

sugars (carbohydrates). The process also releases an output from the forest system: the oxygen that we breathe.

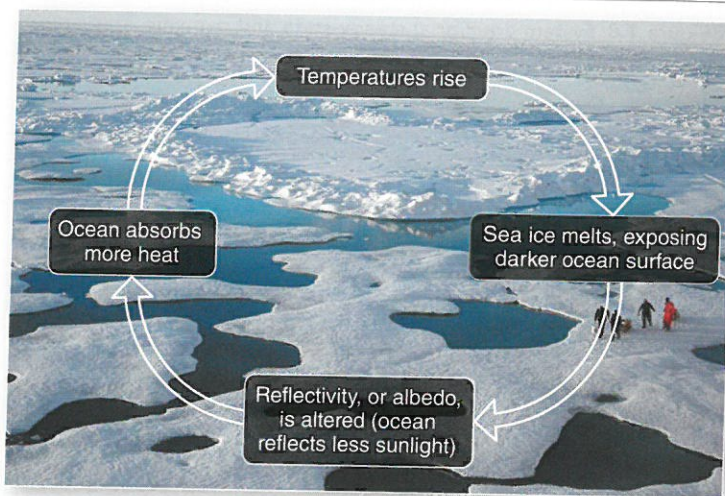
Forest outputs also include products and activities that link to other broad-scale Earth systems. For example, forests store carbon and are thus referred to as “carbon sinks.” A 2011 study found that forests absorb about one-third of the carbon dioxide released through the burning of fossil fuels, making them a critical part of the climate system as global carbon dioxide levels rise. Forest roots stabilize soil on hillslopes and stream banks, connecting them to land and water systems. Finally, the food and habitat resources provided by forests link them closely to other living systems, including humans. (Chapters 11, 16, and 17 discuss these processes and interactions.)

The connection of human activities to inputs, actions, and outputs of forest systems is indicated by the double-headed arrow in Figure 1.6. This interaction has two causal directions, since forest processes affect humans and humans influence forests. Forests affect humans through the outputs of carbon storage (which mitigates climate change), soil stabilization (which prevents erosion and sedimentation into source areas for drinking water), and food and resources. Human influences on forests include direct impacts such as logging for wood resources, burning to make way for agriculture, and clearing for development as well as indirect impacts from human-caused climate change, which may enhance the spread of disease and insects, and pollution, which affects tree health.

System Feedback As a system operates, it generates outputs that influence its own operations. These outputs function as “information” that returns to various points in the system via pathways called **feedback loops**. Feedback information can guide, and sometimes control, further system operations.

If the feedback information discourages change in the system, it is **negative feedback**. Further production of such feedback opposes system changes and leads to stability. Such negative feedback causes self-regulation in a natural system. Negative feedback loops are common in nature. In a forest, for example, healthy trees produce roots that stabilize hillslopes and inhibit erosion, providing a negative feedback. If the forest is damaged or removed, perhaps by fire or logging practices, the hillslope may become unstable and subject to landslides or mudslides. This instability affects nearby systems as sediment is deposited into streams, along coastlines, or into developed areas.

If feedback information encourages change in the system, it is **positive feedback**. Further production of positive feedback stimulates system changes. Unchecked positive feedback in a system can create a runaway (“snowballing”) condition. In natural systems, such unchecked system changes can reach a critical limit, leading to instability, disruption, or death of organisms.



▲**Figure 1.7** The Arctic sea ice–albedo positive feedback loop. Average ice thickness in the Arctic summer has dropped dramatically, leaving thinner ice that melts more easily. Since 2000, 70% of the September ice volume has disappeared. If this rate of loss continues, the first ice-free Arctic September might happen before 2017. [NOAA.]

Global climate change creates an example of positive feedback as summer sea ice melts in the Arctic (discussed in Chapters 3, 8, and 14). As arctic temperatures rise, summer sea ice and glacial melting accelerate. This causes light-colored snow and sea-ice surfaces, which reflect sunlight and so remain cooler, to be replaced by darker-colored open ocean surfaces, which absorb sunlight and become warmer. As a result, the ocean absorbs more solar energy, which raises the temperature, which, in turn, melts more ice, and so forth (Figure 1.7). This is a positive feedback loop, further enhancing the effects of higher temperatures and warming trends.

System Equilibrium Most systems maintain structure and character over time. An energy and material system that remains balanced over time, in which conditions are constant or recur, is in a *steady-state condition*. When the rates of inputs and outputs in the system are equal and the amounts of energy and matter in storage within the system are constant (or, more realistically, fluctuate around a stable average), the system is in **steady-state equilibrium**. For example, river channels commonly adjust their form in response to inputs of water and sediment; these inputs may change in amount from year to year, but the channel form represents a stable average—a steady-state condition.

However, a steady-state system may demonstrate a changing trend over time, a condition described as **dynamic equilibrium**. These changing trends may appear gradually and are compensated for by the system. A river may tend toward channel widening as it adjusts to greater inputs of sediment over some time scale, but the overall system will adjust to this new condition and thus maintain a dynamic equilibrium. Figure 1.8 illustrates the steady-state and dynamic equilibrium conditions.

Note that systems in equilibrium tend to maintain their functional operations and resist abrupt change.