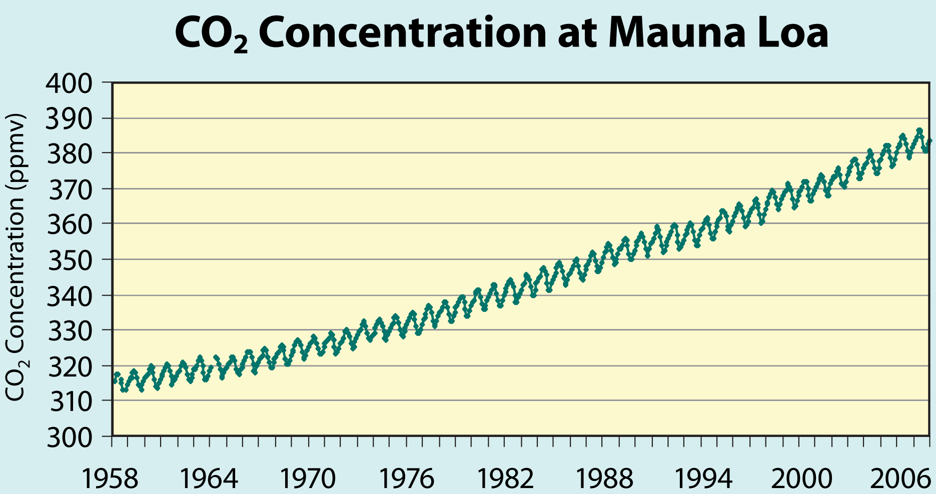
Fig. 1.4. Biological Influence on Atmospheric Carbon Dioxide Concentration. The zigzag pattern in Mauna Loa atmospheric CO_2 measurements results from seasonal carbon flows between the atmosphere and biosphere. Greater landmass and deciduous vegetation in the Northern Hemisphere cause a drop in atmospheric CO_2 as photosynthesis fixes large amounts of CO_2 in spring and summer. In fall and winter, respiration and the decay of fallen leaves, combined with lower photosynthetic productivity, cause a net flow of CO_2 from the biosphere to the atmosphere. The upward slope of the trendline reflects the atmospheric increase of fossil CO_2 from human activities. [Source: Figure adapted from Keeling, R. F., S. C. Piper, A. F. Bollenbacher, and J. S. Walker. 2008. Atmospheric CO_2 records from sites in the SIO air sampling network. In *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., USA. http://cdiac.ornl.gov/trends/co2/graphics/mlo144e.pdf.]



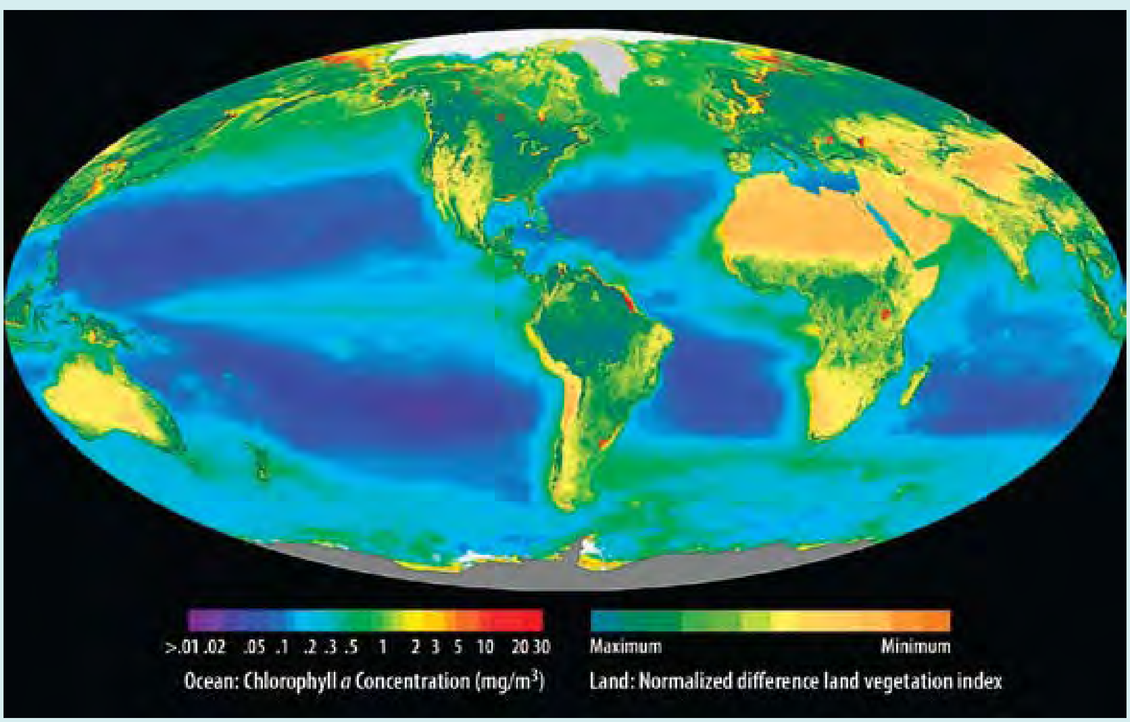


Fig. 1.5. Photosynthesis in the Global Biosphere. This NASA SeaWiFS image of the global biosphere shows the density of photosynthetic organisms on land and in the oceans. On land, the dark greens represent areas of abundant vegetation, with tans showing relatively sparse plant cover. In the oceans, red, yellow, and green regions depict dense blooms of phytoplankton (photosynthetic microbes), while blues and purples show regions of lower productivity. [Source: NASA SeaWiFS Project. http://oceancolor.gsfc.nasa.gov/SeaWiFS/.]

Key Biological Carbon Cycling Research Areas

Terrestrial Ecosystem Processes

Plant Photosynthesis. Through photosynthesis, plants convert atmospheric CO_2 into organic compounds used to build plant biomass and drive metabolic and other processes. Research must reveal the impacts on enzymes and biochemical reactions underlying water loss and CO_2 exchange, nutrient uptake, and many other processes that control photosynthetic productivity as plants are subjected to changing levels of atmospheric CO_2 and climatic conditions.

Mechanistic Understanding of Respiration. Although the biochemistry of respiration and growth has been studied extensively, current understanding of respiration is limited by the lack of a mechanistic model. For certain levels of temperature increase, plants grown in high-CO_2 concentrations display increased biomass production and higher respiration rates, but the molecular and cellular mechanisms controlling this observed response need more detailed analysis. How plants acclimate to increasing temperature is another key area for investigation. In addition, distinguishing root respiration from microbial respiration in soils has proven especially difficult, yet doing so is important because each type of respiration responds differently to environmental signals, including those associated with climate change. New technologies for measuring carbon flux through metabolic pathways are becoming available and can help quantify respiratory carbon loss at cellular, microbial community, plant, and ecosystem levels.

Partitioning of Carbon in Plant Biomass. Carbon fixed by photosynthesis is translocated and partitioned among different plant compartments (e.g., leaves, stems, roots, and mycorrhizae), respired as CO_2, or released as exudates into soil. The pattern of partitioning has feedback effects on photosynthetic capacity via leaf area and nutrient-uptake capacity through root deployment. Residence times of carbon compounds in these compartments vary greatly. Simple carbohydrates are metabolized in minutes to hours. Plant structural compounds can persist for years to decades. Although most plant compounds released into soils are consumed and respired by fungi and bacteria, a small fraction may be stored in long-lived pools for thousands of years. The regulatory systems and molecular controls for partitioning carbon among plant structures, cellular respiration, or release into different soil pools must be better understood and represented in models.

Plant-Microbe Interactions in the Rhizosphere. In the narrow zone of soil surrounding the root (the rhizosphere), fungal, bacterial, and archaeal interactions with plant roots can impact plant growth and development significantly. In turn, rhizosphere microbes obtain carbon and energy for growth from root exudates. Fungi and bacteria can enhance plant productivity by providing nutrients such as phosphorus and nitrogen or by suppressing plant pathogens in the soil. Glue-like proteins and other molecules secreted by rhizosphere fungi and bacteria form stabilized soil structures that support plant growth by increasing soil moisture and organic carbon content. Explicit chemical communications between plants and rhizosphere microbes facilitate these interactions.

Characterization of the Plant Microbiome. Plant surfaces and internal passages are colonized by a diverse array of microorganisms (collectively called the “microbiome”), many of which confer beneficial properties to their hosts. Interactions between plants and their resident microbial communities can influence plant metabolism, improve resistance to stress, increase access to limiting nutrients, and deter pathogens. Understanding the nature and functions of the plant-associated microbiome and its potential importance to plant primary production is a key challenge.

Microbial Processing of Plant Materials. Soils represent the largest and most stable reservoir of carbon in terrestrial ecosystems and contain more than twice as much carbon as the atmosphere (Schlesinger 1997). Soil microbial communities mediate the multistep conversion of dead plant tissue and organic compounds exuded from plant roots into CO_2 or soil organic matter (SOM). The heterogeneous array of organic molecules composing SOM can reside in terrestrial ecosystems for decades to thousands of years. Microbial activity also contributes to the formation of mineral–organic matter complexes called microaggregates that physically protect organic carbon from degradation. Understanding the enzyme-catalyzed reactions and environmental conditions controlling the transformation of various SOM compounds into long-lived humic compounds or highly stable microaggregates could lead to opportunities for sequestering vast quantities of carbon in ways that improve soil quality and benefit the environment.

Oceanic Processes

Marine Microbial Photosynthesis. Phytoplankton (microscopic marine plants) and photosynthetic bacteria convert dissolved CO_2 into organic compounds in surface waters. By reducing the partial pressure of CO_2 in the upper ocean, photosynthetic marine microbes enhance the oceans’ physical absorption of CO_2 from the atmosphere. Without phytoplankton photosynthesis, atmospheric CO_2 concentration would be 150 to 200 ppmv higher (Laws et al. 2000). Large oscillations in phytoplankton abundance, therefore, significantly affect the oceans’ ability to take up atmospheric CO_2. Using metagenomics and other cultivation-independent techniques, scientists are just beginning to understand the composition of microbial communities dominating primary production in oceans. Differences in functional potentials of various photosynthetic microbes remain poorly understood, and predicting the effects of climate change on microbial communities and the marine carbon cycle is difficult.

Biological Pump. Although most organic matter produced in surface waters is consumed by heterotrophic microorganisms and other forms of marine life and then returned to the atmosphere as CO_2, carbon in the form of plankton, fecal pellets, calcium carbonate shells, and dead cells, for example, sinks to the deep ocean. Carbon in the deep ocean is effectively sequestered because it can remain there for thousands to millions of years due to the slow vertical mixing of ocean water. The process that results in transferring organic carbon into the deep ocean and sediments is known as the biological pump. The percentage of photosynthetically fixed carbon that is sequestered by the biological pump is difficult to measure and varies widely among different marine environments. Predicting the magnitude of future changes in oceanic carbon uptake (Falkowski et al. 2000) requires understanding factors controlling the efficiency of the biological pump.

Processing of Photosynthetically Fixed Carbon. The fate of organic carbon in marine systems is governed largely by microbial heterotrophs that are responsible for most carbon transformation, solubilization, and subsequent remineralization occurring in the water column. Despite microbes’ crucial role in mediating these processes, only limited information is available regarding the identity of organisms and key genes and proteins involved in degradation of organic matter, as well as the relative degradation rates of various types of compounds.