Part Two

CHAPTER 9

BIODIVERSITY AND SOIL

As population and consumption levels rise, natural ecosystems are being replaced by agriculture, energy, mining, and settlement. Poor land management leads to widespread loss of soil biodiversity, undermining food production systems throughout the world. Ecosystems are collapsing under the onslaught of deforestation, grassland loss, wetland drainage, and flow disruptions, all leading to a biodiversity crisis and the fastest extinction rate in the Earth's history.

Yet we depend on living soil and the biodiversity that underpins functioning ecosystems and supports productive land-based natural capital. Threats are increasing which require a committed and sustained response. A mixture of protection, sustainable management and, where necessary, restoration is needed at a landscape scale to ensure the future of a diverse, living planet.

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INTRODUCTION

The term biodiversity refers to the total diversity of life – ecosystems, species, and within-species variation.[1] Its critical importance is underlined by the existence of the Convention on Biological Diversity (CBD) signed in 1992. But despite global conservation efforts, biodiversity, above and below ground, remains in retreat, threatening the Earth's land base and the services that it supplies to humanity. Five key trends are evident:

- **Degradation of soil and its biodiversity**, undermining food production and other critical ecosystem services
- **Deforestation and forest degradation**, particularly in the tropics
- **Loss of natural grasslands** and transformation to erosion-prone, species-poor ecosystems
- **Disappearing wetlands**, creating a crisis for freshwater biodiversity
- **Mass extinction**, the unprecedented loss of wild plant and animal species

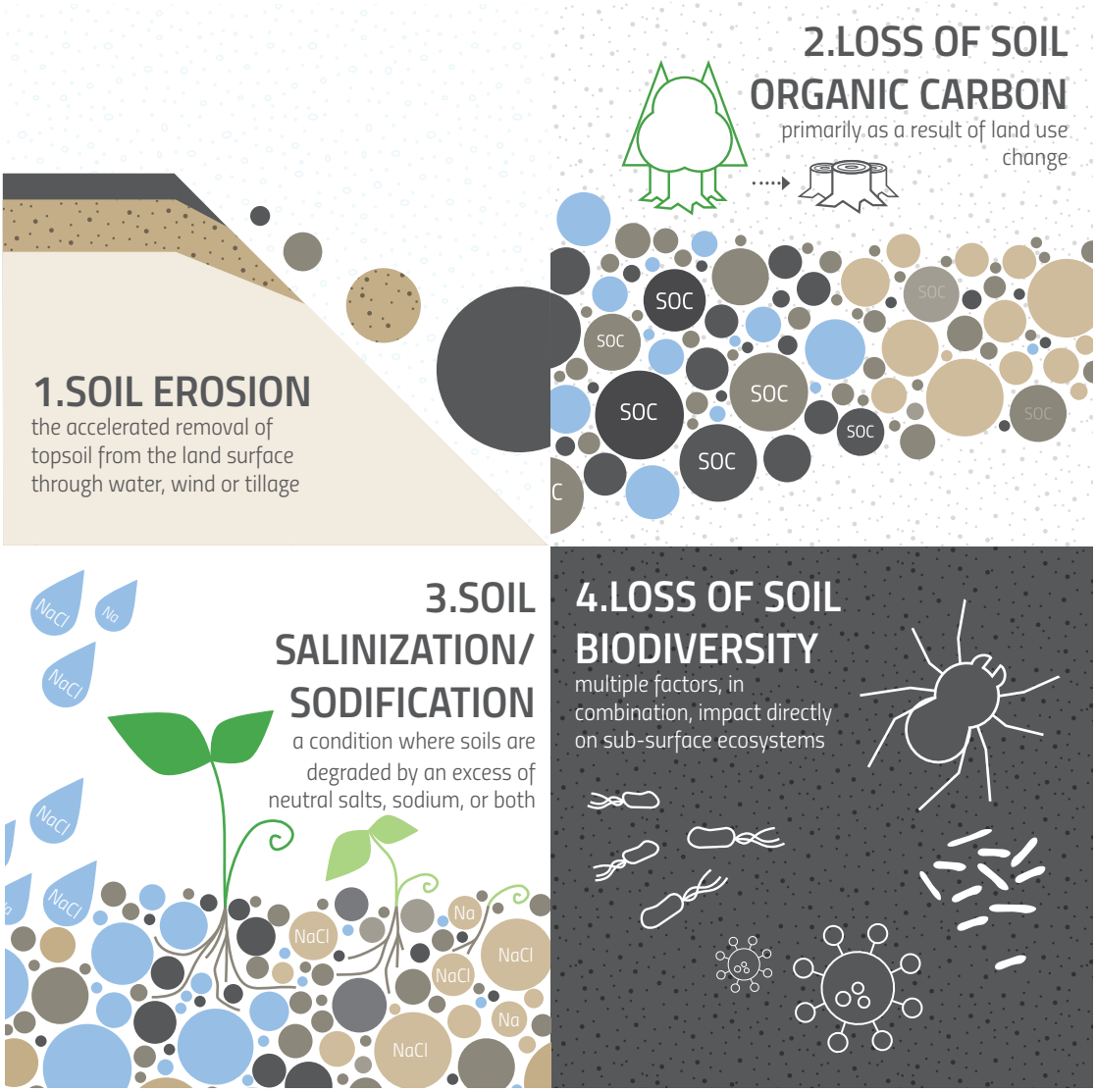
Many of these disconcerting trends are generally well known. In fact, Sustainable Development Goal 15.5 states "*Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species.*"

Soil forms the basis of all terrestrial ecosystems, yet soil status and its biodiversity are often virtually ignored in environmental assessments. As an essential component of land resources, soil issues are given particular attention here.

1. Degradation of soil and its biodiversity

An aspect of biodiversity, often overshadowed by the focus on iconic and colorful species, is the health and security of the soil ecosystem. The World Soil Charter states that "*Soils are fundamental to life on Earth but human pressures on soil resources are reaching critical limits. Further loss of productive soils will amplify food-price volatility and send millions of people into poverty. This loss is avoidable. Careful soil management not only secures sustainable agriculture, it also provides a valuable lever for climate regulation and a pathway for safeguarding ecosystem services.*"[2]

Ecosystem services from soil – which can include, in particular, contributions to food security, climate change mitigation, water retention, and biomass – differ markedly between soil types, with some soils offering numerous benefits and others very few.[3] Yet currently around one-fifth of the world's population lives and works on



degraded agricultural land,[4] and communities, governments, and corporations[5] are now waking up to the critical need for a new approach to sustainable soil management. Maintaining or in many cases recovering soil health in stressed ecosystems will require targeted public policies.[6]

Healthy soils help to ensure food security, climate regulation, water and air quality, and a rich array of biodiversity above and below ground; they also help to prevent erosion, desertification, and landslides.[7] The terms land and soil are often incorrectly used as synonyms. Land is the solid surface of the Earth that is not permanently under water while soil is unconsolidated mineral or organic material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants.[8] Land use changes impact soil conditions usually resulting in deterioration.

The 2015 *Status of the World's Soil Resources* report[9] identified the main threats to soil. At the global level, soil erosion, loss of organic carbon, and nutrient imbalances were considered the most severe threats. Close behind were soil salinization and sodification, loss of soil biodiversity, soil contamination, acidification, and compaction as well as waterlogging, soil sealing, and land take.[10]

Soil erosion: the accelerated removal of topsoil from the land surface by water, wind, or tillage. Estimated rates of soil erosion in arable or intensively grazed lands are 100-1,000 times higher than natural erosion rates, and far higher than rates of soil formation.[11] The subsequent nutrient losses need to be replaced through fertilization at significant economic and environmental costs. For example, if US farm-gate prices for fertilizers are used as a guide, global soil erosion annually costs USD 33-60

billion for nitrogen application and USD 77-140 billion for phosphorus.[12]

Estimating the global costs of soil erosion is challenging, but scientists are starting to warn of an unfolding crisis. The likely range of global soil erosion by water is 20-30 Gt per year. Rates of wind erosion are highly uncertain with around 430 million ha of drylands being particularly susceptible.[13] Estimates place an upper limit on dust mobilization by wind erosion on arable land at around 2 Gt per year.[14] Erosion rates on hilly croplands in tropical and sub-tropical areas may reach 50-100 tons per ha per year, with a global average of 10-20 tons per ha per year. Grasslands are not necessarily more stable. Rangelands and pasture in hilly tropical and sub-tropical areas may undergo erosion at a rate similar to those of tropical croplands, especially when there is overgrazing. Furthermore, soil erosion by water induces annual fluxes of 23-42 Mt of nitrogen and 14.6-26.4 Mt of phosphorus from agricultural land,[15] much of which contaminates freshwater ecosystems.

Soil organic carbon: the primary driver of soil organic carbon (SOC) loss globally is land use change and subsequent management practices, particularly the replacement of tropical forests with cropland and, to a lesser extent, pastures and plantations[16] as well as by converting tropical grasslands to cropland and plantations.[17] Selective logging has fewer impacts.[18] This change in land cover is the primary driver that influences SOC change over time, followed by temperature and precipitation.[19] SOC increases when cropland is afforested, left under fallow, planted with green manure, or converted to grassland;[20] similarly long-lasting SOC sinks are created through the conversion of cropland back to

forest or grassland in temperate climates.[21] Other options for sequestering carbon are no- or low-till farming, adding biochar or worm castings (increasing recalcitrant materials), or the use of perennial crops. Soil organic carbon is dynamic and management practices can turn soil into either a net sink or source of greenhouse gases.[22]

Deforestation is a major cause of carbon loss from soils, with impacts in the tropics being twice as great on average as those in temperate regions.[23] Land management practices, including tillage, are the second major driver of SOC losses, with regional assessments in Africa, Asia, and parts of the Pacific identifying decreasing fallow periods and competing uses for organic inputs (e.g., using animal dung as fuel, or burning stubble to control soil-borne pathogens)[24] as major reasons for reduced SOC. Fire, particularly wildfire, also reduces soil carbon and nitrogen.[25] Peatlands represent a soil ecosystem that emits particularly large amounts of carbon when drained;[26] globally there are an estimated 250,000 km^2 of drained peatlands under cropland and grassland[27] and over 500,000 km^2 under forests.[28]

Soil nutrient balance: is the net gain or loss of nutrients from the soil zone that is accessible by plant roots. Soil flora and fauna play a key role in determining nutrient balance through nitrogen fixing, mineral lift, and other processes. A negative nutrient balance indicates a net loss and thus declining soil fertility, whereas a positive nutrient balance indicates a net gain and that one or more plant nutrients are entering soil systems faster than they are being removed. Positive nutrient balances also suggest an inefficient use of natural resources (energy and finite resources such as phosphorus and potassium), resulting in leakage contributing to climate change and reducing the quality of surface and ground water resources. On a global scale, soil nutrient balances for nitrogen and phosphorus are positive across all continents, except Antarctica, and are predicted to remain stable or in a worst case scenario increase by up to 50 per cent by the year 2050.[29] Conversely, on a regional and local scale, particularly in parts of Africa, Asia, and South America, soil nutrients are scarce with negative balances limiting plant growth.[30]

Soil salinization and sodification: a condition where soils are degraded by an excess amount of neutral salts, sodium, or both. Excess soil salinity can damage plants by altering their ability to absorb water and sometimes by direct toxicity. Salts will accumulate in soils by upward wicking from salty groundwater, precipitation, or irrigation faster than they leach from the system. Natural causes include the weathering of soil parent materials, saltwater intrusion, and wet or dry atmospheric deposition of salt from the oceans. Human-induced causes include the use of high salt or sodium irrigation water, poor management of salts and sodium in soils, and practices that allow groundwater to rise close to the soil surface, such as insufficient soil drainage and the replacement of deep-rooted vegetation with plants that have a shallow root system. Globally, the extent of salt-affected soils is 955 Mha while secondary salinization affects some 77 Mha, with 58 per cent of these in irrigated areas.[31] It is estimated that 20 per cent of irrigated cropland has salt-induced yield declines causing an estimated economic loss of USD 27.3 billion.[32]

Loss of soil biodiversity: multiple factors, either solely or in combination, impact directly on surface ecosystems" to "impact directly surface ecosystems. The loss of soil biodiversity is not just a conservation issue but impairs multiple ecosystem functions, including decomposition rates, nutrient retention, soil structural development, and nutrient cycling.[33] These functions are needed for clean water, pest and pathogen control, soil fertility and crop production, and climate change mitigation. Addressing losses in soil biodiversity is therefore a key step in building healthy soils.

Soil communities are highly diverse, containing millions of species and several billion individuals within a single ecosystem,[34] including high levels of endemism.[35] Soils harbor a large part of the world's total biodiversity.[36] By far the most abundant and diverse groups of organisms are soil bacteria and fungi, playing a vital role in decomposing soil organic matter, binding soil aggregates together to prevent erosion, and permitting efficient drainage, water holding, and aeration. Soil fauna also consists of protozoa (amoebae, flagellates, ciliates), nematodes (feeding on roots, microbes, or nematodes), mites, collembola, enchytraeids, and earthworms. Together, these organisms form food webs that drive soil ecosystem processes, like nutrient cycling and carbon sequestration, and are major components in the global cycling of matter, energy, and nutrients.[37] Soil food webs also play a key role in the delivery of ecosystem services that help to maintain crop productivity[38] and biodiversity conservation.[39] (see Table 9.1)

Soil contamination: the misuse of agricultural inputs, mining residues, fossil fuels, and other contaminants can create dangerous levels of heavy metals, trace elements, radionuclides, pesticides,

Table 9.1: Flora and fauna in soils

Soil Biota	Examples	Functions
Fauna	Earthworms	Major decomposer of dead and decomposing organic matter, deriving nutrition from bacteria and fungi leading to recycling of nutrients Generate tons of casts each year, improving soil structure Stimulate microbial activity Mix and aggregate soil Increase infiltration Provide channels for root growth and habitat for other organisms Invasive earthworm species from Europe and Asia into the northern US (where ice glaciers were) have led to loss of forest floor litter layer now threatening the future regeneration of forests.[40]
	Nematodes	Graze on microbes controlling diseases and recycle nutrients Help in dispersal of microbes Omnivores or plant parasites feeding on roots of plants[41]
	Arthropods (e.g., springtails, beetles)	Shred organic matter Stimulate microbial activity Enhance soil aggregation Improve water infiltration Control pests
	Protozoa	Mineralize nutrients by preying on bacteria, fungi, and soil fauna, thereby making mineral nutrients available for use by plants and other soil organisms and thus help in nutrient recycling Stimulate lateral root production by producing auxin analogs[42]
Flora	Fungi	Nutrient cycling through decomposition of organic matter Nutrient translocation to plants through fungal hyphae (Mycorrhizal fungi) Water dynamics Disease suppression Enhance soil aggregation Decompose organic matter, build SOC, and improve soil structure
	Bacteria	Breakdown and consume soil organic matter Part of energy and nutrient flow through soil food web Decompose and breakdown pesticides and pollutants Enhance soil aggregation Transform nitrogen between reactive and non-reactive forms
	Actinobacteria	Degrade recalcitrant compounds

plant nutrients, and other pollutants.[43] The extent of soil contamination is difficult to assess or quantify. In Western Europe, 342,000 contaminated sites have been identified[44] and contaminated sites impact 9.3 Mha in the United States,[45] of which around 1,400 are highly-contaminated Superfund sites.[46] While these are places with extreme contamination, data on land impacted by diffuse contaminant sources, such as the deposition of heavy metal aerosols from upwind smelters, are less available but would represent a significant portion of the land resource in many countries. In general, excess nutrients and pesticides are a major problem in many agricultural areas.

Soil acidification: a natural, long-term process involving the leaching of basic cations from the soil, which can be accelerated by farm management practices (e.g., use of fertilizers containing ammonium, continuous harvesting of nitrogen fixing crops), acid deposition from fossil fuels and mine drainage. Naturally acid soils are found especially in areas with old soils or humid climates. Up to 30 per cent of ice-free land has acid soils (pH below 5.5), some 4,000 Mha,[47] and half the world's potentially arable soil is acidic.[48] Soil acidification limits the availability of plant nutrients, can result in toxic levels of soluble aluminum and manganese, and inhibits nitrogen fixation in legumes. Addressing this threat entails economic and environmental costs associated with applications of lime, gypsum, and other basic materials to reduce levels of acidity.

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One recent estimate suggests that 50-70 Gt of carbon has been released from global agricultural land over the course of human history.

Soil compaction: dramatically reduces long-term productivity of soils, impacting crop production, increasing surface runoff and water erosion, and sometimes also increasing the impacts of wind erosion.[49] Subsoil compaction, caused by heavy traffic and plowing,[50] is among the most permanent forms of soil degradation, potentially lasting decades or centuries.[51] A primary cause of soil compaction is an increase in weight and frequency of use of vehicles,[52] although excessive trampling by livestock can also be a factor.[53] Compaction inhibits the growth of beneficial soil microorganisms,[54] reduces habitat for micro-invertebrates,[55] reduces access to nutrients,[56] and can result in the emission of methane.[57] Long-term reduced or conservation tillage is one method that can minimize this threat.[58]

Soil sealing: rapid urbanization and lack of land use planning can lead to soil sealing,[59] the more-or-less permanent sealing of the soil surface with concrete, pavement, or other impermeable surfaces. Along with the direct loss of farmland, soil sealing reduces the ability of areas to absorb water, and thus are more susceptible to increased urban flooding. These issues are discussed in more detail in Chapter 11.

Soils used in agriculture ("domesticated soil") are highly modified forms of their wild predecessors and have often lost many of their original properties, including a large proportion of their carbon content and other nutrients. One recent estimate suggests that 50-70 Gt of carbon has been released from global agricultural land over the course of human history.[60]

2. Deforestation and forest degradation

Sustainable Development Goal 15.2 states "*promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally.*"

Impacts below the land surface are mirrored and influenced by rapid transformation above ground. Some of the most dramatic changes have taken place in forests. Deforestation has occurred since prehistory, accelerating during European colonial expansion,[61] and continuing today. In most temperate regions, forests are now expanding after a historical low[62] but this is more than offset by losses in the tropics.[63] Many tropical forests that were undergoing deforestation a few decades ago[64] have now virtually disappeared. Although the overall deforestation rate is slowing, tropical forest area nevertheless declined by 5.5 million hectares annually from 2010 to 2015;[65] other types of forests underwent degradation[66] or were overgrazed, transformed into shrub and bush land, or converted to plantations. Up to 70 per cent of global forests are at risk of further degradation.[67]

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Net forest loss is expected to continue for several decades. A set of 11 deforestation fronts (see Table 9.2) show where the largest permanent forest loss or severe degradation are projected between 2015 and 2030 under business-as-usual scenarios and without interventions.[68] Forest loss has serious impacts on the land, especially if forests are growing on peat where deforestation risks releasing large amounts of carbon, or in the drylands where tree loss results in rapid soil erosion.

The rates of forest disturbance are higher still. Between 40-55 per cent of temperate and boreal forests were classified as "undisturbed by man" in 2003 (i.e., undisturbed for at least 200 years). Over 90 per cent of these were in Russia and Canada, with smaller areas in the United States, Australia (where there have been major losses since), the Nordic countries, Japan, and New Zealand. In the rest of Europe, the undisturbed proportion is usually zero to less than one per cent, making European temperate forests among the most highly endangered ecosystems in the world.[79]

Table 9.2: Deforestation fronts

Deforestation Front	Projected loss in millions of hectares by 2030
Amazon	23-48
Chocó-Darién	3
Cerrado	11
Atlantic Forest/Gran Chaco	~10
Congo Basin	12
Coastal forest of East Africa	12
Borneo	21.5
Sumatra	5
New Guinea	7
Greater Mekong	15-30
Australia	6
Total from 11 deforestation fronts	**136.5-176.5**

3. Loss of natural grasslands

Natural and semi-natural grasslands have been heavily influenced by human management both destroying and creating grasslands, radically changing composition and patterns of renewal. Impacts include changes in fire frequency and intensity;[80] types and intensity of grazing;[81] introduction of non-native grasses;[82] application of agrochemicals;[83] invasive plant and animal species;[84] and air pollution.[85] The clearance of natural forests often creates new grassland areas.[86] Conversely, grasslands are being destroyed to produce soy, oil palm,[87] cotton,[88] wood pulp,[89] and biofuels.[90] Dramatic changes in grasslands are occurring in Latin America,[91] North America,[92] Africa,[93] Asia,[94] Australasia,[95] and in the remnants in Europe.[96] While some of these changes have taken place over millennia, and ecosystems have to some extent adapted, the pace of change is increasing in many parts of the world. The crisis in global soil health is closely related to the management of the world's natural and semi-natural grasslands.

Relatively little is known about the ecological status of grasslands as compared to forests and other ecosystems. There have been attempts to distinguish natural and non-natural grasslands,[97] and map their distribution,[98] set criteria for high conservation value grasslands,[99] and identify biodiversity-rich grasslands in Latin America.[100] But these have not been translated into global assessments.[101] Knowledge of grassland status is incomplete at a global scale but does indicate serious losses.

Box 9.1: Deforestation in the dry forests of South America

The Gran Chaco is the largest dry forest in South America covering 100 million hectares,[69] in Argentina, Paraguay, Bolivia, and Brazil,[70] with high levels of biodiversity.[71] From 2000-2012, the Chaco in Argentina, Paraguay, and Bolivia underwent the world's highest rate of tropical forest loss,[72] reaching 1,973 hectares ***per day*** in August 2013.[73] From 2010-2012, 823,868 hectares were cleared in these countries, three-quarters in Paraguay.[74] In Argentina, 1.2-1.4 million hectares (85 per cent of the national total) has been cleared in 30 years, with the deforestation rate accelerating.[75] As controls have tightened on felling Atlantic Forest remnants, in other parts of the country pressure has mounted on the Gran Chaco, with social costs as resistance has sometimes been violently suppressed.[76] In Bolivia, deforestation progressed at 16,000 ha/yr in the 1980s and 120,000 ha/yr in the 1990s, with 80 per cent of the forest significantly fragmented by 1998;[77] protected areas have also been affected.[78]

An analysis in 2000 found 49 per cent of grasslands to be lightly to moderately degraded and another 5 per cent severely degraded.[102] Temperate grasslands are the most altered terrestrial ecosystem,[103] with only 4.5 per cent in protected areas.[104] Forest conservation can increase the threats to grasslands,[105] as in Brazil where the voluntary Amazon Soy Moratorium increases pressure on the Cerrado savanna.[106]

Many grassland ecosystems are being altered by ranching.[107] In 2000, grassland covered 40 per cent of global land surface[108] with 18-23 per cent of land surface, excluding Antarctica, grazed by domestic livestock.[109] A more recent estimate is that grazing covers 26 per cent of ice-free land with an additional 33 per cent of arable land used for livestock fodder.[110]

Despite these changes, natural and semi-natural grasslands retain important ecological values. Managed grasslands can support high levels of biodiversity;[111] management practices influence biodiversity[112] but can also support biodiversity in the absence of natural herbivores.[113]

4. Disappearing wetlands

At the same time as lakes and wetlands are being destroyed, rivers are also being transformed and redirected. Almost half the global river flow is already affected by flow regulation and/or fragmentation,[125] and there are currently 3,700 more dams planned around the world, which will undoubtedly disturb many remaining wild rivers.[126] Dams reduce sediment flow downstream, damaging coastal fisheries, and blocking fish migration. For example, several catfish species swim 6,000 km from the Atlantic to spawning areas in the Amazon headwaters,[127] but this unique migration is threatened by proposals to dam some major rivers.[128] Amazon fisheries were valued at USD 389 million a year in 2003.[129]

Freshwater habitats cover less than one per cent of the Earth's surface but support at least 100,000 out of 1.8 million described species.[114] Yet wetlands are declining rapidly.[115] Despite efforts to conserve them (e.g., through the Ramsar Convention),[116] 64-71 per cent of global wetlands have been lost since 1900,[117,118] along with their biodiversity and ecosystem services,[119] and losses are accelerating.[120] The causes of wetland loss and degradation include draining; drying due to upstream diversion; pollution and sedimentation; impacts of alien invasive species; overexploitation of species; climate change, and changes to the flow regime.[121]

Sustainable Development Goal 6.6 aims to "*protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.*"

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Box 9.2: Freshwater species loss in the Eastern Mediterranean[122]

The Eastern Mediterranean supports 4.4 per cent of the global human population yet contains only 1.1 per cent of its renewable water resources.[121] Water use, mainly for irrigation has led to the rapid depletion of ground waters[122] while dam construction alters flows, and agricultural and domestic pollution causes further problems. In addition, climate change is leading to an increase in mean annual temperatures. Reduced water flows have led to the total loss of some water bodies (e.g., Lake Amik in Turkey and Azraq Oasis in Jordan) and the seasonal drying of once permanent rivers (e.g., Qweik River in Turkey and Syria). Nineteen per cent of freshwater species are globally threatened, including 58 per cent of the endemic freshwater species. Six species, all fish, are now extinct and 18 more (7 fish and 11 mollusks) are assessed as "Critically Endangered, Possibly Extinct" by the IUCN. The lack of data from many places may lead to underestimation of losses.

Box 9.3: Biodiversity in the Amazon

The Amazon is a mosaic of different types of vegetation and home to the world`s largest watershed. Tropical evergreen forest covers around 80 per cent of the region along with flooded and deciduous forest, swamp and the threatened Amazonian savannahs.[148] Almost 7 per cent has been converted to agriculture.[149] The catchment has seasonal flood pulses peaking at 15 meters, creating expanses of flooded forests.[150] A fraction of the Amazon's biodiversity is known to science: only 2-10 per cent of insects have been described,[151] an estimated 6,000-8,000 fish species are mostly unknown,[152] and 2,200 new plant and animal species have been described since 1999. Amazon river dolphins (*Inia geoffrensis*) are a key indicator of wider environmental health. Viewed as competition for fish stocks in many parts of the river system, they are actively persecuted and are also victims of "bycatch" when entangled in fishing gear.[153] Other threats include the building of hydroelectric dams, pollution, and a reduction in fish stocks. The protection of the dolphins is often hindered by a lack of understanding of their preferred habitats and movements.[154]

There is also a small but significant reversal in these trends as some dams are being decommissioned because their reservoirs have silted up, have become unsafe, or have simply outlived their usefulness. A hundred dams have already been removed in the United States.[130] Climate change pressures and conservation interests are merging to encourage governments to restore natural hydrology and flooding patterns.[131]

5. Mass extinction

Over the past half century, human activities have transformed ecosystems faster than in any other period in history.

Over the past half century, human activities have transformed ecosystems faster than in any other period in history. This has created a "mass extinction" event, with even conservative projections of extinction over the next century being over a hundred times faster than expected under natural conditions;[132] although the rate and scale of future extinctions remain hard to predict.[133] Ecologists fear that land use change has been so widespread that terrestrial biodiversity has been pushed beyond the "planetary boundary" signaling continued decline,[134] although others argue that safe thresholds remain uncertain.[135] Even where species have not gone extinct, populations have often dramatically decreased: one study found an average of 38 per cent decline in species numbers since 1970,[136] and up to 81 per cent for freshwater species.[137] The proportion of species threatened with extinction ranges from 13 per cent for birds to 63 per cent for cycads (an ancient group of seed plants), with levels of threat continuing to increase.[138] Biodiversity loss reduces overall ecosystem functioning and ecosystem services,[139] in ways that are still not fully understood,[140] but that are likely to accumulate over time[141] with impacts on land productivity similar to those occurring as a result of climate change.[142]

The decline in species is mirrored by, and to a large extent caused by, a wider decline in natural ecosystems,[143] with over 60 per cent already degraded.[144] While much loss is prehistoric or historical,[145] the rates of loss and degradation are continuing and often accelerating. One-tenth of the world's remaining wilderness areas (3.3 million hectares) has disappeared in the last twenty years, particularly in the Amazon and Central Africa.[146] The CBD set a target to "significantly reduce" the rate of biodiversity loss by 2010, but this was not achieved. Despite global conservation efforts, biodiversity loss is continuing or even accelerating.[147]

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ADDRESSING THE LOSS OF BIODIVERSITY AND SOIL

There are compelling reasons – both practical and ethical – for halting the extinction event currently devastating the world's biodiversity and undermining the health and productivity of the land. Seen through the lens of land management, in the long term this means ensuring the survival of large areas of natural ecosystems, supporting wild plant and animal species in managed areas, and restoring and protecting the soil ecosystem. All are needed, it is not a question of either/or: many ecosystems have already been so badly degraded that active steps are needed to regain at least some of their functions and values. Three elements are critical for biodiversity and soil conservation:

- **Protection**, through protected areas and other formal or informal mechanisms
- **Management** that promotes healthy ecosystem functioning
- **Restoration** of natural and semi-natural ecosystems following degradation

These three pathways of action need to be integrated into a coordinated management strategy at broad scales, often referred to as a *landscape approach*.[155]

1. Protection

Pressures on land resources are so great in many parts of the world that it is no longer possible to preserve remaining natural ecosystems without aggressive policy and regulation, management, and often legal decisions being taken. There is a growing body of thought that suggests at least 50 per cent of the world's land surface should remain in a more or less natural state to ensure continuation of vital ecosystem services and the biodiversity that underpins them.[156] Furthermore, this half of the planet needs to include sufficient quantities of all ecosystems; it is not enough to maintain deserts, high mountains, and other lands with low potential for exploitation.

One effective way of maintaining natural landscapes is through official or unofficial protected areas.

One effective way of maintaining natural landscapes is through official or unofficial protected areas: areas of land and water set aside as refuges for biodiversity and ecosystem services, and sometimes also to preserve cultural landscapes, fragile human communities, spiritual sites, and areas of recreation. They are defined by the IUCN World Commission on Protected Areas (WCPA) as: *A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.*[157] Protected areas vary greatly in their management approaches. The WCPA defines six categories by management objective, ranging from strictly protected wildlife reserves to landscape or seascape areas with some protective functions.[158]

Protected areas can be the cornerstone of national and regional conservation strategies. They act as refugia for species and ecological processes that cannot survive in intensely managed landscapes and seascapes, and provide space for natural evolution and ecological regeneration. People, near and far, benefit from the genetic potential of wild species and the environmental services of natural ecosystems, such as recreational opportunities and the sanctuary given to traditional and vulnerable societies. Flagship protected areas are as important to a nation's heritage as, for instance, Notre Dame Cathedral or the Taj Mahal.

About 15 per cent of the world's terrestrial area and inland waters are designated as protected areas,[164] an area greater than South and Central America. Over half have been recognized since 1970; a unique example of governments and other stakeholders consciously changing management approaches to land and water at a significant scale. The total area covered is augmented by protected areas that are not included in the official UN List of Protected Areas, but established by local communities, indigenous peoples, private individuals, non-profit trusts, religious groups, and corporations; some of which, such as indigenous territories in the Amazon, can be extremely large. They are subject to different types of governance, such as various forms of state governance, co-governance between different stakeholders, private governance, and governance by indigenous peoples and local communities.

Protected areas are effective in conserving biodiversity[165] but only if properly resourced and managed; many face severe pressures from illegal use,[166] the withdrawal of government support,[167] and from climate change.[168] At the same time, their wider social and cultural values are increasingly being recognized.[169] The role of some of the less formal conservation approaches is seen as important but still largely not quantified.[170]

Along with places that are recognized explicitly as protected areas, there are many other spatially-defined areas that have been more or less permanently set aside from development: territories of indigenous people, community-controlled natural

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grasslands used for low-level grazing, urban watershed protection areas, coastal protection areas, military training areas, steep slopes unsuitable for agriculture or forestry, and so on. Recently, there have been attempts to define and describe such areas, the so-called *other effective area-based conservation measures (OECMs),*[171] since they were officially recognized by the CBD in 2010.[172]

Box 9.4: Protected areas – an ancient concept

Protected areas are not a modern concept. They have existed for millennia, although early protected areas usually had utilitarian or recreational aims rather than consciously protecting nature for its intrinsic value. Examples include indigenous communities guarding sacred sites,[159] "tapu" areas for communal resource use in the Pacific,[160] *hima* in the Arabian Peninsula to maintain grazing and ecosystem services,[161] and hunting areas set aside to benefit the ruling classes.[162] Areas of natural or semi-natural habitats have also long been protected by particular faith groups, and these sacred natural sites can often have high conservation values.[163]

2. Management

Sustainable approaches to land management aim to preserve multiple values, including biodiversity, within the managed landscape. These approaches are focused on a wider suite of ecosystem services, such as those provided by healthy and productive soils. The conscious management for biodiversity values can also provide habitat for a proportion of wild species, avoiding damage or pollution to surrounding natural habitats that could further undermine their integrity. With some notable exceptions,[173] managed production lands will never support the full range of biodiversity and ecosystem services, hence the need to conserve natural ecosystems. The balance between conservation and sustainable management – land sparing versus land sharing – has been debated by ecologists for years; in practice both are needed.[174]

Many of the elements of sustainable land management are described in other chapters. From the perspective of biodiversity and soil health, they fall into six major categories:

1. Avoiding clearing new areas containing natural or important semi-natural vegetation
2. Protecting the soil ecosystem to maximize productivity and minimize degradation

Box 9.5: Sustainable soil management

The management of soil ecosystem services is a critical part of land management. Reduced soil disturbance and increased organic matter can help to build soil health as can the use of improved crop varieties (e.g., deeper rooting varieties),[177] cover crops,[178] changes to crop rotations,[179] and in some cases no-till approaches.[180]

Approaches to minimizing soil erosion range from engineering measures, such as terracing, sediment pit construction,[181] and the improvement of waterways to vegetative measures, such as agroforestry approaches, contour strips, and cover crops.[182] No-till farming can radically improve topsoil physical properties.[183] Measures to reduce wind erosion include the use of drought-resistant species, rotational grazing, and windbreaks, coupled with no-tillage and stubble-mulch tillage techniques.[184]

The reversal of soil degradation and build-up of soil organic matter would also help mitigate climate change by sequestering atmospheric carbon into the soil and, at the same time, improve the resilience of agricultural systems.[185] Increased soil organic carbon in cropping systems consistently leads to increased yields, particularly in areas of low and variable rainfall.[186]

Avoiding soil salinization is best achieved through the use of high quality irrigation water and the provision of adequate drainage through the use of drainage tiles and/or drainage ditches; occasional applications of gypsum may also be needed. Preventing soil compaction requires site-specific management as restoration may take many decades. Long-term reduced or conservation tillage is considered an effective approach in many regions worldwide.[187]

The adoption of soil conservation measures has frequently been slow. While critical for long-term soil health, these measures often do not provide immediate, tangible benefits to farmers; this is true in both intensive mechanized systems and smallholder farming in the developing world. Farmers therefore do not have a direct incentive to adopt soil conservation measures, especially when they do not have land tenure, and stronger inducements are needed.[188]

3. Maintaining areas of natural habitat within managed areas, including biological corridors and stepping stones to support landscape connectivity
4. Ensuring that any uses of renewable natural resources, such as fish, non-timber forest products, or grazing lands, do not exceed sustainable levels
5. Reducing impacts of economic development on land including offsite impacts, such as pollution and soil damage
6. Minimizing the overall footprint of land use, including the use of energy and other resources, to reduce impacts on biodiversity in other parts of the world

There are many ways to encourage and support such actions, ranging from legal and regulatory instruments to financial incentives (including the removal of perverse subsidies), voluntary certification schemes,[175] criteria and indicator schemes,[176] best management guidance and codes of practice. Extension services and capacity building are needed to help farmers and other land managers to adopt and scale up more sustainable soil management approaches; this support needs to be coherent and sustained over the long term.

Sustainable land management, the primary focus of this *Global Land Outlook* and of the United Nations Convention to Combat Desertification (UNCCD) needs to address all aspects of land use. Huge efforts have been made over the past few decades, involving actors ranging from individual land managers and civil society activists to global research and policy institutions:

- **Sustainable water management**,[189] or Integrated Water Resources Management (IWRM), with emerging initiatives such as the Alliance for Water Stewardship and global coordination from the Ramsar Convention on Wetlands and the Global Water Partnership[190]
- **Sustainable forest management**,[191] with multiple processes underway, many voluntary certification systems, codes of practice and leadership within the UN from FAO and the Forum on Forests[192]
- **Sustainable pastoralism**,[193] which is seeking to build viable pastoral societies with the World Initiative for Sustainable Pastoralism (WISP) playing a key role[194]
- **Agroforestry**,[195] through the auspices of institutions such as the Center for International Forestry Research and the World Agroforestry Centre[196]

Pulling these and other similar initiatives together into a coherent global action programme is a critical next step for making progress towards the 2030 Agenda for Sustainable Development.

3. Restoration

Ecological restoration is required when the degraded ecosystem is unable to self-repair: it is defined as "*the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.*"[197] The main aim of restoration is to reinstate ecological processes and functions that are resilient and adaptable to change and that deliver important ecosystem services. Restoration improves soil stability and condition, surface and groundwater water quality, and habitat and biodiversity values; it increases micro and global climate stability, and provides amenity, cultural, and recreational benefits to people.[198] Integrated landscape approaches to the restoration of land and water resources provide opportunities for wider uptake, by minimizing trade-offs and taking advantage of synergies between food and timber production and water supply, biodiversity conservation, the supply of other ecosystem services, and poverty alleviation.[199]

The restoration of degraded land will also improve the flow of many other ecosystem services by conserving and improving the condition of natural capital.[200] Ecological restoration can also provide economic benefits.[201] One recent estimate is that the restoration of grassland ecosystems could provide a benefit cost ratio of up to 35:1 if the monetary value of the flow of additional ecosystem services provided is taken into account.[202] Additionally, the employment benefits and enhancement effects of restoration are a valuable part of national economies. For example, the ecological restoration sector in the USA directly generates about 126,000 jobs and USD 9.5 billion in annual expenditure, and a further 95,000 jobs and USD 15 billion of annual expenditure indirectly.[203]

Many ecosystems are already at a stage where the long-term survival of species and ecosystem functioning are threatened and restoration is urgently required.[204] For example, some of the world's most important forest ecoregions have lost at least 85 per cent of their forests, with sometimes as little as 1-2 per cent left.[205]

Restoration is generally not a matter of re-establishing a well-known historical ecosystem. Extensive ecosystem modification, in combination with rapid global change, will likely lead to the emergence of novel and hybrid ecosystems, especially in landscapes that have undergone higher degrees of degradation and are therefore less resilient to rapid change.[206] As a consequence, it may be unrealistic to attempt to restore landscapes to a desired pre-disturbance state;[207] in addition, there may be no appropriate reference ecosystem to guide restoration.

Restoration will need to consider future trajectories of climate, land use, demographic and socio-economic change, and species range shifts. For example, seeds sourced for restoration should be drawn from species suitable to modeled future climates at the restoration site, combined with seeds of local provenance.[208] Restoration will need to be more attuned to the multiple functions of landscapes[209] in order to satisfy the requirements of ecosystems and landscapes to supply multiple ecosystem services,[210] including a wide range of cultural and social values.[211] Furthermore, successful restoration programmes, such as the 300,000 ha of Acacia and miombo woodland restored in the

Box 9.6: Major forest restoration in South Korea

Thirty-five years ago South Korea had a GDP not dissimilar to Kenya or Tanzania. Today average wages in the country are about the same as Australia. Within a generation, South Korea has assumed a place among the wealthiest nations. One of the reasons for this success has been a massive effort at ecological restoration. The country underwent devastating environmental degradation during the Second World War and subsequent civil war, leaving the ecology in crisis; most forests disappeared as a result of conflict and the harvesting of fuelwood. Since then, the Korean government has undertaken one of the most spectacular forest restoration programmes in history,[221] reforesting 2.8 million hectares and increasing the growing stock by 12 times,[222] so that the majority of the land is now covered with maturing forest. Korea has developed a protected area system that covers 16,000 km^2 and is hugely popular with the mainly urbanized society; in 2007, there were 38 million visitors to national parks alone, 99 per cent of whom were tourists from within the country.[223]

Shinyanga region of Tanzania, are driven by far more than technical expertise, with success being facilitated by a complex mixture of personalities, supportive policies, and issues related to gender politics, traditional knowledge and institutions, and participation.[212] Each case is unique and no single model for success exists.

In South African livestock production systems, the restoration of diverse grassland of conservation value benefited long-term farm income by increasing hay yields.[213] Furthermore, the potential economic returns of other ecosystem services in the restored area exceed by a ratio of 7:1 the returns from intensive grazing.[214]

One visible feature of many landscapes is the abandonment of less productive and marginal agricultural land. Estimated to cover 60 per cent of arable land globally,[216] low productivity, marginal agricultural lands are characterized by the low input of agrochemicals, low levels of mechanization, and high dependence on manual labor. The drivers for abandonment are aging and declining rural populations, mechanization, remoteness from markets, and increased productivity of agriculture elsewhere; rural populations across Europe have declined by 17 per cent since 1961, with some in mountainous rural areas in the Mediterranean region declining by more than 50 per cent.[217]

One option is to allow these abandoned lands to "re-wild" by passively assisting the natural regeneration of forests and other natural habitats, gradually removing human control and influence.[218] Abandonment is not confined to the richer countries: over 360,000 km^2 of abandoned lands in Latin America and the Caribbean were naturally reforested between 2001 and 2010.[219] Re-wilding is not without controversy. European agricultural landscapes hold important cultural and historical values[220] and wild landscapes are resisted by some people in part due to their link with increases in large carnivore populations. A balanced approach to landscape planning, which includes re-wilded land as a part of multi-functional agricultural landscapes, will supply multiple ecosystem services and more likely be accepted by society.

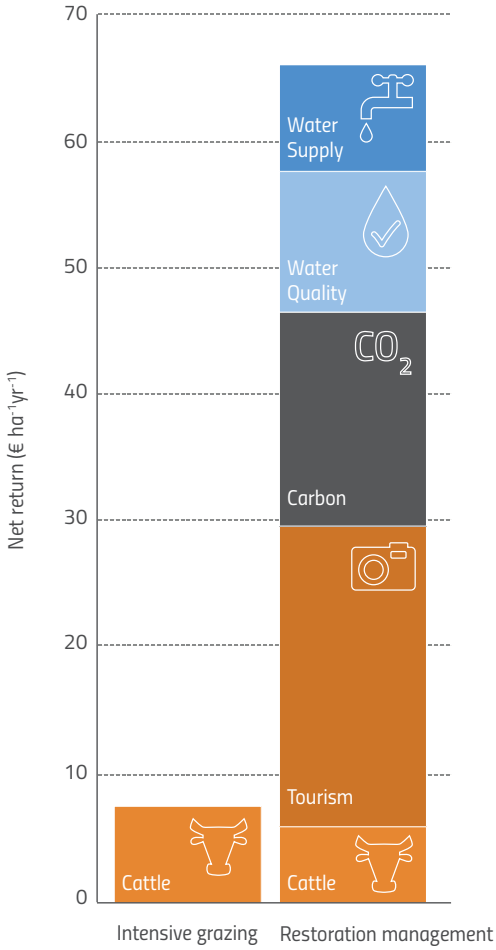

Figure 9.1: Restoration of grazing lands in South Africa: Adapted from [214]

CONCLUSION: LANDSCAPE APPROACHES

These three elements – conservation, sustainable management, and restoration – are integral parts of a single coherent management framework, commonly known as the landscape approach defined as: *A conceptual framework whereby stakeholders in a landscape aim to reconcile competing social, economic and environmental objectives.*[224]

In order to operate on a relatively large scale, with what will inevitably be a broad range of competing interests, at its core the landscape approach entails negotiating trade-offs between different stakeholders. Ensuring that biodiversity conservation and the protection of a suite of ecosystem services endure against narrower and more personal interests requires long-term commitment, strong and locally embedded leadership, clear policies and guidance, and the provision of adequate finance from grants, public money, and private investments.

Box 9.7: Elements and catalysts of the landscape approach[225]

1. Interested stakeholders come together for dialogue and action in a multi-stakeholder platform.
2. They undertake a systematic process to exchange information and discuss perspectives to achieve a shared understanding of the landscape conditions, challenges, and opportunities.
3. This enables collaborative leadership and planning to develop an agreed long-term and systemic action plan.
4. Stakeholders then implement the plan with care to maintaining collaborative commitments.
5. Stakeholders also undertake monitoring for adaptive management and accountability, which feeds into subsequent rounds of dialogue, knowledge exchange, and the design of new collaborative action.
6. Success is catalyzed by good governance, long-term planning, and access to adequate and sustainable finance and markets, all of which are presented in Part Three of this *Outlook.*

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