Box 2.5. The Terrestrial Carbon Cycle

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The terrestrial carbon cycle is the *chemical engine* that supplies energy and mass to most life on earth, including human life. It is also intimately involved in regulating the composition of the global atmosphere, and thus the energy balance of the climate system.

Plants remove carbon dioxide (CO_2) from the atmosphere and convert it to carbohydrate, through the process of photosynthesis (Fig. 2.34). Some of this carbon is used by the plant to fuel its own metabolism in a process known as autotrophic respiration, resulting in the release of CO_2 back to the atmosphere. The remainder, called net primary production, builds the leaves, stems and roots of the plants. At around 500 Pg C, the global quantity of plant biomass is small relative to the huge amount of carbon stored in the ocean and in fossil fuels, but it is important because it can increase or decrease relatively rapidly in response to climate or management, with strong and immediate effects on the atmospheric carbon pool.

Plant parts eventually die and decay, or are eaten by herbivores, or are consumed by fire. In the first two cases, the carbon is used by microorganisms or animals as an energy source and to build their own biomass, which also eventually passes into the food chain. In these processes most of the carbon is released as CO_2, a pathway known as heterotrophic respiration. Disturbances, such as storms, pest outbreaks, harvesting or clearing accelerate heterotropic respiration. So, in general, does climate warming.

Part of the carbon flowing through the terrestrial ecosystem builds up in the soil as dead plant and animal material, and byproducts of microbial metabolism or fire that are resistant to decomposition. Although the carbon retained in the soil is a small fraction of the flow, cumulatively it amounts to 1 500–2 000 Pg C. Soil organic matter is less easily returned to the atmosphere than is plant biomass, causing the soil to act as a medium-term buffer in the global carbon cycle. Intensive tillage, coupled with removal of most of the crop biomass, reduces the carbon content of the topsoil by up to half, over a period of decades. It can be built up again over a similar period by fallowing or by reduced tillage practices.

Almost all land ecosystems burn at some stage in their history, but the permanently moist ones do so very infrequently. Tropical savannas and boreal forests, on the other hand, emit about 2–5 Pg C yr^{-1} to the atmosphere through fire (Crutzen and Andreae 1990).

There are several other minor mechanisms by which carbon returns to the atmosphere. Plants give off a wide range of carbon-based gases, collectively known as Volatile Organic Compounds (VOC), generally in small quantities. When decomposition occurs in oxygen-starved conditions (such as underwater or in the gut of an animal), carbon is given off as the powerful but short-lived greenhouse gas CH_4. Gases such as the VOCs and CH_4 eventually convert to CO_2 in the atmosphere, but in the process they alter the regional air chemistry, in some cases generating another powerful greenhouse gas, tropospheric ozone.

A very small fraction of the carbon cycling through terrestrial ecosystems leaks into groundwater, rivers, and eventually the ocean, in the form of dissolved or suspended organic carbon (Schlesinger and Melack 1981). It contributes to the organic-rich sediments in lakes and on the coastal shelf, where it eventually decomposes and returns to the atmosphere. This leakage is important in that it results in land ecosystems being small net sinks of carbon, even when the biosphere as a whole is in equilibrium. Another long-term sink mechanism is the formation of black carbon (soot) when biomass burns. Black carbon is virtually inert and is thus removed from an active role in the biosphere for a very long time.

The absolute annual exchange of carbon between land-based ecosystems and the atmosphere is somewhat larger than the exchange between the atmosphere and the oceans (about 120 Pg C yr^{-1} and 90 Pg C yr^{-1} in each direction, respectively). Together these biospheric exchanges dwarf the annual input of carbon to the atmosphere by modern human activities (about 7 Pg C yr^{-1}). In pre-industrial times the exchanges in each direction were approximately in balance. That is no longer true. Between about 1700 and 1960 the land is calculated to have been a net source of carbon to the atmosphere, due to the emissions resulting from the conversion of natural vegetation to croplands. More recently, photosynthesis has exceeded respiration, despite ongoing land conversion in the tropics, and the land has become a net sink for carbon. The terrestrial sink is currently removing about 30% of the additional CO_2 injected into the atmosphere by human activity. Unlike the ocean carbon sink, it cannot continue to do so at the present rate for centuries or millenia. Models project that the sink will peak within the twenty-first century (Cramer et al. 2001).

More details on the terrestrial carbon cycle can be found in Scholes et al. (1999), Bolin et al. (2000) and Prentice et al. (2001).

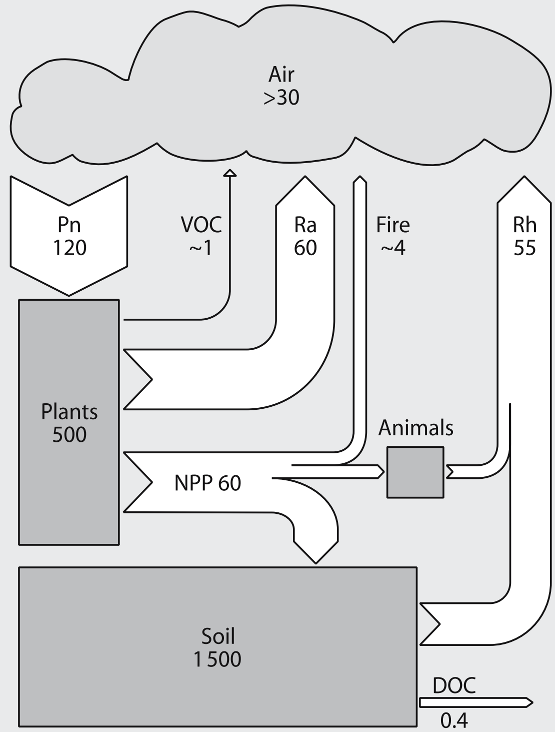

Fig. 2.34. The main elements of the terrestrial carbon cycle. The units are global totals for a pre-industrial world, in Pg C for the pools and Pg C yr^{-1} for the fluxes (Prentice et al. 2001). The rate of biomass formation (net primary productivity, *NPP*), is equal to photosynthesis (*Pn*) minus autotropic respiration (*Ra*) and Volatile Organic Carbon (*VOC*) losses. The rate of carbon uptake or loss from a given patch of land is the *NPP* minus the heterotrophic respiration (*Rh*) and denotes Net Ecosystem Productivity (*NEP*). Over a long period of time, the small but steady loss as dissolved carbon (*DOC*), and the larger intermittent losses due to disturbance, fire or harvesting, become important and must be subtracted to give the Net Biome Productivity (*NBP*) (Schulze and Heimann 1998), the true long-term effect of the land on the atmosphere. Under equilibrium conditions this is a very small number. Under the current human-induced disturbance it is about 1.4 Pg C yr^{-1}

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