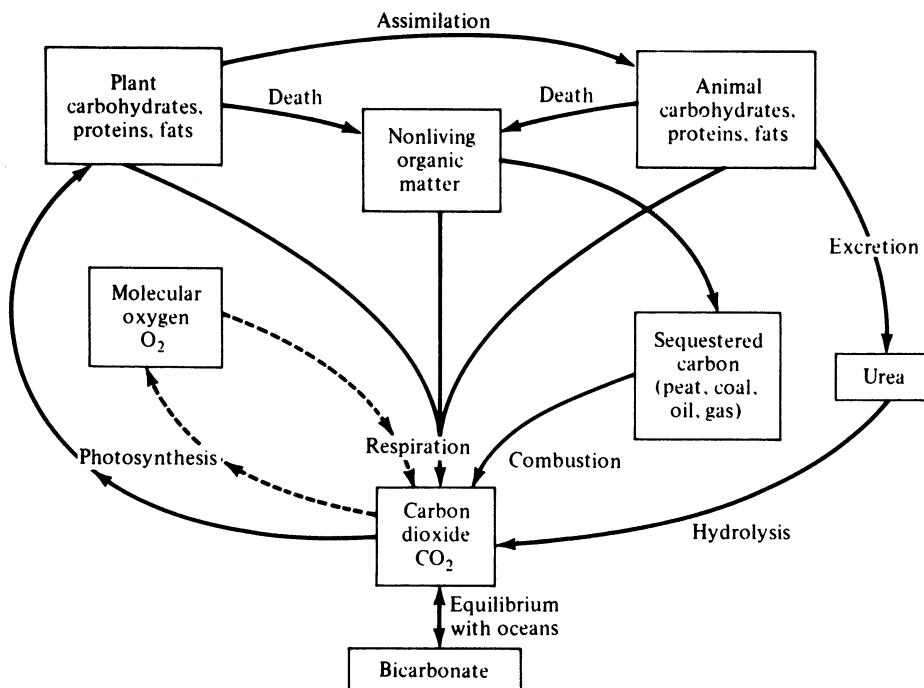


(eqs. 16.15–16.17) explains the more stable and sustained oscillations observed in nature, which are independent of initial conditions (that is, hard oscillations).

## 16.4. MIXED CULTURES IN NATURE

Mixed cultures of organisms are common in natural ecological systems. Microorganisms are involved in the natural cycles of most elements (e.g., carbon, nitrogen, oxygen, and sulfur). Simplified diagrams of the carbon and nitrogen cycles are presented in Figs. 16.4 and 16.5. Organisms living in soil and aquatic environments actively participate in carbon and nitrogen cycles. For example, certain organisms fix atmospheric CO<sub>2</sub> to form carbohydrates, while others degrade carbohydrates and release CO<sub>2</sub> into the atmosphere. Similarly, some organisms fix atmospheric nitrogen (N<sub>2</sub>) to form ammonium and proteins, while others convert ammonium into nitrite and nitrate (nitrification), and others reduce nitrate into atmospheric nitrogen (denitrification). Sulfur-oxidizing organisms convert reduced sulfur compounds (sulfur and sulfide) into sulfate, and sulfate-reducing organisms reduce sulfate into hydrogen sulfide.

The aforementioned interactions among different species take place in natural systems in a more complicated manner. The complexity of such a system is depicted in



**Figure 16.4.** Simplified diagram of the carbon cycle. Also shown (dashed lines) is the major component of the oxygen cycle, which is closely linked to the cycle of carbon. (With permission, from J. E. Bailey and D. F. Ollis, *Biochemical Engineering Fundamentals*, 2d ed., McGraw-Hill Book Co., New York, 1986, p. 914.)