

Human Impact of Chemical Cycles

DIRECTIONS: Read the following excerpts on human impact on nutrient cycles. Describe the impact humans have on the carbon cycle, water cycle, phosphorous cycle, and nitrogen cycle in AT LEAST 3 SENTENCES per cycle.

Impact on Chemical Cycles

Human activities often intrude in biogeochemical cycles by removing nutrients from one location and adding them to another. This may result in the depletion of key nutrients in one area, excesses in another place, and the disruption of the natural chemical cycling in both locations. For example, nutrients in the soil of croplands or rangelands make their way into the waste products of humans and livestock and then appear in streams and lakes through discharge as sewage and runoff from stockyards. Someone eating a salad in Washington, DC, is consuming nutrients that only days before might have been in the soil in California. And a short time later, some of these nutrients will be in the Potomac River, having passed through an individual's digestive system and the local sewage facilities.

Humans have altered chemical cycles to such an extent that it is no longer possible to understand any cycle without taking the human impact into account. Let's consider just a few examples.

Impact on the Carbon Cycle The increased burning of fossil fuels (coal and petroleum) as well as wood from deforested areas is steadily raising the level of CO_2 in the atmosphere. This is leading to significant environmental problems, such as global warming (discussed later).

Impact on the Nitrogen Cycle Sewage treatment facilities typically empty large amounts of dissolved inorganic nitrogen compounds into rivers and streams. Additionally, farmers routinely apply large amounts of inorganic nitrogen fertilizers, mainly ammonium and nitrates, to croplands. Lawns and golf courses also receive sizable doses of fertilizer. Crop and lawn plants take up some of the nitrogen compounds, and soil bacteria convert some to atmospheric nitrogen (N_2) (see Figure 19.29b). However, chemical fertilizers usually exceed the soil's natural recycling capacity, and the excess nitrogen compounds often enter streams, lakes, and groundwater. While nitrogen is a beneficial nutrient to plants, too much of it can create an imbalance. In lakes and streams, nitrogen compounds from runoff continue to fertilize, causing heavy growth of algae. Groundwater pollution by nitrogen fertilizers is also a serious problem in many agricultural areas. In the human digestive tract, nitrates in drinking water are converted to nitrites, which can be toxic.

Impact on the Phosphorus Cycle Like nitrogen compounds, phosphates are a major component of sewage outflow. They are also used extensively in agricultural fertilizers and are a common ingredient in pesticides. Phosphate pollution of lakes and rivers, like nitrate pollution, stimulates a heavy algal growth. Such overfertilization, or **eutrophication**, leads to population explosions of algae and cyanobacteria that can eventually remove so much oxygen from lakes or ponds that aerobic life suffocates (Figure 20.5).

Impact on the Water Cycle One of the main sources of atmospheric water is transpiration (evaporation) from the dense vegetation of tropical rain forests. The destruction of these forests, which is occurring rapidly today, will change the amount of water vapor in the air (Figure 20.6). This, in turn, will most likely alter local, and perhaps global, weather patterns. Another change in the water cycle caused by humans results from pumping large amounts of groundwater to the surface to use for crop irrigation. This practice can increase the rate of evaporation from soil, and unless this loss is balanced by increased rainfall over land, groundwater supplies are depleted. Large areas in the midwestern United States, the southwestern American desert, parts of California, and areas bordering the Gulf of Mexico currently face this problem.



Does Deforestation Change Chemical Cycles?

A case study of chemical cycling has been ongoing since 1955 at the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire. The research area consists of a deciduous forest with several valleys, each drained by a small creek that is a tributary of Hubbard Brook. Bedrock impermeable to water is close to the surface of the soil, so each valley constitutes a watershed that can drain only through its creek.

The research team first determined the mineral budget for each of six valleys by measuring the inflow and outflow of several key nutrients. They collected rainfall at several sites to measure the amount of water and dissolved minerals added to the ecosystem. To monitor the loss of water and minerals, the scientists constructed small concrete dams, each with a V-shaped spillway, across the creek at the bottom of each valley (Figure 20.7a). About 60% of the water added to the ecosystem as rainfall and snow exits through the streams, and the remaining 40% is lost by transpiration from plants and evaporation from the soil.

The researchers **observed** that local cycling within each watershed conserved most of the mineral nutrients. That is, mineral inflow balanced outflow and both were relatively small compared with the quantity of minerals being recycled within the forest ecosystem.

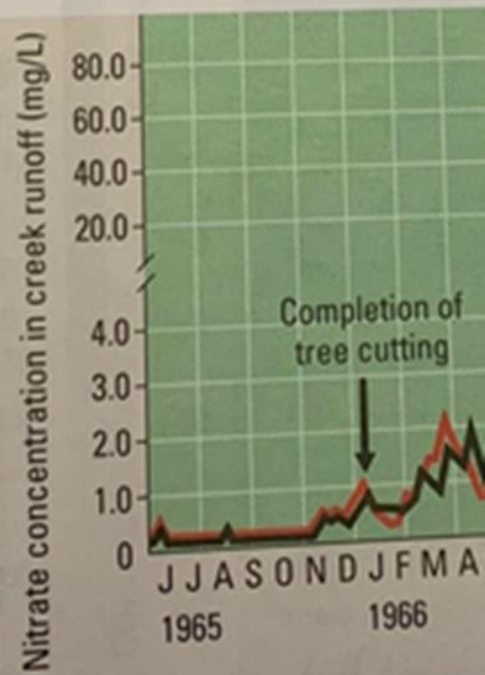


The researchers posed the **question**: What would happen to the chemical cycles if a region was deforested? They made the **hypothesis** that a lack of plant life would have a drastic effect on the flow of chemicals through an experimental valley. Their **experiment** involved completely deforesting one valley and then comparing the inflow and outflow of water and minerals in the experimentally altered watershed with the inflow and outflow in a control watershed for three years (Figure 20.7b).

The **results** of the experiment showed that water runoff from the altered watershed increased by 30–40%, apparently because there were no plants to absorb and transpire water from the soil. Net losses of minerals from the altered watershed were huge. Most remarkable was the loss of nitrate, which increased in concentration in the creek 60-fold (Figure 20.7c). Not only was this vital mineral nutrient drained from the ecosystem, but nitrate in the creek reached a level considered unsafe for drinking water.

The Hubbard Brook researchers concluded that the amount of nutrients leaving an intact forest ecosystem is controlled mainly by plants. Nutrients were lost from the system when plants were not present to retain them. These effects were almost immediate, occurring within a few months of

(a) A dam at the Hubbard Brook study



(c) The loss of nitrate from a deforested watershed

logging, and continuing as long as plants were absent. As new plants grew in the treatment area, transpiration increased and runoff decreased. Though scientists designed the Hubbard Brook experiments to assess natural ecosystem dynamics, the results also provided important insights into the mechanisms by which human activities such as deforestation affect these processes. ■

The Release of Toxic Chemicals to Ecosystems

In addition to transporting vital chemical elements from one location to another, humans have added entirely new materials, many of them toxic, to ecosystems. We produce an immense variety of these toxic chemicals, including thousands of synthetics previously unknown in nature. Many of these poisons cannot be degraded by microorganisms and consequently persist in the environment for years or even decades. In other cases, chemicals released into the environment may be relatively harmless but are converted to more toxic products by reaction with other substances or by the metabolism of microorganisms. For example, mercury, a by-product of plastic production, was once routinely expelled into rivers and the sea in an insoluble form. Bacteria in the bottom mud converted the waste to methyl mercury, an extremely toxic soluble compound that then accumulated in the tissues of organisms, including humans who consumed fish from the contaminated waters.

Organisms acquire toxic substances from the environment along with nutrients and water. Some of the poisons are metabolized or excreted, but others accumulate in specific tissues, especially fat. Examples of industrially synthesized compounds that act in this manner are the chlorinated hydrocarbons (which include many pesticides, such as DDT) as well as the industrial chemicals called PCBs (polychlorinated biphenols).

One of the reasons the toxins we add to ecosystems are such ecological disasters is that they become more concentrated in successive trophic levels of a food web, a process called **biological magnification**. Magnification occurs because the biomass at any given trophic level is produced from a much larger toxin-containing biomass ingested from the level below (see Figure 19.26 to review energy pyramids). Thus, top-level carnivores are usually the organisms most severely damaged by toxic compounds that have been released into the environment.

One classic example of biological magnification involves DDT, the poisonous pollutant that pioneering ecologist Rachel Carson warned about more than 40 years ago (see Chapter 18). In the 1960s, researchers began finding traces of DDT in marine mammals in the Arctic, far from any places DDT had been used. The chemical had been transported and concentrated as it passed through food webs. In the Great Lakes food chain shown in **Figure 20.8**, the concentration of PCBs measured in herring gull eggs was almost 5,000 times higher than that measured in phytoplankton. The concentration increased at each successive trophic level. Yet another example is the 1999 spraying of insecticides called pyrethroids in several areas of New York City. The spraying was a precaution against West Nile virus, which is carried by mosquitoes (see the opening essay in Chapter 14). Within months, there was a massive die-off of lobsters in Long Island Sound, likely caused by pyrethroid magnification within the local food chain. Scientists hypothesize that the poisons reached the ocean in rainstorm runoff from the city.

Human Impact on the Atmosphere and Climate

We are causing radical changes in the composition of the atmosphere and, consequently, in the global climate. Our activities release a variety

of gaseous waste products. We once thought that the vastness of the atmosphere could absorb these materials without significant consequences, but an astronaut's view of our little planet squashes such naive notions (**Figure 20.9**). One pressing problem that relates directly to one of the chemical cycles we examined is the rising level of carbon dioxide in the atmosphere.

Carbon Dioxide Emissions, the Greenhouse Effect, and Global Warming

Since the Industrial Revolution, the concentration of CO_2 in the atmosphere has been increasing as a result of the combustion of fossil fuels and the burning of enormous quantities of wood removed by deforestation. Various methods have estimated that the average CO_2 concentration in the atmosphere before 1850 was about 274 parts per million (ppm). When a monitoring station on Hawaii's Mauna Loa peak began making very accurate measurements in 1958, the CO_2 concentration was 316 ppm (**Figure 20.10**). Today, the concentration of CO_2 in the atmosphere exceeds 370 ppm, an increase of about 17% since the measurements began just over 45 years ago. If CO_2 emissions continue to increase at the present rate, by the year 2075 the atmospheric concentration of this gas will be double what it was at the start of the Industrial Revolution. It is difficult to predict the multiple ways this intrusion in the carbon cycle will affect the biosphere and its various ecosystems.

One factor that complicates predictions about the long-term effects of rising atmospheric CO_2 concentration is its possible influence on Earth's heat budget. Much of the solar radiation that strikes the planet is reflected back into space. Although CO_2 and water vapor in the atmosphere are transparent to visible light, they intercept and absorb much of the reflected heat radiation, bouncing it back toward Earth. This process, called the



Figure 20.10 Increase in atmospheric CO_2 concentration. The data were collected at Mauna Loa, Hawaii, a major contributor to the increase.

Depletion of Atmospheric Ozone Life on Earth is protected from the damaging effects of ultraviolet (UV) radiation (see Chapter 10) by a very thin protective layer of ozone molecules (O_3) located in the atmosphere between 17 and 25 km above Earth's surface. This **ozone layer** absorbs UV radiation, preventing much of it from reaching organisms in the biosphere. Measurements by atmospheric scientists document that the ozone layer has been gradually thinning since the middle of the 20th century (**Figure 20.12**).

The destruction of atmospheric ozone probably results mainly from the accumulation of chlorofluorocarbons, chemicals used in refrigeration, as propellants in aerosol cans, and in certain manufacturing processes. When the breakdown products from these chemicals rise in the atmosphere, the chlorine they contain reacts with ozone, converting it to O_2 . Subsequent chemical reactions liberate the chlorine, allowing it to react with other ozone molecules in a chain reaction. The effect is most apparent over Antarctica, where cold winter temperatures facilitate these atmospheric reactions. Scientists first described an "ozone hole" over Antarctica in 1985. Since then, the size of the ozone hole has increased (see Figure 20.12a), sometimes extending as far as the southernmost portions of Australia, New Zealand, and South America. And at the more heavily populated middle latitudes, ozone levels have decreased 2–10% during the past 20 years.

The consequences of ozone depletion may be quite severe for all life on Earth, including humans. Some scientists expect the growing intensity of UV radiation to increase the incidence of skin cancer and cataracts among humans. It is likely that there will also be damaging effects on crops and natural communities, especially the phytoplankton that are responsible for a large proportion of the biosphere's primary productivity. The danger posed by ozone depletion is so great that many nations agreed in 1987 to end the production of chlorofluorocarbons by the year 2010. (The United States and other industrialized nations have already substituted safer compounds for chlorofluorocarbons, but a grace period was allowed for developing countries.) As a result of such action, ozone depletion has slowed. Unfortunately, even if all chlorofluorocarbons were banned today, the chlorine molecules already in the atmosphere will continue to degrade atmospheric ozone for at least a century. It is just one more example of how far our technological tentacles reach in disrupting the dynamics of ecosystems and the entire biosphere.