nutrient supplies are critical aspects of an ecosystem. Ecosystems recycle essential nutrient carbon, oxygen, nitrogen, phosphorus, sulfur, and trace elements. An important part of any ecosystem is the **food chain**, or more complicated **food webs**, in which food generated by photosynthesis is utilized by different organisms at different levels. An important aspect of the food chain in respect to persistent, poorly degradable organic chemicals that are soluble in lipid (fat) tissue occurs through the sequence of animals eaten in the food chain (small creatures in water are fed upon by small fish that are eaten by large fish that are eaten by large birds). Thus, aquatic pollutants become more concentrated in lipid tissue at the top of the food chain, a process called biomagnification (see Section 12.9). An objective of the practice of green chemistry is to avoid the generation and use of chemicals capable of biomagnification in the environment.

The surroundings over a relatively large geographic area in which a group of organisms live constitute a **biome**. There are a number of different kinds of biomes. Regions near the equator may support **tropical rain forest** biomes that stay warm all of the year and in which nutrients remain largely in the organisms (rain forest soil is often notably poor in nutrients, which are mostly held in forest biomass). Temperate regions may support **temperate deciduous forests** in which the trees grow new leaves for a warm, wet summer season and shed them for cold winters. Temperate regions may also have **grassland biomes** in which grass grows from a tough mass of dense roots called **sod**. **Tundra** are treeless arctic regions in which during summer only a layer of wet soil thaws above a permanently frozen foundation of permafrost. Global warming is causing some profound changes in tundra biomes.

Different kinds of biomes pose a variety of environmental challenges. Some of these have come about from the conversion of biomes to cropland. Grasslands in which the sod has been broken to support wheat and other crops have proven susceptible to wind erosion, which gave rise to the catastrophic Dust Bowl that caused such great hardship on the U. S. Great Plains during the 1930s. Climate changes resulting from global warming could change the distribution of biomes, giving rise to much larger areas of hot deserts that humans might have to learn how to utilize.

Biomes in Unexpected Places

The conventional thinking in the past was that biomes would occur only in those areas where sunlight enabled conversion of inorganic carbon to biomass that could sustain a food web. It came as a surprise to marine scientists in 1977 that thousands of meters below the surface of the Pacific ocean, far too deep for light to penetrate and without significant amounts of fallout from biomass generated in surface waters, biomes existed that teemed with tubeworms, clams, and mussels. It is now known that this abundance of life is nourished by microorganisms that thrive in hot volcanic springs and that get their energy through chemosynthesis by mediating reactions of hydrogen sulfide and other substances often toxic to more familiar organisms.

A new kind of habitat was found in 1954 with the discovery of organisms, including tubeworms over two meters long that may be centuries old, that thrive on petroleum seepage on relatively cold ocean floors. These colonies, which may contain hundreds of different species, are especially abundant on the seabed of the Gulf of Mexico, where Spanish accounts from the 1500s noted oil slicks from natural petroleum leakage.

Response of Life Systems to Stress

Organisms and the ecosystems in which they exist are subject to a number of threats that can result in loss of populations and even total destruction of the system. Natural threats include drought, flooding, fire, landslide, and volcanic eruption. Humans threaten life systems with cultivation, deforestation, mining, and severe pollution. The ability of a community of organisms to resist alteration and damage from such threats, sometimes called **inertia**, depends upon several factors and provides important lessons for the survival of the human community in the face of environmental threats. One of the basic factors involved in providing resistance of a community to damage is its overall rate of photosynthesis, its **productivity**. Another important factor is **diversity** of species so that if one species is destroyed or seriously depleted, another species may take its place. **Constancy** of numbers of various organisms is desirable; wide variations in populations can be very disruptive to a biological community. Finally, **resilience** is the ability of populations to recover from large losses.

The ability of a biological system to maintain high levels of the desirable factors listed above is commonly determined by factors other than the organisms present. This is clearly true of productivity, which is a function of available moisture, suitable climate, and nutrient-rich soil. Since all organisms depend upon the availability of good food sources, diversity, constancy, and resilience tend to follow high productivity.

Relationships Among Organisms

In a healthy, diverse ecosystem, there are numerous, often complex relationships among the organisms involved. Species of organisms strongly influence each other. And organisms may greatly alter the physical portion of the system in which they live. An example of such an influence is the tough, soil-anchoring sod that develops in grassland biomes.

In most ecosystems there is a **dominant plant species** that provides a large fraction of the biomass anchoring the food chain in the ecosystem. This might be a species of grass, such as the bluestem grass that thrives in the Kansas Flint Hills grasslands. Herbivores feed upon the dominant plant species and other plants and, in turn, are eaten by carnivores. At the end of the food cycle are organisms that degrade biomass and convert it to nutrients that can nourish growth of additional plants. These organisms include earthworms that live in soil and bacteria and fungi that degrade biological material.

In a healthy ecosystem different species compete for space, light, nutrients, and moisture. In an undisturbed ecosystem the **principle of competitive exclusion** applies in which two or more potential competitors exist in ways that minimize competition for nutrients, space, and other factors required for growth. Much of agricultural chemistry is devoted to trying to regulate the competition of weeds with crop plants. Large quantities of herbicides are applied to cropland each year to kill competing weeds. In this never-ending contest, green chemistry has an important role in areas such as the synthesis of herbicides that have maximum impact on target pests with minimum impact on the environment.

Within ecosystems there are large numbers of **symbiotic relationships** between organisms which exist together to their mutual advantage. The classic case of such a relationship is that of lichen consisting of algae and fungi growing together. The fungi anchor the system to a rock surface and produce substances that slowly degrade the rock and extract nutrients from it. The algae are photosynthetic, so they produce the biomass required by the system, which is utilized in part by the fungi. Another important symbiotic relationship is that in which nitrogen-fixing bacteria grow in nodules on leguminous plant roots. The bacteria receive nutrients from the plants in exchange for chemically fixed nitrogen required for plant nutrition.
