VI.6

Grasslands

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OUTLINE

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This section focuses on the ecosystem services provided by natural grasslands. These regions of the world are mostly limited by water availability, and they exclude anthropogenic grasslands, which derived from forests that were logged and converted into pastures, often to support cattle grazing. Grasslands account for 41% of Earth's land surface, and 38% of Earth's 6.8 billion people live in natural grasslands. Grasslands support a diversity of uses, but until recently they have been primarily used for grazing and wood gathering for fuel, with conversion to agriculture at the wet end of their climatic envelope. Alternative uses of these regions—e.g., recreation, conservation, and carbon sequestration—are gaining in societal value, particularly in developed countries. This chapter used the definition of ecosystem services presented above and the categorization developed by the Millennium Ecosystem Assessment with four types of ecosystem services: provisioning services, regulating, cultural, and supporting services.

GLOSSARY

albedo. Energy reflected from the land or water surface. Generally, white or light-colored surfaces have high albedo, and dark-colored or rough surfaces have low albedo.

carbon sequestration. The process of removing carbon dioxide from the atmospheric pool and making it less accessible or inaccessible to carbon-cycling processes.

grasslands. Short-stature vegetation dominated by grasses, characteristic of locations with a strong water limitation for at least part of the year.

petagram. One trillion million (10^{18}) grams.

soil texture. Soil texture is described by the proportions of sand (large particles), silt (intermediate-sized particles), and clay (smallest particles). Sandy, loose-textured soils allow rapid water infiltration and fast leaching of nutrients. Denser, clayey soils have poor drainage and poor soil aeration.

transpiration. The evaporation of water from the leaves, stems, and flowers of plants. Transpiration occurs through small pores, or stomata, on leaf and stem surfaces, which must remain open to take up carbon dioxide.

1. SCOPE OF GRASSLANDS

Grasslands occur where there is not enough water to support forests, although temperature also plays a role: cool locations can support forests at precipitation levels that can only support grasslands in warmer climates. For instance, rainfall in the United States generally increases from west to east, and temperature increases from north to south. The grassland–forest boundary thus runs in a diagonal fashion from southeast to northwest, reflecting the issue that lower temperatures characteristic of the north allow forest to grow at lower precipitation than in the south. Grasslands are dominated in general by herbaceous vegetation, mainly grasses and forbs, although shrubs account for an important fraction of grassland biomass in some regions, and grasslands can also support occasional trees. The proportion of shrubs and grasses depends on the texture of the soil and the seasonality of precipitation. Grasslands encompass different vegetation types with different shrub abundance from prairies to steppes.

2. PROVISIONING ECOSYSTEM SERVICES

Grasslands, through their support of grazing, produce meat, milk, and blood for many people who depend on animals for their daily protein intake. Grasslands in developed countries are primarily managed by cow-calf producers where calves are sold to fattening operations that feed grain to calves until they become mature and ready for slaughter. In contrast, in developing nations most of the meat production occurs in grasslands themselves. The type of animal used varies enormously depending on cultural and climatic conditions and ranges from goats to camels.

Especially in developing countries, residents often harvest shrubs and trees from grasslands for fuel, and the resource can provide a large percentage of household energy use in dryland regions. Overuse of this service can increase soil erosion, decrease recruitment of new plants, and degrade the ecosystem.

Grasslands support a wide variety of grazing animals, including sheep, goats, llamas, alpacas, vicuñas, and even muskoxen, which can sustainably produce fiber for household use and sale. The trade-offs between grazing density and grassland sustainability vary with the productivity of the system, which depends largely on soil type and precipitation. Most grassland plant species evolved under some grazing pressure, and a moderate population of grazers can help replicate past conditions and sustain or even increase plant species richness. Increasing grazing intensity to higher levels reduces plant cover, exposing bare ground and increasing soil erosion.

The majority of the human diet derives originally from grassland species. Annual grasses and legumes are most abundant in grasslands, and the wheat, barley, and other staple grains on which most northern countries depend today were selectively bred from wild grasses. Similarly, most of our domestic animals—including cattle, goats, and sheep—originated in grassland regions. The value of this genetic library lies not only in the sourcing of today's diet but as insurance against future pests and diseases. In grassland ecosystems, wild relatives of domesticated plants and animals continue to face evolving pests and pathogens. The defenses they develop may one day help protect domestic species from unforeseen threats.

3. REGULATING SERVICES

Grasslands play a role in regulating both local weather and global climate by influencing albedo, dust movement, evapotranspiration, and carbon storage. As grazing intensity increases, surface roughness decreases initially, increasing albedo, which defines the amount of energy reflected from the land surface. All else being equal, the increase in albedo would lead to lower surface temperatures, but it is offset by decreasing transpiration. Like sweat evaporating off the body, this evaporation of water through plants acts to reduce the local temperature and cycle water through the atmosphere. When transpiration is reduced, temperatures increase, and rainfall decreases, nudging the system toward desertification. Comparison of temperature data north and south of the United States–Mexico border, for instance, suggested that temperatures were higher south of the border, where grazing is more intense and plant cover is lower.

Beyond a certain threshold of use, grazers remove most of the herbaceous plants, promoting the establishment of woody shrubs. This change in land surface cover reduces albedo, increases wind and water erosion, and decreases infiltration of rainfall and snowfall, further accelerating the ecosystem degradation and reinforcing the local climate feedbacks.

Pollination and seed dispersal are important regulating services in grasslands, but there are few studies of their scale, distribution, or trends. In patchy landscapes, where crops are interspersed with natural grasslands, the grasslands support a diverse and abundant community of pollinators that maintain crop productivity. Reduction of the proportion of native grasslands and the population of pollinators has reduced crop yield in some cases. In these cases, farmers have resorted to bringing colonies of pollinators from a distance with the resulting cost of transportation and artificial maintenance of the pollinator populations.

Intact grasslands sequester a large amount of carbon in living biomass (both above and belowground) and in soils. Organic plus inorganic carbon in grasslands has been estimated at 770–880 Pg of carbon globally, which is equivalent to 20–25% of all the carbon stored in terrestrial systems. The amount of carbon stored varies spatially and depends mainly on long-term climatic conditions at the site. Increasing precipitation tends to increase biomass production and carbon storage in grasslands, and warmer temperatures increase decomposition, reducing soil carbon stocks (plate 19).

Established grassland systems accumulate carbon gradually but can release large quantities quickly when converted to cultivated agricultural systems. Tilling grassland soils breaks up aggregates, giving decomposers access to previously unavailable carbon compounds. Many grassland systems lose nearly 50% of carbon stocks in the first year of cultivation. However, when land is retired from cultivation and returned to natural grassland or rangeland, it can take 50 to 100 years to regain the lost carbon. This sets up a trade-off between natural grasslands, which sequester carbon, and agricultural systems, which produce food and, more recently, biofuels. Many of the world's most productive agricultural areas have already been converted from natural grasslands, and expanding agricultural conversion reduces the potential for carbon storage in terrestrial systems.

As economic markets begin to place realistic values on ecosystem services from grasslands, it may become possible to compile a package of services provided by intact grassland that approaches the economic value of agriculture conversion. Such a package could include cultural services such as recreation, ecotourism, and scenic vistas (which contribute directly to real estate value) as well as carbon sequestration services.

The Intergovernmental Panel on Climate Change (IPCC) uses benchmarks of \$20, \$50, and \$100 per metric ton of CO_2-equivalent to estimate the future economic value of carbon mitigation strategies. The value rises as the amount of CO_2 in the atmosphere is expected to increase because damage from climate change is expected to be higher as atmospheric concentrations rise. Although the United States has no mandatory carbon limits or carbon trading markets, the Chicago Climate Exchange is beginning to place a value on the (voluntary) sequestration of carbon through offset purchases. The value of 1 metric ton of CO_2-equivalent on the Chicago Climate Exchange currently hovers around \$5, which stands in stark contrast to the IPCC estimates.

4. CULTURAL SERVICES

The open spaces, arid climate, and biodiversity of many grassland regions make them attractive destinations for both tourism and recreation. Tourists pack African safaris to view large mammal species, and the trans-Sahara bird migration draws enthusiasts from across the globe. Cultural sites are especially well preserved in arid climates, from Egyptian pyramids to the Native American ruins of the American Southwest. Middle Eastern religious sites attract both local and international visitors.

The same qualities that attract tourists to these destinations also make it difficult to accommodate large numbers of visitors. Water is scarce, temperatures are high, and locations are often remote. Travelers must come long distances, and infrastructure for energy, accommodation, and water supply is often modest. Recent increased awareness of the environmental impact of tourism may open the door to more environmentally gentle development, including the use of on-site solar and wind energy, reuse of local wastewater, and structure design that incorporates passive heating and cooling.

5. SUPPORTING SERVICES

Supporting services maintain ecosystem functioning and are essential to the provision of all other services, but their effects may be indirect or observable only over long time scales. The most important supporting services in grassland systems, as in most other terrestrial systems, are primary production, soil formation, and nutrient cycling, which are closely interrelated. Plant production contributes above- and belowground biomass to the system, supplying organic matter and nutrients. Roots from growing plants hold soil in place, reducing wind and water erosion and facilitating soil development. Nutrient cycling processes, such as decomposition and microbial mineralization and immobilization, retain essential nutrients within the system and release them gradually from organic matter, maintaining a steady supply of plant nutrients and limiting leaching losses.

Natural grasslands exist primarily in areas of marginal precipitation and therefore support lower rates of primary productivity than forests or cultivated systems. Among semiarid grasslands, productivity generally increases with increasing precipitation and decreases with increasing temperature because of the effect of temperature on water availability. This pattern is illustrated nicely in the Great Plains of the United States, where mean annual temperature increases from north to south and mean annual precipitation increases from west to east. This produces a large-scale pattern of increasing net primary production from southwest to northeast. At the high end of the productivity gradient, grasslands transition to forests or agricultural systems.

Precipitation also exhibits a strong temporal influence on productivity, although the relation is not as tight as the spatial correlation, probably because of such factors as time lags in response to variable precipitation. Greater precipitation late in the season permits a longer growing season and greater production.

Soil texture clearly affects productivity, but its influence is smaller than that of climate and varies depending on water availability. In wetter areas, water loss through deep percolation limits production, and fine-textured soils promote higher yields. In drier areas, evaporative loss is a greater concern, and sandy soils may allow quicker infiltration and higher production.

It can be difficult to distinguish degraded grassland systems from those with low productivity because of low precipitation. The ratio of net primary productivity to rainfall, known as rain use efficiency, helps to separate water-limited grasslands from those that may be limited by nutrient losses, desertification, or declining organic matter.

The strong dependence of grassland production on precipitation highlights the potential for global climate change to have large impacts in these ecosystems. Reports of the IPCC predict significant changes in total precipitation and precipitation variability in the coming century. Although precipitation changes caused by climate change vary among regions, the trend for temperature increase is common across all grasslands. Increased temperature, independent of changes in precipitation, will decrease water availability because of increasing evaporative demand. Therefore, increased temperature is expected to decrease grassland production.

Although precipitation may determine how much water is delivered to grasslands, interception and retention by plants and soils determine how much water stays in the system and how much is lost as surface runoff. Soil is an almost-magical amalgam of mineral and organic particles formed over centuries by the physical-chemical breakdown of rocks and the biological recycling of organic material. Together, soil texture and organic matter content are the major determinants of soil quality, a general description for the features that make a soil hospitable to plant, animal, and microbial life. These include water infiltration, water retention, nutrient cycling and retention, and a rooting environment that is neither too acidic, too basic, nor too saline.

A strong positive feedback loop exists between plant biomass and soil formation, especially in grasslands, where belowground biomass forms a large proportion of total plant biomass. When there is sufficient water and limited grazing, grasses form strong, dense networks of roots that resist wind and water erosion and quickly intercept water and nutrients, which can otherwise be lost from the system. Moist (but not waterlogged) soils support active microbial communities, which break down plant litter and quickly incorporate it into soil organic matter, further improving soil quality. A large standing biomass of grasses also helps intercept surface runoff, retains plant litter, and contributes a larger amount of organic material each season.

Conversely, when biomass declines—either from insufficient precipitation or through overgrazing or overuse—a group of feedbacks is set in motion that leads to greater water losses and slower soil formation or even soil loss. Water, when it comes, runs quickly over bare ground, taking plant litter and surface soil with it. When it does infiltrate soils, it may not be intercepted by roots and can percolate below the rooting depth of most plants. The resulting drier soils form a less hospitable environment for decomposition and recycling of plant nutrients, making soils more vulnerable to wind erosion and accelerating the feedback loop. Soil formation, and the balance between formation and erosion, is a key supporting service for grassland systems.

Another phenomenon of arid grasslands should also be mentioned here. Crusts—composed of cyanobacteria, mosses, and lichens—form a fragile barrier that fixes atmospheric nitrogen and channels rainwater to intermittent clumps of vegetation. These create islands of active growth, soil formation, and decomposition, preserving some ecosystem services. Trampling and air pollution, however, can quickly destroy these living crusts and expose the soils beneath.

The nature of nutrient cycling, in which dead plant biomass is broken down to release the nutrients and organic matter it contains, varies with water availability. In very arid grasslands, ultraviolet radiation plays an important role in physically decomposing plant litter. In addition, termites, beetles, and other invertebrates, which can survive extremely arid conditions, prepare plant material by breaking it down into smaller particles and digesting it, which releases a large proportion of the nutrients directly into the soil matrix. Burrowing invertebrates also increase water infiltration by providing physical channels into the soil. Mesic grasslands, in contrast, provide enough water to support soil microbes and fungi, which act directly on plant material, breaking it down in place and slowly releasing nutrients and organic matter.

Mammalian grazers add another dimension to the nutrient cycling picture. Their high rates of metabolism burn off a large proportion of the carbon in the biomass they consume, reducing the amount available for recycling within the system. The meat, milk, and hair they produce is often removed from the system (a provisioning service) but is then unavailable for nutrient recycling. Large grazers also play an important role by redistributing nutrients in the landscape. Usually, these animals graze and harvest nutrients from large areas but concentrate their feces around water holes, where large nutrient losses occur.

6. THE SIGNIFICANCE OF GRASSLANDS

Grasslands cover almost 41% of the earth's surface and span the gamut from extremely arid near-deserts to highly productive systems supporting grazing animals. Agricultural systems are not included in this chapter because they are covered elsewhere in this volume, but there is much overlap between the regions that support grasslands and some of the planet's most productive agricultural areas. Because of this large extent, even services that proceed at moderate rates, such as carbon sequestration, are of global significance.

Grasslands also are home to societies experiencing some of the greatest development challenges, with little infrastructure or money, and located far from the centers of decisionmaking. To solve these development challenges, it is essential to understand the nature and value of services provided on both a local and a global scale. People living in arid and semiarid regions are among the most vulnerable to environmental degradation because they harvest goods and services directly from the natural ecosystems. In addition, grassland ecosystems are far more variable than more mesic ecosystems such as forests because the interannual variability of precipitation increases with decreasing average precipitation.

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