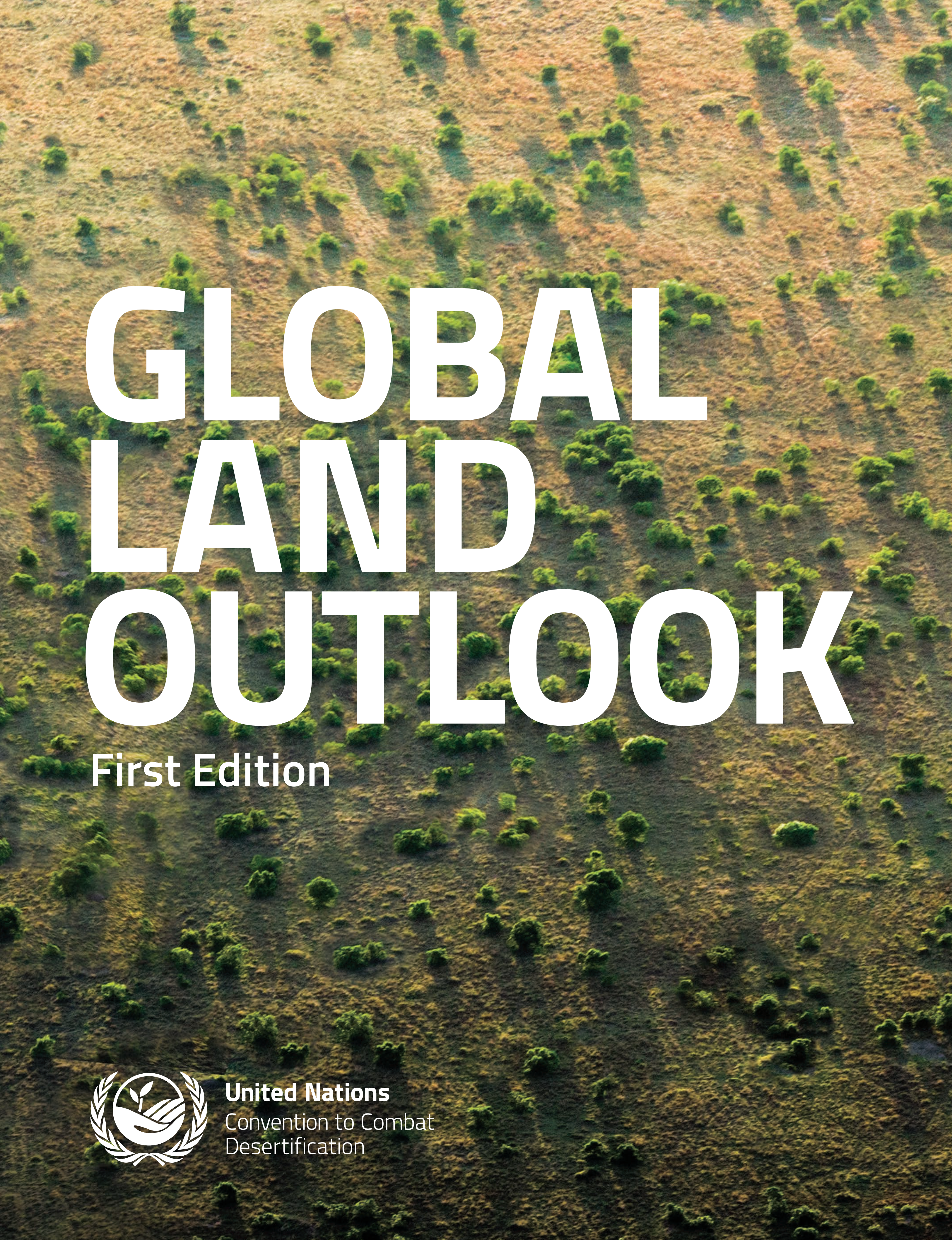

GLOBAL LAND OUTLOOK

First Edition

United Nations
Convention to Combat
Desertification

United Nations Convention to Combat Desertification

The objective of the United Nations Convention to Combat Desertification (UNCCD) is to combat desertification and land degradation, and to mitigate the effects of drought in affected countries around the world, particularly in Africa, through effective action at all levels.

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ELD — The Economics of Land Degradation

Food and Agriculture Organization of the United Nations

IASS Potsdam

ICARDA — Science for Better Livelihoods in Dry Areas

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International Land Coalition

International Organization for Migration (IOM) — The UN Migration Agency

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PBL Netherlands Environmental Assessment Agency

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Secretariat of the United Nations Convention to Combat Desertification
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GLOBAL LAND OUTLOOK

First Edition

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For more information and GLO materials, please visit www.unccd.int/glo.

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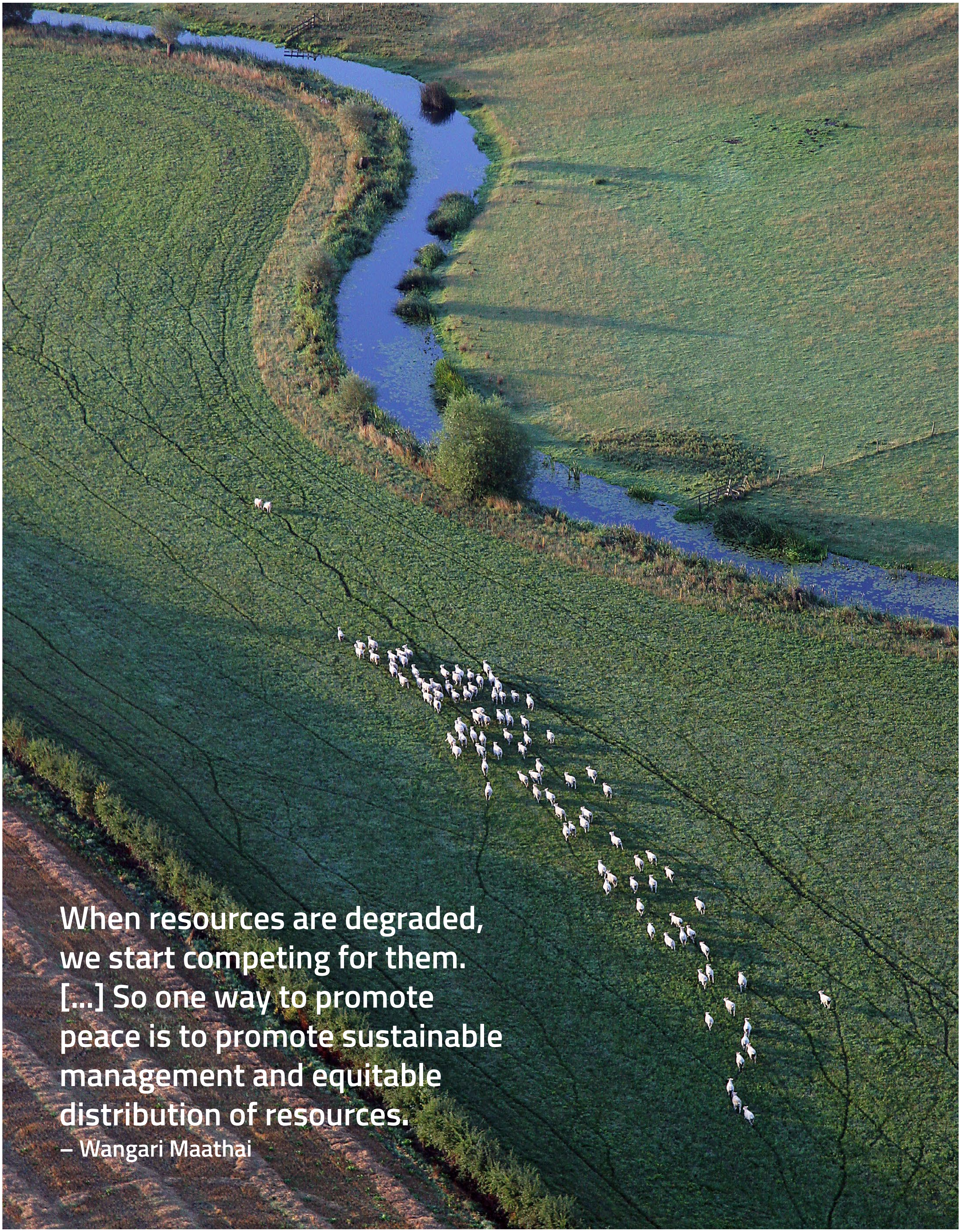

When resources are degraded, we start competing for them. [...] So one way to promote peace is to promote sustainable management and equitable distribution of resources.
– Wangari Maathai

FOREWORD

Monique Barbut
Executive Secretary of the United Nations Convention to Combat Desertification

It is with great pleasure, but also with a growing sense of urgency, that I introduce the first edition of the UNCCD's new flagship publication, the Global Land Outlook. In considering the need for another Outlook, we looked at the full range of challenges we collectively face: from the pressures of population growth, climate change, urbanization, migration, and conflict to food, energy, and water insecurity. In all its dimensions, human security is increasingly fragile and in many parts of the world, land degradation and climate change are now recognized as contributing factors to a sense of growing instability.

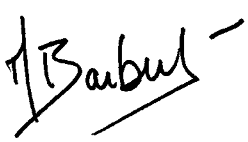
Without better adaptation strategies and resilience building devoted to responsibly managing and restoring our natural capital, land degradation, especially in developing countries, will continue to be a significant factor threatening rural livelihoods, triggering forced migration, and aggravating conflicts over limited natural resources. As you will see, we argue that land – its health and productivity – is vital for any effective global effort to counter these worrying trends.

Yet it is evident in countries big and small, rich and poor, that the health and condition of our land resources are often not thought about. Indeed, land's vital role in tackling climate change, securing biodiversity and the delivery of critical ecosystem services is underappreciated. Land is of unparalleled importance to our livelihoods, prosperity, and wellbeing; in a very real sense, our way of life and that of future generations is being greatly undervalued.

With our current trends in production, urbanization, and environmental degradation, we are losing and wasting too much land. We are losing our connection with the earth. We are losing far too quickly the water, soil, and biodiversity that support all life. At a time when every asset and every option to deliver benefits to people and the planet should be being harnessed, the availability of good quality land is declining. As the American author Mark Twain jokingly put it *"Buy land, they're not making it anymore."* He was absolutely correct. As an engine of economic growth and a source of livelihood for billions worldwide, we need to step back and transform the way we use and manage the land.

This Outlook explores this, but it goes much further. Land is more than economics and physical geography. So this is not just an assessment of how much land there is and how much is degrading. It aims to also answer the question, "And so what can we do?" The answer is based on the premise that we are all decision-makers, and that our choices can make a difference. Even small changes today can bring about a very different tomorrow.

This Outlook presents a vision for transforming the way in which we use and manage land. It underscores how land is the key to human security and future wellbeing, the thread that holds together the fabric of society. I expect this Global Land Outlook to be the first of many that put forth bold solutions and concrete pathways of action.



KEY MESSAGES

THE BIG PICTURE: LAND UNDER PRESSURE

The current pressures on land are huge and expected to continue growing: there is rapidly escalating competition between the demand for land functions that provide food, water, and energy, and those services that support and regulate all life cycles on Earth.

A significant proportion of managed and natural ecosystems are degrading: over the last two decades, approximately 20 per cent of the Earth's vegetated surface shows persistent declining trends in productivity, mainly as a result of land/water use and management practices.

Biodiversity loss and climate change further jeopardize the health and productivity of land: higher carbon emissions and temperatures, changing rainfall patterns, soil erosion, species loss and increased water scarcity will likely alter the suitability of vast regions for food production and human habitation.

Land degradation decreases resilience to environmental stresses: increased vulnerability, especially of the poor, women and children, can intensify competition for scarce natural resources and result in migration, instability, and conflict.

Over 1.3 billion people are trapped on degrading agricultural land: farmers on marginal land, especially in the drylands, have limited options for alternative livelihoods and are often excluded from wider infrastructure and economic development.

The scale of rural transformation in recent decades has been unprecedented: millions of people have abandoned their ancestral lands and migrated to urban areas, often impoverishing cultural identity, abandoning traditional knowledge, and permanently altering landscapes.

AN EMERGING CONSENSUS: A BROKEN SYSTEM

Our inefficient food system is threatening human health and environmental sustainability: along with other degrading and polluting land uses focused on short-term returns, the current patterns of food production, distribution, and consumption largely fail to tackle these global challenges.

The widening gulf between production and consumption, and ensuing levels of food loss/waste, further accelerate the rate of land use change, land degradation and deforestation: in poor countries, food loss is primarily due to the lack of storage and transport while in wealthy nations, food waste is a result of profligacy and inefficiencies towards the end of the food supply chain.

The current agribusiness model benefits the few at the expense of the many: small-scale farmers, the essence of rural livelihoods and backbone of food production for millennia, are under immense stress from land degradation, insecure tenure, and a globalized food system that favors concentrated, large-scale, and highly mechanized farms.

Large-scale land acquisitions have increased dramatically in the last two decades: domestic elites and food-importing countries grab large tracts of arable land, usually with water rights and access to transport infrastructure, as a hedge against future price volatility and food insecurity.

It is the sum total of our individual decisions that is fueling a global land crisis: whether we act as consumers, producers, corporations, or governments, a business-as-usual approach will be insufficient to address the magnitude of this challenge.

A MORE SECURE FUTURE: RESPECT FOR LIMITS

Land is finite in quantity, however: the evidence presented in this *Outlook* suggests that, with changes in consumer and corporate behavior, and the adoption of more efficient planning and sustainable practices, we will have sufficient land available in the long-term to meet both the demand for essentials and the need for a wider array of goods and services.

We need to think in terms of respect for limits, not limits to growth: we can take immediate action without compromising the quality of life today or our aspirations for the future; informed and responsible decision-making, along with simple changes in our everyday lives, can help promote economic growth and at the same time reverse the current trends in land degradation.

To advance a new global land agenda, rights and rewards need to be underpinned by responsibility: increased security of tenure, gender equity, and appropriate incentives and rewards are essential enabling factors to help producers adopt and scale up more responsible land management practices.

Our ability to manage trade-offs at a landscape scale will ultimately decide the future of land resources: integration of conservation, land and water management, and restoration, the core pathway to achieve the target on Land Degradation Neutrality, is also acknowledged as an important accelerator for achieving most of the Sustainable Development Goals.

Smart land use planning is about doing the right thing in the right place at the right scale: a multifunctional landscape approach advocates for more rational land use allocations that lead to greater resource use efficiency and the reduction of waste; it is based on the principles of participation, negotiation, and cooperation.

Bold decisions and investments made today will determine the quality of Life on Land tomorrow: the numerous approaches, technologies, and practices highlighted in this *Outlook* serve as a timely reminder of proven, cost-effective pathways that will shape a prosperous and more secure future based on rights, rewards, and respect for our precious land resources.

EXECUTIVE SUMMARY

Land is an essential building block of civilization, yet its contribution to our quality of life is perceived and valued in starkly different and often incompatible ways. A minority has grown rich from the unsustainable use and large-scale exploitation of land resources with related conflicts intensifying in many countries. The world has reached a point where we must reconcile these differences and rethink the way in which we plan, use, and manage the land.

Our ability to manage trade-offs at a landscape scale will ultimately decide the future of land resources – soil, water, and biodiversity – and determine success or failure in delivering poverty reduction, food and water security, and climate change mitigation and adaptation. Indeed, integrated land and water management is recognized as an accelerator for achieving most of the Sustainable Development Goals.

While we are at a critical juncture, fast approaching and in some cases surpassing planetary boundaries, the evidence presented in this first edition of the *Global Land Outlook* demonstrates that informed and responsible decision-making, improved land management policies and practices, and simple changes in our everyday lives, can, if widely adopted, help to reverse the current worrying trends in the state of our land resources.

THE BIG PICTURE

The pressures on global land resources are greater than at any other time in human history. A rapidly increasing population, coupled with rising levels of consumption, is placing ever-larger demands on our land-based natural capital. This results in growing competition among land uses and its provisioning of goods and services.

In basic terms, there is increasing competition between the demand for goods and services that benefit people, like food, water, and energy, and the need to protect other ecosystem services that regulate and support all life on Earth. Terrestrial biodiversity underpins all of these services and underwrites the full enjoyment of a wide range of human rights, such as the rights to a healthy life, nutritious food, clean water, and cultural identity.

A significant proportion of managed and natural ecosystems are degrading and at further risk from climate change and biodiversity loss. From 1998 to 2013, approximately 20 per cent of the Earth's vegetated land surface showed persistent declining trends in productivity, apparent in 20 per cent of cropland, 16 per cent of forest land, 19 per cent of grassland, and 27 per cent of rangeland. These trends are especially alarming in the face of the increased demand for land-intensive crops and livestock.

Land degradation contributes to climate change and increases the vulnerability of millions of people, especially the poor, women, and children. Current management practices in the land-use sector are responsible for about 25 per cent of the world's greenhouse gases, while land degradation is both a cause and a result of poverty. Over 1.3 billion people, mostly in the developing countries, are trapped on degrading agricultural land, exposed to climate stress, and therefore excluded from wider infrastructure and economic development.

Land degradation also triggers competition for scarce resources, which can lead to migration and insecurity while exacerbating access and income inequalities. Soil erosion, desertification, and water scarcity all contribute to societal stress and breakdown. In this regard, land degradation can be considered a "threat amplifier," especially when it slowly reduces people's ability to use the land for food production and water storage or undermines other vital ecosystem services. This in turn increases human insecurity and, in certain circumstances, may trigger or increase the risk of conflict.

The scale of rural transformation in recent decades has been unprecedented in its speed and scale. Millions of people have abandoned their ancestral lands and migrated to urban areas, often impoverishing cultural identity, abandoning traditional knowledge, and permanently altering landscapes.

AN EMERGING CONSENSUS

Higher temperatures, changing rainfall patterns, and increased water scarcity due to climate change will alter the suitability of vast regions for food production and human habitation. The mass extinction of flora and fauna, including the loss of crop wild relatives and keystone species that hold ecosystems together, further jeopardizes resilience and adaptive capacity, particularly for the rural poor who depend most on the land for their basic needs and livelihoods.

Our food system has put the focus on short-term production and profit rather than long-term environmental sustainability. The modern agricultural system has resulted in huge increases in productivity, holding off the risk of famine in many parts of the world but, at the same time, is based on monocultures, genetically modified crops, and the intensive use of fertilizers and pesticides that undermine long-term sustainability. Food production accounts for 70 per cent of all freshwater withdrawals and 80 per cent of deforestation, while soil, the basis for global food security, is being contaminated, degraded, and eroded in many areas, resulting in long-term declines in productivity.

Small-scale farmers, the backbone of rural livelihoods and food production for millennia, are under immense strain from land degradation, insecure tenure, and a globalized food system that favors concentrated, large-scale, and highly mechanized agribusiness. These farmers often have limited options to pursue alternative livelihoods.

The widening gulf between production and consumption, and ensuing levels of food loss/waste, further accelerates the rate of land use change, land degradation and deforestation. The rapid expansion of global value chains and associated trade in land commodities (and their "virtual" components) has shifted many natural resource pressures from the developed to developing countries, where the direct effects of land degradation are unevenly distributed, especially when there is excessive speculation and/or weak governance.

In order to hedge against future food insecurity and price volatility, large-scale land acquisitions or "land grabs" have increased dramatically since 2000, covering more than 42 million hectares dedicated to food, timber, and biofuel crops, primarily in Africa. About 25 per cent of global cropland area, and its associated use of water and other inputs, now produces commodities that are exported to land-poor but cash-rich countries.

SCENARIOS OF CHANGE

Except for some regions in Europe, the human use of the land before the mid-1700s was insignificant when compared with contemporary changes in the Earth's ecosystems. The notion of a limitless, human-dominated world was embraced and reinforced by scientific advances. Populations abruptly gained access to what seemed to be an unlimited stock of natural capital, where land was seen as a free gift of nature.

The scenario analysis carried out for this *Outlook* examines a range of possible futures and projects increasing tension between the need to increase food and energy production, and continuing declines in biodiversity and ecosystem services. From a regional perspective, these scenarios predict that sub-Saharan Africa, South Asia, the Middle East, and North Africa will face the greatest challenges due to a mix of factors, including: high population growth, low per capita GDP, limited options for agricultural expansion, increased water stress, and high biodiversity losses. The lack of economic and institutional means to cope with these factors will increase the risks of violent conflict and mass migration.

Other global land use scenarios suggest that management practices in a landscape context, accounting for interdependencies, are more significant determinants of shared environmental and food security outcomes than population and economic growth projections. These models imply that the perceived trade-offs are not simply a matter of the number of people but rather the predictable consequence of narrowly-focused and unsustainable land use planning, policies, and practices.

Land is finite in quantity, but the evidence presented in the *Outlook* suggests that with changes in consumer and corporate behavior, and sustainable management policies and practices, we still have sufficient land available to meet both the demand and the need for a wide array of goods and services. However, difficult choices and trade-offs will be necessary.

Long-term food and water security will require shifts away from resource-intensive production, carbon-intensive processing and transport, land-intensive diets (primarily from the increased demand for animal products and processed foods), and the current high levels of food waste, including post-harvest losses.

Effective response pathways therefore need to address the way we value and manage the quality of the land, striving to balance its biological and economic productivity. It is the sum total of our individual decisions – as consumers, producers, corporations, and governments – that has created a global land crisis. Like our response to climate change, a business-as-usual approach will be insufficient to address the magnitude of this challenge.

A MORE SECURE FUTURE

We already know much of what it takes to build a resilient planet for future generations – to harness the immense opportunities for sustainable growth provided by nature and ensure a more secure future. The question is: can we catalyze a shift from the current "age of plunder" toward an "age of respect" where we respect biophysical limits?

A new age of respect would require a transformation in the way we consume, produce, work, and live together to address major pressures on land resources and associated environmental issues. The condition of land resources is closely bound up with all aspects of human security now and into the future.

It is clear that the next few decades will be the most critical in shaping and implementing a new and transformative global land agenda. In much of the developing world, achieving more secure rights in terms of tenure, gender equity, and social justice, will be an essential step to improving the long-term stewardship of land resources.

For this new agenda to take hold and generate impacts at the scale needed, rights and rewards must be underpinned by responsibility. Security of tenure and appropriate incentives and rewards are needed to enable producers to adopt and scale up more responsible land management practices. Ultimately, how can we ignore the moral and ethical obligation to safeguard and preserve the land for future generations?

Part One of this *Outlook* takes a broad brush in painting the big picture while **Part Two** discussed some of the most pressing global issues that impact land use, demand, and condition as well as the responses needed to achieve the target of Land Degradation Neutrality, and the related objectives of poverty reduction, food and water security, biodiversity and soil conservation, climate change mitigation and adaptation, and sustainable livelihoods.

Part Three highlights six response pathways that producers and consumers, governments and corporations can follow to stabilize and reduce pressure on land resources as well as illustrative case studies and key tools to help achieve success.

1. **Multifunctional landscape approach:** prioritizing and balancing different stakeholder needs at a landscape scale while incorporating site-level specificity on land use, demand, and condition so that a full range of goods and services are produced. Land use planning helps identify those land uses that best meet the demands of people while safeguarding soil, water, and biodiversity for future generations.

2. **Resilience building:** enhancing the adaptive capacity of communities and ecosystems through a mix of conservation, sustainable management, and restoration of land resources. There are many tools and practices to safeguard healthy, well-functioning, and diverse natural and managed lands that can help to mitigate and adapt to climate change and other natural resource pressures.

3. **Farming for multiple benefits:** optimizing the most desirable suite of ecosystem services from food production activities. This requires a fundamental shift in agriculture practices to support a wider array of social, environmental, and economic benefits from managing land-based natural capital.

4. **Managing the rural-urban interface:** framing a new approach to spatial planning to minimize the impacts of urban sprawl and infrastructure development. Cities designed for sustainability in the wider landscape can reduce environmental costs of transport, food, water, and energy, and offer new opportunities for resource efficiency.

5. **No net loss:** providing incentives for the sustainable consumption and production of natural resources. Land degradation neutrality or no net loss of healthy and productive land means more services onsite and less negative environmental or social impacts offsite. For consumption, it means significantly reducing the current levels of food waste and loss.

6. **Creating an enabling environment:** providing the conditions necessary to scale local successes into large-scale, transformative initiatives. This includes fostering the underlying social and economic conditions and institutions, particularly those relating to stakeholder engagement, land tenure, gender equality, and the availability of sustained investment and infrastructure.

The numerous practices and progressive approaches highlighted in this *Outlook* serve as a timely reminder of proven, cost-effective response pathways that will shape a prosperous and more sustainable future based on rights, rewards, and respect for our precious land resources.

INTRODUCTION

An outlook is a vantage point, a platform, a perspective; it broadens our vistas and allows us to examine our prospects, both present and future. It is within this broader frame of thinking that the *Global Land Outlook* (GLO) aims to present a unique perspective on one of the Earth's most precious assets: land.

Land, literally the ground beneath our feet, is a finite resource composed of soil, water, minerals, plants, and animals. It is an essential part of our life support system and the key building block of our societies and economies. As we grapple with the current state of land resources – a sober reminder of past misuse and mismanagement – the first edition of the GLO presents both grounds for concern and opportunities for action.

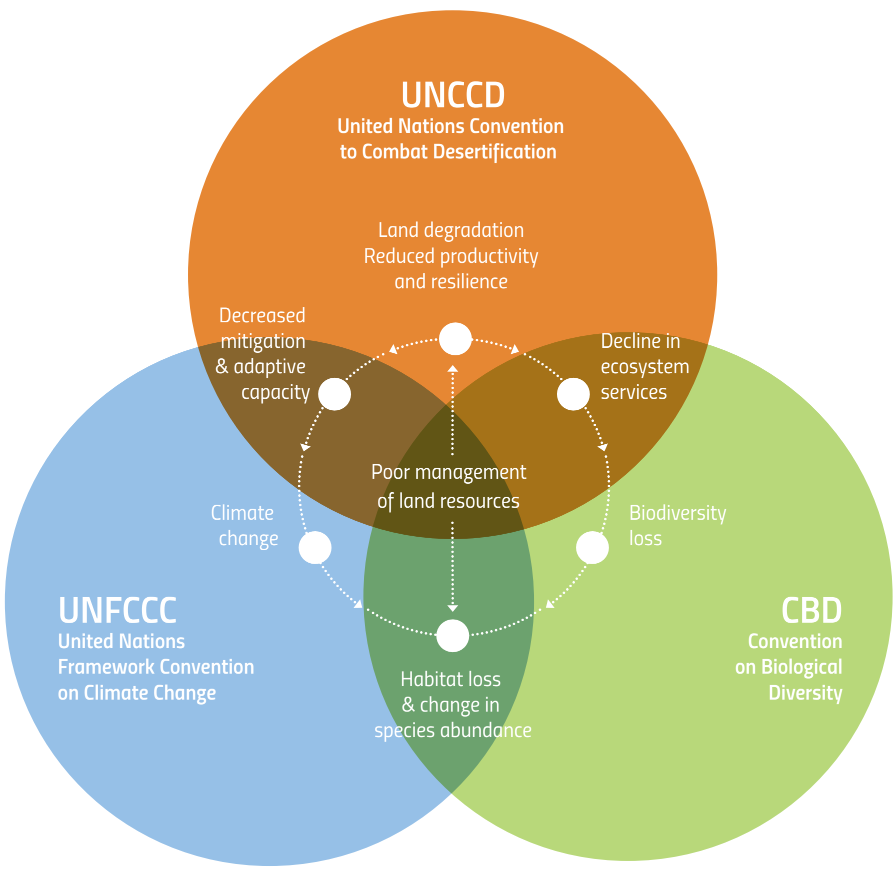
The health and resilience of our land resources are largely determined by management practices, governance systems, and environmental changes. The transformation of our natural ecosystems, the inefficient use of water resources, and the excessive use and misuse of agrochemicals[1] contributes to land degradation at the local level as well as increased greenhouse gas emissions, reduced biodiversity, and changes in rainfall on regional and global scales.[2] Land degradation, biodiversity loss, and climate change are now recognized as intertwined threats to multiple dimensions of human security and contribute to a downward spiral in the productivity and availability of land resources.[3]

The GLO provides a brief overview of how land is used today and assesses likely scenarios for how we can sustainably meet the demand for land-based goods and services into the future. It focuses on broader policy and practice, the cardinal issues long requiring attention, as well as the emerging concerns that need to be considered in the global public policy agenda. The GLO is a strategic, forward-looking discussion and analysis that draws upon well-documented scientific research and empirical evidence. A comprehensive global assessment of land degradation and restoration is being undertaken by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

The premise is that land, and its associated resources, comprise a stock of natural capital. The increasing demand for land-based goods and services, and the manner in which they are today produced is adversely impacting the health and future productivity of the planet. The misuse and over-exploitation of land resources are threatening human security on multiple fronts: diminishing food and water security as well as reduced soil health and ecosystem resilience make us more vulnerable to extreme weather events and the impacts of climate change, and even threaten stability and security within and between nations.

The GLO presents an overview of the status of land and a clear set of responses to optimize land use, management, and planning, and thereby create synergies among sectors in the provision of land-based goods and services. This integrated approach is the basis of the conceptual framework for land degradation neutrality (see Annex One), a target which is seen as the driving vehicle for the implementation of the United Nations Convention to Combat Desertification (UNCCD) and an important part of the 2030 Agenda for Sustainable Development.

Figure 1: Intertwined threats and the objectives of the Rio conventions



The GLO not only puts forth practical pathways to a more sustainable and desirable future but also highlights likely scenarios, recognizing that decisions and investments made today will influence land use and management tomorrow. Many already point to the urgent need to reassess the values and attitudes that determine how we currently use and manage our land resources. We are confident that this Outlook will help advance a new a new vision and agenda for action to ensure a more secure future.

One of the UNCCD's main aims is to help countries overcome the barriers to the adoption and scaling up of sustainable land management (SLM) policies and practices needed to reduce poverty, and increase food, water, and energy security for all.

This first edition of the GLO is a response to the mandate given to the UNCCD secretariat: namely, to continually seek innovative approaches and products that increase awareness of desertification, land degradation, and drought while advocating for proven and cost-effective solutions to advance numerous targets contained in the Sustainable Development Goals. It is expected that the GLO, as the UNCCD's flagship publication, will be issued periodically and take its place among other Outlooks.

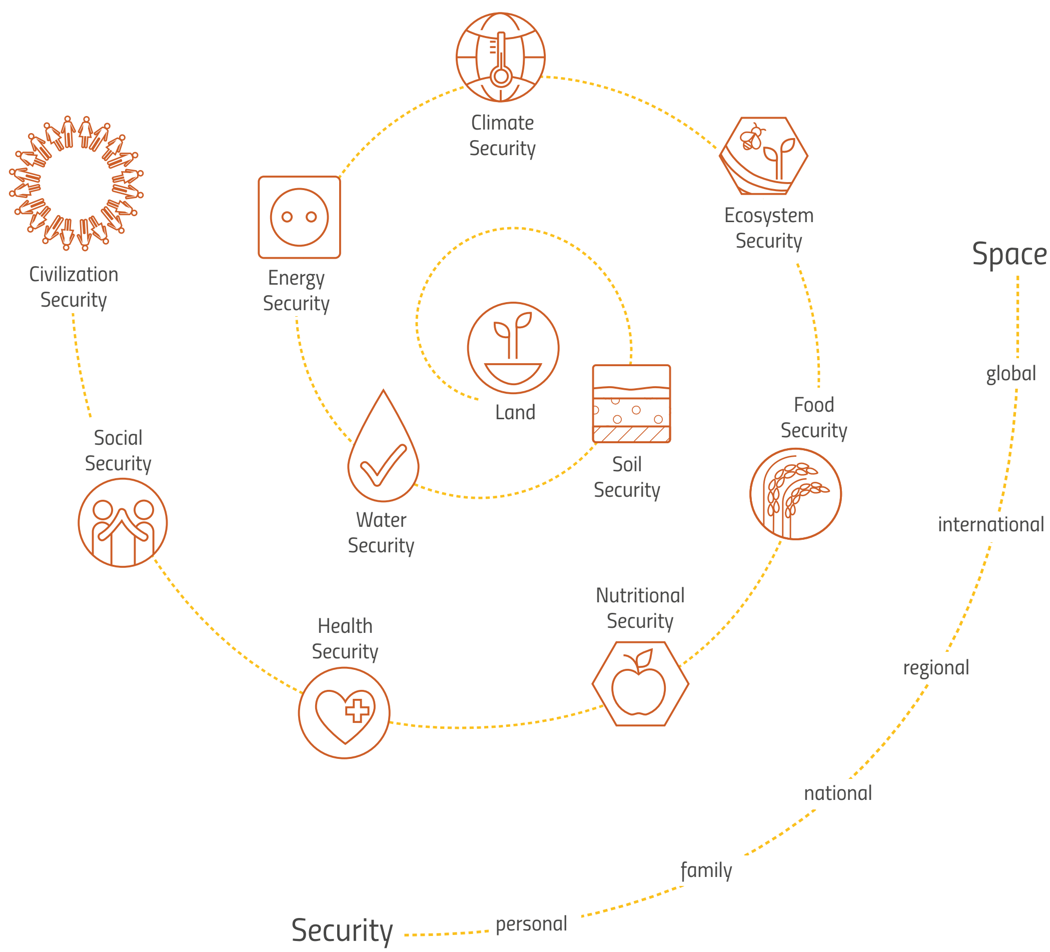
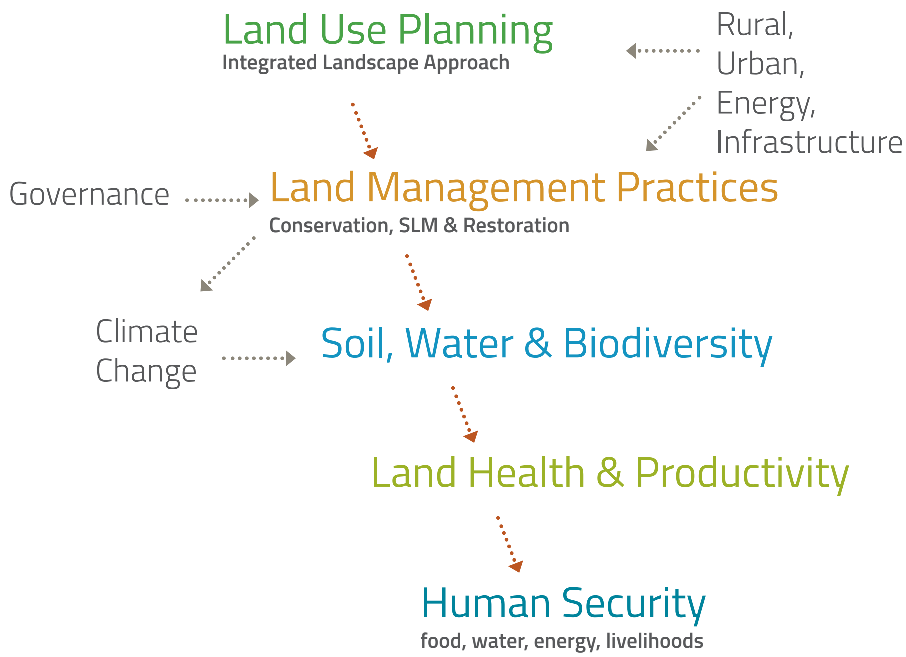


Figure 2: Dimensions of human security: Adapted from[4]

Figure 3: Main themes of the *Global Land Outlook*



The GLO is presented in such a manner as to be accessible to civil society and decision-makers in both the private and public sectors. It is part of a broader effort to facilitate discussion on land use policy and practice by illustrating the fundamental importance of good land management. In doing so, the GLO argues that we all are decision-makers with the power to make change.

Part One looks at the big picture both in space and time, with a brief history of land use. It examines the drivers of degradation and land use change, and details the current pressures on land resources. It also looks at the impacts that land degradation can have on the economic, social, and environmental dimensions of our lives.

Part Two explores future scenarios or pathways, outlining a number of forecasts on the production and consumption of land-based goods and services. This is followed by thematic treatments of issues of global concern, highlighting current trends and future solutions.

Part Three presents an action agenda for a more secure future, examining proven and cost-effective options to scale up conservation, sustainable land management, and restoration practices to accelerate progress towards more equitable sustainable development.

While this first edition presents a constructive and optimistic Outlook, it deals with grim realities and daunting challenges. Let us start by taking a look at the big picture.

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Part One
THE BIG PICTURE

The big picture is a mosaic of many smaller ones. Different countries, cultures and communities define, perceive and value land in very different ways. Any one area of land can be used for many different purposes. Such is the multi-dimensional character of land: where some see certain lands as inhospitable, others feel very much at home; where some see wilderness to be tamed, others see grandeur and beauty to be preserved. All these factors influence attitudes towards land use and the way that land is managed. Yet keeping the land in a healthy state is an essential contribution to human security – access to food and water, the stability of employment and livelihoods, resilience to climate change and extreme weather events, and ultimately social and political stability.

Part One

CHAPTER 1

MEANING OF LAND

Our perceptions of land are not only a response to the outside world, but also a cause and an effect of cultural filtering, by which certain phenomena feature prominently, while others recede into the background. In other words, the less visible the elements of land are to a particular stakeholder, the less meaning they have for that person and perhaps result in a lack of awareness as to their possible critical functions.

The meaning and value of land can change as we become wealthier or do not directly depend on the land for our immediate survival. Furthermore, land is often infused with a feeling of sovereignty and jurisdiction – aligned with different patterns of ownership and use rights – which in turn governs our economic and socio-political interactions and conflicts with others.

All these factors influence attitudes towards land use and the way that land is managed. Nevertheless, keeping land in a healthy state is an essential contribution to human security – access to food and water, the stability of employment and livelihoods, resilience to climate change and extreme weather events, and ultimately social and political security.

LAND AS A BOUNTIFUL ASSET

Whether land is a private or public asset, it has the potential to provide a full suite of goods and services: mitigating climate change at the global scale, regulating water supply at the landscape scale, and supporting food production at the local scale. Natural and managed ecosystems support local livelihoods and allow communities to grow and prosper. Land is bountiful, but also bounded and its goods and services are relatively finite. To ensure equitable use, it is not enough to simply identify who owns the land and how they use it. Land management practices often have downstream consequences; as a result, landowners increasingly face restrictions on how they use or manage land so as to safeguard the multiple ecosystem services it provides.

A more comprehensive understanding of land's multiple functions and services (i.e., the benefits to humans and other species) and the process of ascribing value to them suggests that in the future farmers and other land managers should have an expanded role as stewards of the land and its associated resources.

To protect and nurture this bountiful asset, it is important to recognize rights, rewards, and responsibilities as the pillars of sustainable land management. Farmers and land managers often require incentives to ensure the supply of goods and services their land provides, including those beyond the market, whether conserving biodiversity, safeguarding water supplies, protecting against flooding, or sequestering carbon. The extent to which the wider community should compensate owners for these ecosystem services is an evolving debate, and, even if consensus is reached on how much should be paid, there are a number of practical problems regarding how compensation ought to be allocated.[1] For most countries, long-term food security and economic growth are highly dependent on the sustainable management of their land-based natural capital.

Land has forever been intertwined with human development; its economic function being but one of many. Land is a unique, valuable, and immovable resource of limited quantity, providing multiple benefits to society. It is the most basic element of subsistence, valued for its richness above and below ground. Land is a strategic socio-economic asset, particularly in poor societies where survival and wealth are often still largely determined by the control of, and access to, land. As a result, land is tied to a complex network of issues ranging from power relationships to economics, from symbolic attachments to systemic inequities. Land is a central element in the varied and complex social relations of production and consumption.

Definitions of land

The UNCCD defines land as "the terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological and hydrological processes that operate within the system."[2] Alternatively, land is defined as "a delineable area of the Earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface, including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), the near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations (biodiversity), the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, etc.)."[3]

THE MULTI-DIMENSIONAL CHARACTER OF LAND

Effectively negotiating the sustainable use, management, and planning of land resources requires integrative systems and participatory stakeholder approaches rather than linear, sectoral strategies. An aspiring outlook requires seeing and understanding land in all its dimensions. In Figure 1.1, we present indicative perspectives on the meaning of land to illustrate the diversity of the challenges, issues, and priorities confronted by different stakeholders.

Of course, these are just stereotypes for the purpose of illustration. Most stakeholders hold multiple views on specific land uses and on the concept of land itself. They often fit into more than one category, or may hold significantly differing views from the majority. By definition, a holistic approach better reflects the diversity of views and promotes a greater understanding of trade-offs and synergies in identifying the most appropriate solutions for scaling-up sustainable management practices.

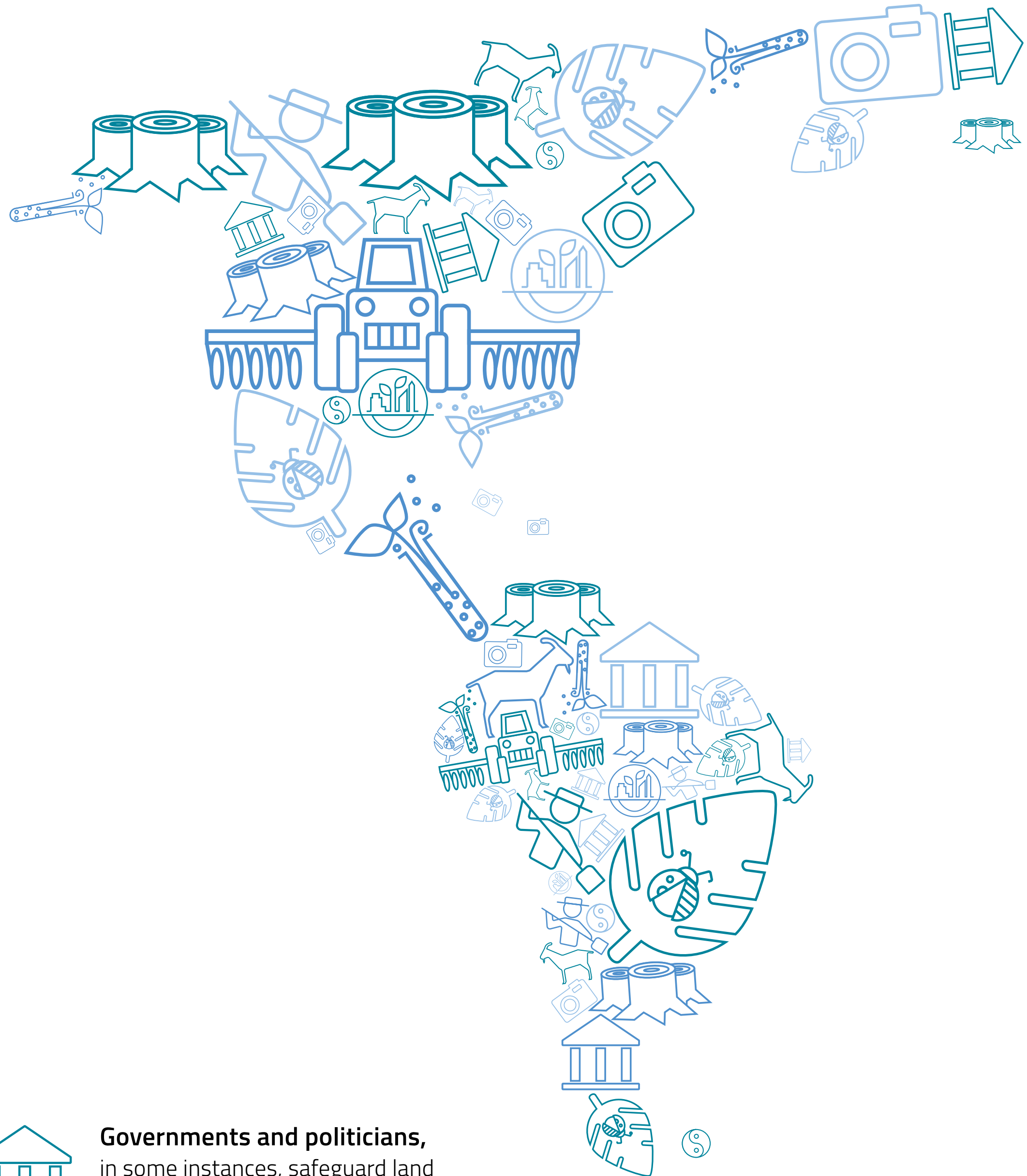
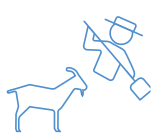


Figure 1.1: Stakeholder perceptions on the meaning and value of land

Governments and politicians,
in some instances, safeguard land for the public good, while in other instances, they employ it as an instrument of power and control.

Scientists and researchers
see land as a composite of soil, water, biodiversity and minerals, interacting to provide goods and services that benefit humans and sustain ecosystem functions.



Subsistence farmers and pastoralists
view it as source of food and livelihood; an intergenerational transfer of wealth, and a sense of place and belonging.

Indigenous and local communities
often consider land to be a communal or sacred asset, to be protected for current and future generations. Many faith groups regard certain landscapes or land forms as imbued with particular spiritual significance or power.

Conservationists and environmental activists
tend to appreciate the value of land as a habitat for species or as a wilderness to be protected.

Agri-business and industrial farmers/ranchers
consider it as a business opportunity and profit-making asset.

Timber, paper and pulp companies
focus on the trees, while the mining and energy sectors are primarily concerned with what lies below the surface of land.

Urban developers and frontier settlers
are constantly searching for land to expand the human domain and create economic wealth. Gardeners and architects enjoy the prospect of modifying or transforming landscapes in pursuit of the aesthetic enhancement of our cultural environment.

Artists, philosophers and tourists
see land as a respite or refuge, a source of spirituality, inspiration and beauty.

LAND AS PRIVATE PROPERTY

Land as private property is a relatively recent phenomenon and is more dominant in some cultures than others. In many countries, the government still controls vast tracts of land, yet some of the most productive were and are being reallocated or sold as private property to individuals and corporations. Acquisition by both the state and private entities[4] can have devastating impacts on the people who have traditionally lived on the land, but do not hold formal or legal title.[5]

Although land has always been a uniquely valued and trusted asset, an exclusive political and legal system that encourages private ownership has changed people's relationship to land, particularly in urban and other high-value economic areas.[6] Large areas of land change hands around the world via transactions that are subject to different degrees of regulation and formality, although attempts are being made to promote voluntary guidelines on the governance of tenure.[7]

In some developing countries, there has been significant consolidation of land holdings in the past few decades, and legal titling is now the norm and closely linked to wealth creation. Historically, many rural lands around the world, that were traditionally owned and governed by local communities and indigenous peoples under customary tenure systems, have now been acquired by the state. More recently, some countries have started the process of relinquishing state control of land, returning it to indigenous peoples and local communities.[8]

People living in the developed world expect land ownership to be clearly identified, mapped and protected by legal title, and supported by land administration institutions. However, throughout much of the developing world, individual property rights are not recognized as such, and rights to natural resources are often shared among different users within local communities.[9] For instance, in West Africa, different user groups (e.g., men, women, farmers, pastoralists, churches) may have rights and access to different parts of the same land resource: trees in a community-managed forest provide fodder for livestock; fruits and vegetables are collected by women; timber is harvested by men. Moreover, even in this overlapping system of land use, shared access may vary at different times of the year.[10]

Statutory legal systems are not always appropriate or sufficiently flexible to cope with the complexity of customary land use. On the other hand, where land rights are not formally established or regulated by government authorities, they can easily be disregarded due to increasing pressure on, and competition for, land resources. Ignoring the rationale for customary tenure systems – which support long-term regenerative practices and multiple uses by different parties – may be detrimental to both society and the environment.[11]

Many developing countries lack adequate laws, or fail to implement established provisions that legally determine who owns the land and its resources. This can lead to default ownership by the state, powerful individuals, or corporations. Such events frequently result in dire consequences for traditional land users, whose lands are often expropriated without consent or compensation, leaving them alienated from their community and their property. Multiple factors can converge to dispossess people from their land, induce conflicts, and increase migration from rural areas. Traditional sustainable approaches to land management also sometimes falter under the pressure of demographic change or the influence of modernity in traditional societies.

LAND AS A PUBLIC GOOD

Land plays an important role in capturing and storing atmospheric carbon; it governs biophysical cycles and provides a multitude of goods and services that benefit society as a whole. However, if badly managed or degraded, these functions are lost. Landscapes are a mosaic of ecosystems and human communities are embedded within them. Unfortunately, the role of land as a public good and common resource does not currently enjoy sufficient recognition in land use policy and planning.

One way of looking at land is assuming that it belongs to everybody, with each field or plot having a local custodian.

The custodian's role in enhancing the positive – or curtailing the negative – impacts associated with different land uses can deliver diffuse benefits of great importance to the health of the wider landscape and society. For example, individual decisions to cut trees or plow permanent pasture will release carbon, thus increasing the negative impacts of climate change and reducing public benefits.

In Nigeria, some floodplains have multiple overlapping uses by different stakeholders: fisher folk have rights to the land during the rainy season, with varying types of fishing permitted; farmers plant crops during the dry season; and livestock herders have rights post-harvest, and to uncultivated grasslands within the floodplain.[12] In these types of customary use systems, the question of "to whom the land belongs" is unclear; even the concept of primary versus secondary users is irrelevant. Rights overlap and care should be taken to avoid misunderstandings when working with traditional concepts of property rights. Land often belongs to a "community," which may include different ethnic groups and land users, so defining land rights often needs to account for these traditional governance systems and mechanisms of negotiation.

LAND AS A SENSE OF PLACE

The questions of belonging and ownership, of rights and responsibilities, are challenging to address in simple terms. The answers lie within a spectrum, from the legal titling of land, to community and customary entitlement, or to a simple sense of belonging. For many people, land is about dignity, culture, and identity. Land ownership implies freedom from exploitation and slavery; it provides safety and security. Unhindered access to land can equal self-determination and the assurance of inter-generational continuity. For some, issues of land tenure are seen as fundamental to human rights.[13]

Many people benefit simply from living and working on the land, or derive cultural or spiritual identity from their place within the landscape. Being in direct contact with the land can lead to both mental and physical health benefits; it can also reinforce who and where we are, giving us a sense of self and place. For communities and societies with strong spiritual connections to the land, sustainable management practices are often an integral part of their traditions, such as sacred groves in India and church forests in Ethiopia.

During the last few years, the concept of existence rights has emerged:[14] the rights of survival of species and ecological interactions. Research shows that this view is prevalent across many societies today. Most people instinctively feel that humans have an obligation to prevent species extinction wherever possible. The huge support for iconic species, such as the tiger or the panda, which most people will never see in the wild, demonstrates that conservation is not just a utilitarian issue.

This view is now shared by the large majority of the world's major philosophies and and religions, which recognize the duty of stewardship. The leaders of all the major faiths have issued statements acknowledging the moral obligation of humans not to destroy what remains of nature.[15]

Culture can have an important role in bringing together divergent views on how humans adapt to or alter their landscapes. While the cultural aspects of land vary greatly by region and evolve as new areas are settled, markets for land-based products are becoming global in reach. The effect of these external economic drivers can significantly influence, or even destroy, the original sense of place. This dichotomy between tradition and modernity, typical of the globalized world, increases the potential for discord surrounding land use and management. While some give precedence to the market value of land, as measured by its exchange value, others feel that regardless of human involvement, land has intrinsic value in and of itself, and fear that this dimension may be lost when there is the drive to maximize profit.

Table 1.1: Links between faith and environmental thinking[16]

Faith	Links to environmental thought
Baha'i	Founded by the Persian Baha'u'llah. Believes all religious leaders are manifestations of God and all scripture sacred. Nature and Scripture are the "two books" of revelation. Shoghi Effendi, Baha'u'llah's great-grandson, noted: "Man is organic with the world. His inner life moulds the environment and is itself also deeply affected by it."[17]
Buddhism	Teaches respect for and interconnectedness of nature; plants and animals are included in schemes of salvation.[18] Gautama Buddha was born, attained enlightenment, and died under trees. Sacred trees are decorated and revered. Buddhism advocates protection, such as ridam in Bhutan, an annual prohibition on entering a designated mountain forest.[19]
Christianity	Teaches that all creation is a loving act of God and that humanity may not destroy God's creations without the risk of destroying itself. St Francis was an early proponent of ecological stewardship. There have been statements by Christian leaders in response to the ecological crisis.[20] Pope Francis published an encyclical in 2015 calling for protection of nature.[21]
Daoism	Traditionally believed to have been founded by Lao Tzu. Stresses harmonious interaction with the environment, symbolized by a balance between two opposing forces of Yin and Yang.[22] Chuang Tzu, a Daoist scholar, warns against the concept that all nature must be "useful" and stresses its existence value.[23] Modern interpretation lays stress on ecology.
Hinduism	The earth is revered as Bhumi, "Mother Earth." There are many references to conservation; e.g., the Arthashastra prescribes fines for destroying trees.[24] Damming India's most sacred rivers, the Ganges and Narmada, generated protests partly for faith reasons.[25] During the Chipko movement, women prevented forest loss by surrounding trees with their bodies.[26]
Jainism	Jains minimize harm to all life-forms and their teachings stress sympathy and compassion with all life.[27] Mahavira stated: "One who neglects or disregards the existence of earth, air, fire, water and vegetation disregards his own existence which is entwined with them." The Institute of Jainology produced the 1990 Jain Declaration on Nature.[28]
Judaism	In the past, reaction to pantheism downgraded the importance of nature, although this is changing.[29] The Tree of Life is one of Judaism's most powerful images. Planting trees has been a widely observed practice, particularly in recent times and the Torah orders creation of green belts around cities (Numbers 35:4). Trees remain a subject of worship in Israel.[30]
Islam	The teaching of Allah in the Qur'an states that humans have stewardship over nature, but nature belongs to God.[31] Rivers and lakes need a buffer zone, and tree planting and kindness to animals are encouraged. Islam developed the use of Hima, land protection for grazing, bee-keeping, forests, or water,[32] which is still practiced in Jordan and Saudi Arabia.[33]
Shinto	Shinto was the traditional faith of Japan before Buddhism. There are many deities with no formal hierarchy or doctrine but strong links to nature. Ceremonies appeal to the kami, forces of nature in mountains, springs, trees, etc. Sacred groves are important, including both cultivated and natural areas.
Sikhism	Sikhs believe in one God and their sacred writings are contained in the Guru Granth Sahib. Guru Nanak said "Within the Universe, Earth was created to be a shrine." All nature is sacred according to the Sikh faith. Sikhism follows a three hundred year cycle; the current cycle, due to end in 2299, is understood as the "Cycle of Creation" putting an emphasis on environmental practices.
Zoroastrianism	Founded by Zoroaster in modern day Iran. Later, many Zoroastrians moved to India where they are known as Parsis. They regard the earth as sacred, implying that life is also sacred. The decline of vultures in India due to chemical poisoning[34] is a problem for Parsi communities, because the birds are essential to the tradition of disposing of the dead in "Towers of Silence."

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Box 1.1: Geomythology[35]

"So the land is actually like a big book, you know?" Alison Anderson, a Papunya elder in Australia said.[36] The Eurocentric worldview requires science to be firmly separated from "folklore." If we are to honestly contemplate the cultural and spiritual values of the land, these assumptions need to be fundamentally re-examined.

For a geologist, the stains streaking rocks in the Kata Tjuta mountain range in Australia are "desert varnish," part mineral, part microbial coating typical of arid areas. For the Pitjantjatjara and Anangu cultures, they are the beard of Wanambi, the snake king who lives on the summit. Geologists see rock domes telling a 500 million year story of pebbles, gravel, and sand flushed down into an ancient sea, buried, solidified, tilted, uplifted, and eroded. For the Aboriginal people, each summit represents – indeed, *is* – a being from the Dreamtime. In 1966, Dorothy Vitaliano, of the U.S. Geological Survey, coined the word *geomythology* to describe relationships between legends and geology.[37] She divided geologically-inspired folklore into stories satisfying the human need for explanation (*etiological*) and those originating from witnessing real events (*euhemeristic*).

Etiological stories of the land abound in almost every indigenous culture. For many, the land is everything: they are part of the land and the land is part of them: their larder, pharmacy, and place of worship.[38] The land itself has memory. Human origins invariably lie beneath the surface; places that provide subterranean access – canyons, craters, and caves – hold great spiritual significance; the concentration of rock art in such places is witness to this. Euhemeristic stories also play a key role in many cultures. Our ancestors have been roaming the Earth since the great Ice Age and recount stories of sea-level change, glacial floods, and dramatic shifts in the climate. In 2014, the evolution of one glacial landscape in Northwest Montana was documented and it was found that: "Hydrologic processes play critical roles in both the geoscientific and the traditional indigenous narratives ... and the traditional stories and Western geoscience theories exhibit intriguing similarities ..."[39]

The indigenous worldview is intrinsically holistic: there is no separation between humans and nature, between personal identity and the land, and there is growing interest in integrating this with conventional scientific thinking.[40] David Bohm, a great theoretical physicist, refers to the "unbroken wholeness of the totality of existence as an undivided flowing movement without borders."[41] Earth sciences themselves are not beyond holistic thinking: even the familiar separation of the organic from the inorganic begins to break down: minerals undergo a process of what is best described as evolution.[42] The relationship between individuals and place is inevitably influenced by culture and experience.[43] In short, the land is a book, to be read in different ways, with different translations. An understanding and integration of those different books into a hybrid knowledge system must, surely, be a fundamental prerequisite for building the diverse bridges necessary for sustainable development.

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CONCLUSION

Recognizing the perspectives of diverse stakeholders and ensuring their participation in decision-making is a critical first step towards better land management and planning. Land is owned and managed by governments, corporations, communities, and individuals, but we all depend upon the land for our health and well-being. We cannot afford to ignore this fundamental connection.

Global challenges, such as land degradation, are complex, but patterns do emerge which allow for organized thinking and creative new solutions to more efficiently use land resources in the future. In a rapidly changing world, with ever increasing pressures and demands on our natural resource base, the Global Land Outlook highlights the challenges and opportunities for sustainable land use, management, and planning. This Outlook is intended for all of us: from policymakers to small farmers; from corporations to communities; from consumers to producers. So let us turn now to a brief history of how we arrived at this juncture.

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Part One

CHAPTER 2

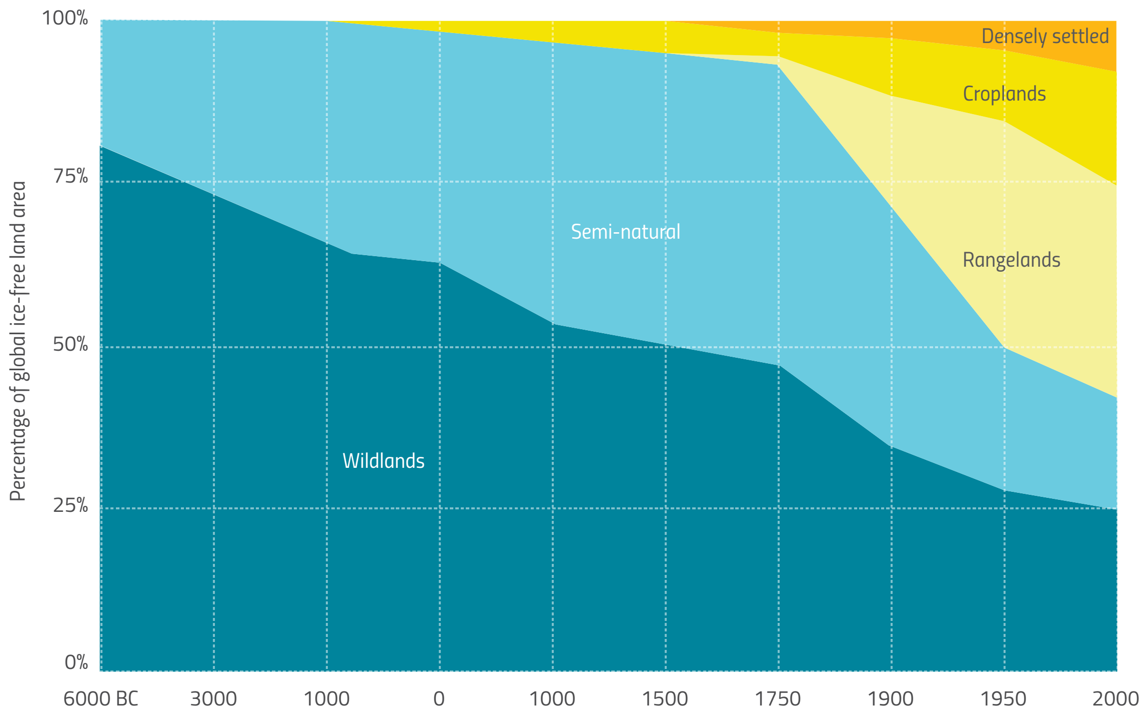
BRIEF HISTORY OF LAND USE

There is broad evidence to suggest that direct human alteration of terrestrial ecosystems by hunting, foraging, land clearing, agriculture, and other activities started about 12,000 years ago. Sometimes referred to as the "Neolithic Revolution," agriculture slowly began to transform societies and the way in which people lived; traditional hunter-gatherer lifestyles were abandoned in favor of more permanent settlements and a reliable food supply. This transformation was particularly significant in some regions, which experienced long-term changes from forest clearing, increased frequency of fire, mega-faunal extinctions, species invasions, and soil erosion.

Beginning around 8,000 years ago, agricultural land use expanded in Mesopotamia and in the Fertile Crescent areas of southwest Asia; this was followed by growth in China, India, and Europe. Intensive land use patterns developed in India, especially on the Ganges plains; in China, along the lower Yellow and Yangtze rivers; in Africa, throughout the Sahel; and in South America, along the Andes. This agricultural expansion led to the development of more complex forms of societal organization. Fertile land and the domestication of wild food crop species allowed nomadic tribes to settle and form early towns and cities. The landscapes of the neo-tropical dry forests of South America, for instance, played a pivotal role in the emergence of pre-Colombian civilizations, such as the Incas.

By approximately 6,000 years ago, agricultural expansion had spread across most continents, leading to the clearing of native vegetation and to the culling, or domestication, of herbivores. Native flora and fauna were replaced with intensive crop and livestock management practices as human populations grew and became denser. Starting around 1750, the transformation of land started to accelerate, and rapid land use change continues to be a dominant influence today.

Figure 2.1: Transformation of the biosphere over 8000 years: Adapted from,[4] Based on[5]



THE COMMON ERA

By the start of the Common Era (CE), up to 60 per cent of the land in Europe was being used by humans, albeit with significant fluctuations as some areas were periodically abandoned due to war, famine, and other events that affected human populations. By the Middle Ages (14^{th} and 15^{th} centuries), land use intensity in both Europe and China increased greatly following the development of cities and towns. During the same period, nearly 90 per cent of the indigenous peoples of the Americas died as a result of European contact, through slaughter and, principally, disease. This led to the massive regrowth of natural vegetation, especially of forests in the Amazon, Andes, Mesoamerica, and the western areas of North America.[1]

These pre-1700 land use changes were substantially smaller, more localized, and less intensive than those that came later but still transformed landscapes, e.g., from closed to open woodlands, altering soils, fire regimes, and regional patterns of biodiversity.[2] In some cases, relatively small human populations are thought to have made widespread and profound ecological changes over 3,000 years ago.[3]

Figure 2.2: Theatrum Orbis Terrarum: Reproduced with permission[7]

THE MAP THAT CHANGED THE WORLD

In 1564, Abraham Ortelius, a thirty-seven year old mapmaker from Antwerp, produced what is generally regarded as the first modern atlas, known as the *Theatrum Orbis Terrarum*. It provided, for the first time, a clearly discernible global map.[6] Not all of it was accurate: the Antarctic was too large, South America too narrow, and Australasia was yet to be discovered. Nevertheless, even to the casual observer it is quite obviously a map of the world. The next several decades witnessed a massive growth in mapmaking, mainly in Europe, and by the middle of the 17th century the accuracy of world maps had significantly improved. New maps encouraged new discoveries: a search for new lands, new experiences, and new products. The age of exploration had dawned, leading quickly to colonialism and to the large-scale exploitation of natural resources around the globe.

The history of global surveying and cartography had enormous influence on the development of humankind's self-image in relation to the natural world. Formerly, the two had been as one, but now nature existed as an object, separate from, and ascribed value only through its usefulness to, humankind.[8] This ultimately led to a profound reconfiguration of the relationship between land and society in some parts of the world.[9] In this regard, the 17th century scientific revolution included, most notably through Francis Bacon but also René Descartes, calls for the "conquest," "mastery," and "domination" of nature.[10] The belief that technological progress could overcome any limitations imposed by nature became central to global political and economic strategies.[11]

While the general contours of the world were becoming more familiar, less was known about what lay beyond the coastlines: most of the interiors of Africa, the Americas, and Australasia lay undiscovered. The population of the world at that time has been estimated at around 500 million,[12] a mere eight humans per square kilometer compared with an average of 57 today.[13] Farming and artisanal mining were small scale, and forests were untouched in large parts of the tropics. As long as new land frontiers continued to open, the social and environmental costs of exploitation were seen as diffuse and/or easily offset. More recently, we have come to understand that this new web of communication and relationships transformed the food system and landscapes in a relatively short period.[14]

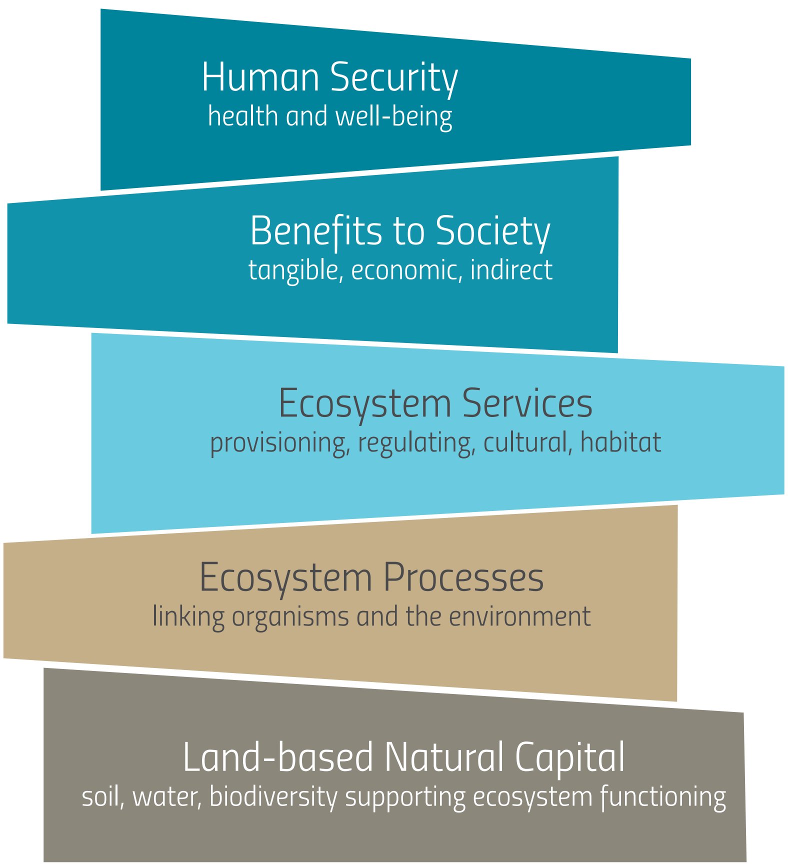
A NEW ECONOMIC PARADIGM

The forces of science and economics came together to completely transform the idea of nature. The notion of a limitless, human-built world[15] was embraced and reinforced by the many voyages of exploration, primarily from Europe. Colonialists abruptly gained access to what seemed to be a limitless stock of natural resources,[16] and in the process externalized their ecological footprint.[17]

Meanwhile, economic thought underwent its own revolution, leading to a philosophy based on free trade and the maximization of self-interest.[18] Land,[19] as the principal source of wealth in classical economics, lost its central role in the transition to neo-classical economics, being replaced by notions of marginal utility and productivity. The distinction between wealth and value, or use value and exchange value, was abandoned; the broader environmental and social costs of capital accumulation[20] were largely ignored in the new economic paradigm.[21] Between 1700 and 2000 the terrestrial biosphere made the critical transition from mostly wild to mostly anthropogenic.[22]

From the standpoint of capitalist value calculation, land is seen as a free gift of nature[23] often referred to a "free goods" in modern economics. The inherent consequence of such capital accumulation was and is the unbridled exploitation of the commons[24,25] and accelerated environmental degradation.[26] The history of civilization is strewn with examples of unsustainable land management practices, leading to deforestation and soil degradation[27] and, eventually, societal collapse. Yet, it was the combination of new commodity relations, reconfigured wealth and value conceptions, and industrialized agriculture that cleared the way for rapid, systematic land use intensification.

Figure 2.3: The relation between natural capital and human security: Adapted from[35]



LAND AS NATURAL CAPITAL

More recently, mass production has led to an economy based on mass consumption and built-in obsolescence, with economic growth as the single fundamental aim and marker of development success, as measured by gross domestic product (GDP). While its strongest supporters dismiss any limits to growth,[28] there has been vocal opposition to this paradigm, spearheaded by the Club of Rome in the 1970s,[29] and which continues today. It is only in the 20th century that mainstream economists have begun to talk about natural capital (including land) on an equal footing with human and built capital;[30] to understand the form and importance of natural capital to – and the effect of its depletion on – human welfare; and to explore the costs and impacts of land degradation on economic growth.[31,32]

While this development signals a step in the right direction, it also carries the profound risk of advancing the commodification of nature. The original motivation of this economic approach was to garner policy and business support for natural resource conservation and sustainable use by demonstrating both tangible and intangible values. This remains worthwhile and relevant. In some cases, the approach has been transformed into one which seeks payments for ecosystem services on the assumption that such remuneration will ensure their provision.[33,34]

Box 2.1: The Revenge of Nature

The power of human social systems to transform the Earth in a destructive way, thus provoking the "revenge" of nature, was already apparent and being observed in the late 18th and early 19th centuries. In 1848, the German botanist Matthias Schleiden, for example, stated *"that those countries which are now treeless and arid deserts, part of Egypt, Syria, Persia, and so forth, were formerly thickly wooded, traversed by streams,"* but were now *"dried up or shrunk within narrow bounds"* and exposed to the full force of the sun. He attributed these environmental changes primarily to the human destruction of forests, and concluded: *"Behind him, he [man] leaves the Desert, a deformed and ruined land and is guilty of the thoughtless squandering of vegetable treasures here again in selfish pursuit of profit, and, consciously or unconsciously, following the abominable principle of the great moral Vileness [sic] which one man has expressed, 'après nous le déluge,' he [man] begins anew the work of destruction."*[36]

EXPLOSIVES AND TRACTORS

The industrial processes of the past three centuries have been critical drivers of anthropogenic global change, including land use change and ecosystem conversion. By the beginning of the 19th century, world population had doubled in a mere hundred years,[37] and the demand for timber, energy, metals, and precious minerals was about to grow exponentially: the industrial revolution had begun. It would profoundly reshape the world. We confront its legacies today and will continue to do so well into the 21st century.

The demand for minerals, such as iron ore and coal, along with fuelwood for the industrial revolution, would give rise to new demands on land resources by a rapidly growing population seeking wealth and prosperity.

Although extracting precious minerals from the earth began as early as 3,000 BCE in Egypt,[38] it was small-scale and heavily dependent on labor. The rise in large-scale mining and quarrying can be traced to the early 17th century. In 1627, the use of explosives was introduced, which allowed the scale of mining to increase dramatically, while the adoption of the steam engine, some years later, propelled the demand for energy-based minerals. The demand for minerals, such as iron ore and coal, along with fuelwood for the industrial revolution, would give rise to new demands on land resources by a rapidly growing population seeking wealth and prosperity. Other minerals, such as gold and precious stones, would rise in importance and become de facto currencies while adding little to real wealth.[39]

While agricultural practices can be traced back some 10,000 years or more, it was the industrial sector, with its rising wages and demand for food along with a growing population, which shifted the focus and scale of agriculture. In the 17th and 18th centuries, as the need for cheap food and fuel grew, significant changes to agricultural systems were introduced, such as crop rotation, selective breeding of animals, enclosures, and mechanization: the advent of industrial agriculture.

The increasing demand for cheap food, energy, and water triggered the necessity to farm land differently. Subsequent technological advancements, such as mechanization, both made this shift possible and encouraged its intensification. In 1901, the first powered tractor was introduced, paving the way for draft animals to be replaced and an era of energy-intensive farming to begin. Over the past hundred years, the application of agricultural science grew dramatically in response to the demand for food. The "Green Revolution" of the early 1970s witnessed significant yield increases coupled with greater intensity of fertilizer and pesticide use. While yields did increase significantly overall, addressing imminent threats of food shortages, they were accompanied by unwelcome environmental impacts as well as by the significant expansion and consolidation of land used for crop and livestock production.

There is no question that modern agriculture has been successful in increasing food production. Contrary to Thomas Malthus's predictions,[40] food production has kept up with, and even outpaced, population growth. However, roughly half of the world's surface area has been converted to land grazed by domesticated animals, cultivated crops, or production forests resulting in the loss of more than half of the world's forests.[41] This expansion and intensification has led to devastating environmental impacts at local, national, and global levels.

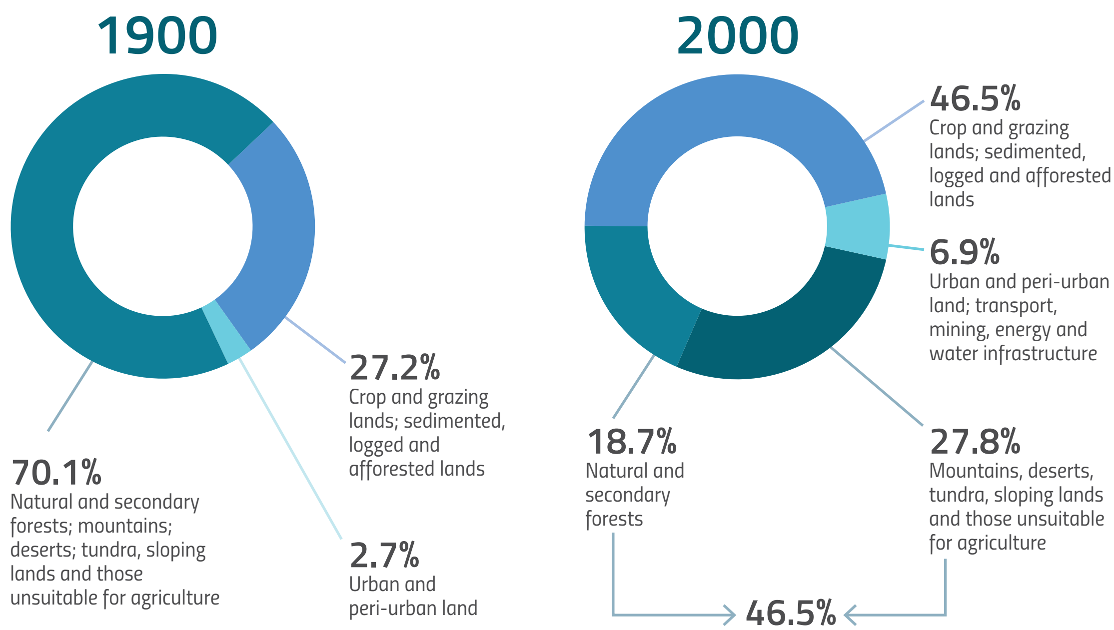


Figure 2.4: A century of land use change: Based on 1900[47] and 2000[48]

A CENTURY OF LAND USE CHANGE

Many factors have driven the growth of cities and the transition from rural to urban living. Cities exist for manifold reasons and the diversity of urban characteristics can be traced back to the wide variety of functions they perform: from transport to security, including, of course, market functions, initially for agricultural surpluses and then for other goods and services including banking and finance. Cities tended to be located in strategically important areas: hubs of trade, close to good agricultural land, presence of government and military complexes, etc.

The size, pace, and nature of urbanization has been a defining characteristic of the 20th and 21st centuries. While the rapid rates of urban population growth over the past century have occurred on less than 3 per cent of the world's terrestrial surface, its impacts have been global. Approximately, 78 per cent of carbon emissions, 60 per cent of residential water use, and 76 per cent of wood used for industrial purposes are attributed to urban areas.[42] It has been estimated that up until the middle of the 19th century, only between 4 and 7 per cent of the world's population lived in towns. The early expansion of cities tended to be horizontal: it has been estimated that as the population of cities such as London and Paris expanded twenty-fold, their corresponding land footprint expanded two hundred-fold.

Land use change to build cities and support the demands of growing urban populations drives other types of environmental change. In 2007, an important transition occurred when, for the first time in history, we moved from being primarily rural dwellers to becoming majority urban dwellers.[43] Urban populations depend on the productive capacities of ecosystems well beyond their city boundaries. Their so-called "ecological footprints," namely that which is required to produce the flows of goods and services (including waste absorption) that sustain human well-being and quality of life, are tens to hundreds of times bigger than the actual urban area they occupy.[44] The response to this conundrum has been a renewed focus on intensive agriculture, concentrated on the most productive lands, and operating according to an industrial agribusiness sector model, with increasing influence on trading systems and research.[45] Although city dwellers have always relied on agricultural surplus, the scale today is unprecedented.[46] The demand for agricultural products has been the single largest historical driver of land use change.

Many peoples have defined their culture and values in terms of the lands they occupy. Indigenous peoples have historically had a close and intimate relationship with land.

THE NON-MARKET VALUES OF LAND

Land offers more than just economic or financial rewards, whether from farming, forestry, or mining. Many peoples have defined their culture and values in terms of the lands they occupy. Indigenous peoples have historically had a close and intimate relationship with land.[49] Lands have been universally celebrated for their intrinsic and inestimable value in religious, spiritual, aesthetic, and recreational terms. People appreciate landscapes as having worth well beyond their exchange value.

At the national level, almost all countries have demarcated some of their territory as protected areas to be conserved in perpetuity. These protected lands and waters provide a legacy for future generations to enjoy. The earliest national parks in Africa, India, Australia, and the United States were created in the late 19th century. Today, approximately 15 per cent of the world's land surface and inland waters are designated as protected areas, a sign that we care deeply about preserving biodiversity and ecosystem services as well as the majesty and beauty of the landscape.

A growing number of protected areas are also internationally recognized. The United Nations has explicitly acknowledged that land embodies important values well beyond the financial. The United Nations Educational, Scientific and Cultural Organization's World Heritage sites, which include both cultural and natural sites, remain a powerful symbol that recognizes the cultural, social, and spiritual values of our lands. To date, over 1,000 sites have been recognized as having World Heritage status, of which over 200 are classified as natural or mixed use sites. The natural sites are deemed to represent "*superlative natural phenomena and significant natural habitats for in situ conservation of biological diversity.*"[50]

CONCLUSION

The understanding of the finite quantity of natural resources at our disposal, a recognition of their importance to our survival, and an increased awareness of the pace at which we are depleting and degrading them has shaped a whole new paradigm in the public discourse. The growth of ecological concerns based upon the sustainability of natural systems and their components has its roots in a wide range of academic disciplines. Climate change has become a major catalyzing force that affects – and is impacted by – the use and management of land resources, further linking land to all dimensions of human security.

Momentum continues to grow at the global and national levels. In the lead-up to Rio+20, two decades after the pivotal 1992 Earth Summit in Rio de Janeiro, the UNCCD set out an ambitious agenda of achieving land degradation neutrality by 2030.[52] The United Nations 2030 Agenda for Sustainable Development, adopted in 2015, set out a series of Sustainable Development Goals (SDGs) and targets that encourage more judicious land use, management, and planning. SDG 15, in particular, puts a strong emphasis on the need to scale up transformative management practices with the goal to "*Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss.*"[53]

There is little doubt that the planet is reaching a critical juncture in terms of how we use and manage our land resources. The demand for these resources will only increase and a range of future scenarios is discussed in Part Two of this Outlook. Sustainable land use is as much about ensuring that land is protected and nurtured for successive generations as it is about providing social and economic opportunities today. Striking a balance will remain an enduring challenge for the 21st century.

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The View from Space

In December 1968, a seminal event occurred which transfixed humanity and transformed our view of Earth. As Apollo 8 left the Earth's orbit for the moon, it sent back a picture of our planet that had not been seen before. This photograph provided a unique perspective on its shape, its blue color, and, perhaps most importantly, its finite size. A series of other images were collected, including the famous "blue marble" image of the planet taken from the last moon mission, Apollo 17, in 1972. These images greatly influenced the research of scientists and scholars. Those responsible for producing the groundbreaking book, "Limits to Growth," that placed the Earth's finiteness into a context of economics and policy – a group of enlightened businessmen led by Aurelio Peccei and a team of scholars and systems planners from the Massachusetts Institute of Technology – have often spoken of the influence the early space photos had on their work. Indeed, by the late 20th century, a new ethic had emerged, underpinning and transforming our understanding of the importance of managing natural resources in a manner that can be sustained over time and with a respect for planetary boundaries.

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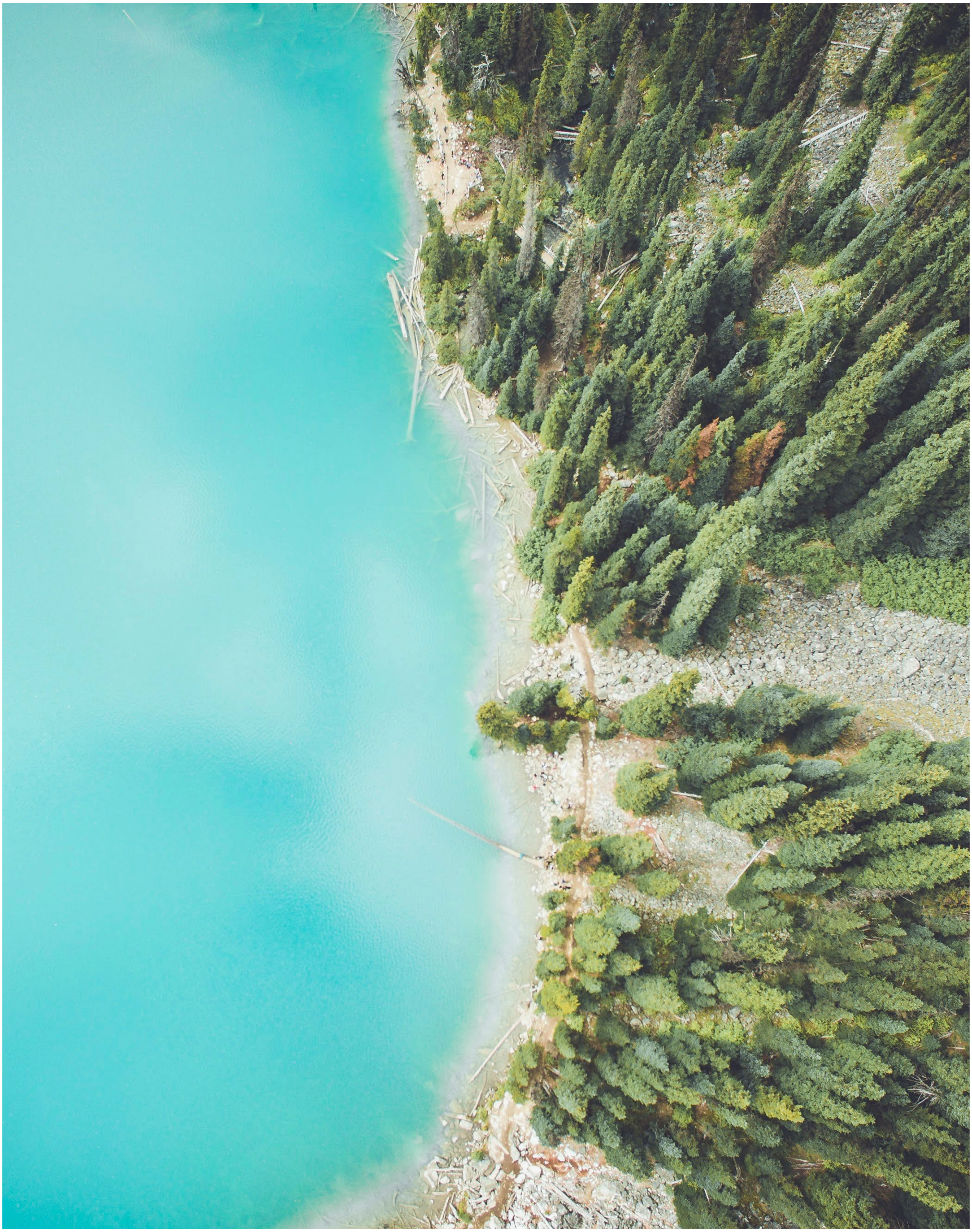

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CHAPTER 3

DRIVERS OF CHANGE

The growing demand for food, fodder, fuel, and raw materials is increasing pressures on land and the competition for natural resources. At the same time, degradation is reducing the amount of productive land available. The drivers of land degradation are mainly external factors that directly or indirectly impact the health and productivity of land and its associated resources, such as soil, water, and biodiversity.

Direct drivers are either natural (e.g., earthquakes, landslides, drought, floods) or anthropogenic (i.e., human-induced); some of the latter influence what would formerly be thought of as natural climatic events. Human-induced drivers such as deforestation, wetland drainage, overgrazing, unsustainable land use practices, and the expansion of agricultural, industrial, and urban areas (i.e., land use change) continue to be the most significant proximate cause of land degradation.

Many modern crop and livestock management practices lead directly to soil erosion/compaction, reduced water filtration/availability, and declining biodiversity, both above and below ground. Meanwhile, mining and infrastructure for transport, energy, and industry are increasingly enlarging their footprint in the landscape and impacting land resources at ever larger scales.

Over the last one hundred years, the amount of land used for urban and peri-urban areas has doubled, and is expected to accelerate further over the next few decades. However, while still relatively small in scale – at approximately 5 per cent of the global land area – urban areas often cover some of the most fertile soils and productive lands.


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Indirect drivers are generally regarded as the underlying causes of one or more direct drivers of land degradation. Unlike direct drivers, these are complex, interlinked, diffuse, and operate at larger and longer scales and originate farther from the area of degradation. They include population growth, land tenure, and migration trends; consumer demand for land-based goods and services; macro-economic policies focused on rapid growth; and public policies and institutions encouraging investments that suppress cross-sector coordination.

INTRODUCTION

Land degradation is a complex phenomenon, usually involving the loss of some or all of the following: productivity, soil, vegetation cover, biomass, biodiversity, ecosystem services, and environmental resilience. Degradation is commonly caused by the mismanagement or over-exploitation of land resources, such as vegetation clearance; nutrient depletion; overgrazing; inappropriate irrigation; excessive use of agrochemicals; urban sprawl; pollution; or other direct impacts, such as mining, quarrying, trampling, or vehicle off-roading. Land use change is not the same as degradation, and some land use changes can be net positive in terms of benefits to humankind. However, in the current context of declining natural ecosystems, coupled with increasing pressures on land resources, land use change is often associated with degradation that reduces biodiversity and ecosystem services.

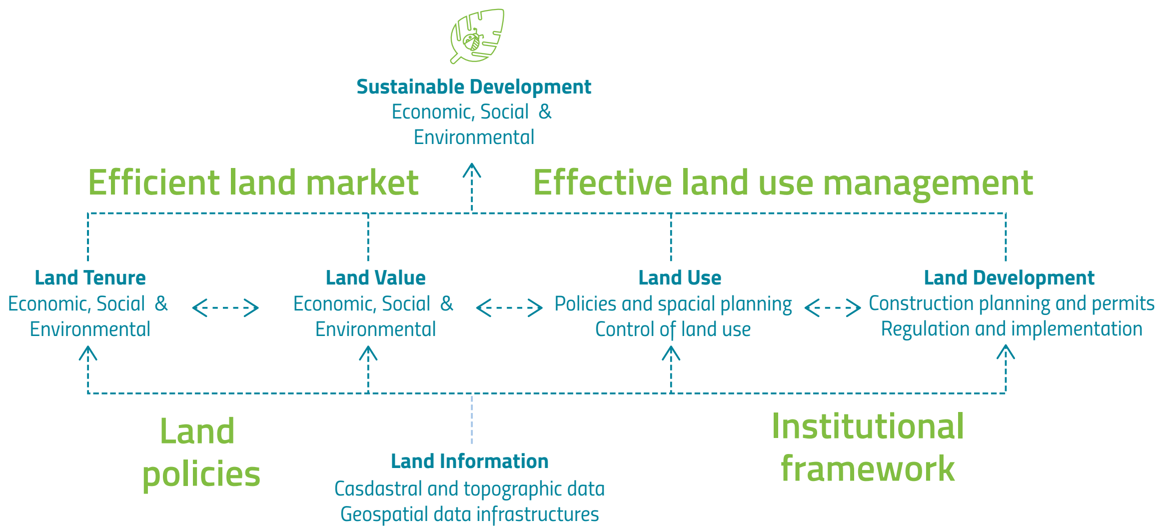
The value of natural capital: The vagaries of our economic system and the quest for wealth accumulation are powerful indirect drivers that multiply and amplify the direct drivers of land degradation. Of the four types of ecosystem services identified by the Millennium Ecosystem Assessment – provisioning, supporting, regulating, and cultural – only provisioning (e.g., food, fuel, fiber) and, to a lesser extent, cultural services (e.g., recreation, tourism) have a market price; most supporting and regulating services do not. Services such as soil formation, climate regulation, and species and habitat protection – although they play a critical role in supporting productive landscapes and human security – have historically been ascribed little or no value in the dominant market systems of the past two hundred years. These systems utilize high discount rates which tend to encourage decisions that are focused on the short-term and ignore the real long-term value of natural capital, which undermines efforts to sustainably manage, conserve, and restore land resources.

As discussed in Chapter 2, this is slowly changing. Since the 1990s, the multiple values of natural capital have become central to the debate surrounding the Millennium Development Goals (2000-2015) and current Sustainable Development Goals (2015-2030). An appropriate valuation of ecosystem functions and services (i.e., in terms of benefits to humans) could reduce some of the impacts of direct drivers by promoting a more holistic approach to land management; one where competing trade-offs are negotiated within a social, political, and administrative framework by which direct and indirect benefits are jointly assessed.

Three broad, inter-related groups of factors drive land degradation: biophysical factors that determine how land is used; institutional factors that govern broader land use policies; and socio-economic factors that affect the demand for and management of land.[2] The climate, vegetation, topography, and availability of water are usually the first set of factors determining land use; and the economic situation influences management decisions including when and how fast changes occur. Institutional factors are often historically determined by long-standing cultural practices, but are also influenced by political and economic decisions. Property rights and tenure are central to understanding the influence of institutional factors. Secure land tenure can create incentives for investment, economic growth, and the good stewardship of natural resources. But tenure is complex, with rights established by a wide variety of formal and informal means, including cultural, historical, customary, or informal arrangements. Rural and urban areas in the same country often operate under quite distinct forms of legal tenure, further complicating land rights in peri-urban areas. As the demand for land increases, those without formal tenure status or property rights are likely to be exposed to varying levels of insecurity.

Land degradation is the reduction or loss of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes arising from human activities.

Figure 3.1: A global perspective of modern land administration systems: Redrawn from[3]



In general, land use change that results in land degradation – and the associated loss of land functions – is driven by multiple, interacting elements, from the local to the global scales.[4] Over the coming decades, a decrease in the availability of productive land will be compounded by competition between land uses.[5] The drivers of land degradation can be categorized into two types: (i) direct or proximate drivers, and (ii) indirect or underlying drivers. Direct drivers are human activities that directly relate to changes in land use and condition.[6] Indirect drivers are less easily detectable or quantifiable, and determining their influence predominantly relies on economic and social indicators as well as trend analysis.[7]

DIRECT DRIVERS OF LAND DEGRADATION

Global estimates of the amount of degraded land vary widely, from 1 billion to 6 billion hectares, which illustrates both the scale of the problem and the need for more accurate data. The critical drivers, briefly discussed here, and in more detail in Part Two of the *Outlook*, include:

- Agriculture and forestry
- Urbanization
- Infrastructure development
- Energy production
- Mining and quarrying

1. Agriculture and forestry

Agriculture is by far the largest human use of land, covering roughly 38 per cent of land surface, not including Greenland and Antarctica.[8] The area used for agriculture is still expanding, at the present time mostly at the expense of natural forests[9] and to some extent grasslands. It is, for instance, the most significant cause of current land conversion[10] in the tropics,[11] resulting in the loss of biodiversity and ecosystem services.[12] Degraded lands account for over a fifth of forest and agricultural lands in Latin America and the Caribbean.[13] Commercial agriculture is a key driver,[14] especially the production of beef, soybeans, and oil palm.[15]

Although the net area devoted to agriculture continues to expand, this expansion masks the loss of land due to degradation and land abandonment that results from soil loss, erosion, nutrient depletion, and salinization.[16] In some places, land abandonment is also driven by political and economic factors. Increasing mechanization and the use of agrochemicals, such as nitrate and phosphate fertilizers, pesticides, and herbicides, have boosted yields in the short term but have also had significant negative impacts on soil and water quality and on the health of ecosystems and species, which can in turn undermine food security.[17]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Drivers of soil degradation[18]

Soil degradation is a key factor undermining food security. Soils can be degraded over time either qualitatively (e.g., salinization) and quantitatively (e.g., erosion). There are several major types of soil degradation processes.

Physical degradation: the structural breakdown of the soil through the disruption of aggregates. This results in the loss of pore function, which in turn leads to a reduction in surface infiltration, increased water run-off, and decreased drainage. In time, this leads to a decrease in the availability of gases for plants and biota. Physical degradation processes include erosion, sealing and crusting, and compaction.

Chemical degradation: processes leading to soil chemical imbalances, including salinization, loss of nutrients, acidification, and toxification.

Biological degradation: the artificial disruption of soil structure (e.g., through tillage) can lead to excessive activity of soil biota due to oxygenation and excessive mineralization of organic matter leading to the loss of structure and nutrients.

All these processes can be influenced by a number of direct drivers, natural and anthropogenic, influencing soil processes in different ways, including the nature and speed of the processes. Direct drivers include climate, natural hazards, geology and geomorphology, and biodiversity. Climate has a significant impact on soil processes and the provision of ecosystem services. Local climate (e.g., rainfall intensity, temperature, sunshine) influences supporting processes and biodiversity by driving soil moisture and temperature. Natural hazards, like earthquakes or volcanic eruptions for example, can change the soil environment and the geological origin of parent material determines the initial minerals that drive soil development and properties as will the type and variety of species present. Anthropogenic drivers, such as land use, farming practices and technologies, also greatly influence soil processes. The type of land use (e.g., cropping, livestock) determines the type of disturbance (e.g., tillage, treading, use of agrochemicals) as well as applied inputs (e.g., excrements, synthetic fertilizers). Farming practices determine the intensity of disturbances (e.g., organic versus conventional cropping) and the amount of inputs (e.g., quantity and timing of fertilization).

Urbanization is projected to cause the loss of between 1.6 and 3.3 million hectares of prime agricultural land per year in the period between 2000 and 2030.

Abandoned agricultural areas are often considered to be a type of degraded land,[19] and the rate of land abandonment is treated as an indicator of land degradation,[20] although they can also offer important opportunities for ecological restoration. Abandonment can be driven by productivity loss, rural-urban migration, an aging population, conflict, increases in invasive species, changes in agricultural subsidies, or other factors that discourage agricultural activities.

Forest activities also create major impacts on ecosystems. Forest clearance is often a precursor to the establishment of plantations for food or fiber where selling timber is frequently a way of financing subsequent operations. Elsewhere, more intensive management practices in natural forests, or the conversion to plantations alters the ecology and hydrology, and if poorly planned can lead to soil erosion and the loss of other ecosystem services.

2. Urbanization

The share of the global population expected to live in cities is projected to grow by around 2.5 billion people by 2050.[21] Such growth often results in urban sprawl, with built-up land spilling over in some cases onto fertile soils and farmland,[22] resulting in a permanent loss of arable land. Globally, about 2-3 per cent of the land area is currently urbanized; this is expected to increase to 4-5 per cent by 2050.[23] Built-up areas in developing country cities, meanwhile, are projected to increase threefold by 2030.[24] Urbanization is projected to cause the loss of between 1.6 and 3.3 million hectares of prime agricultural land per year in the period between 2000 and 2030.[25] In addition to using land directly ("land take"), urban populations have a footprint that spreads far beyond the boundaries of the city.[26] Tropical deforestation has, for instance, been positively correlated with urban population growth and agricultural exports.[27]

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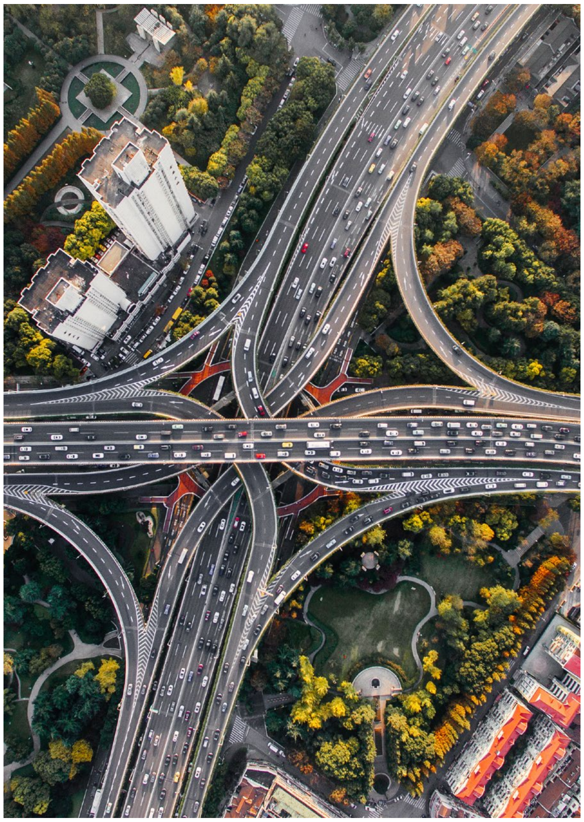
Figure 3.2: Breakdown of projected infrastructure investment: Redrawn from[31]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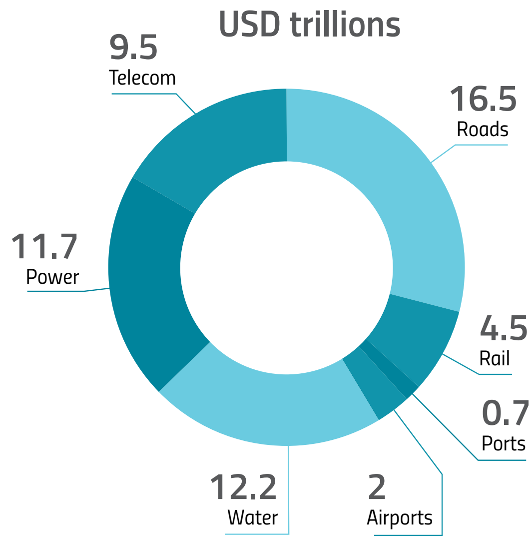

3. Infrastructure development

As more of the world's population crowds into urban centers, the need for infrastructure such as roads, sewage and drainage, and power-lines also grows.[28] Simultaneously, in many older cities, much of this infrastructure needs to be improved or replaced.[29] It is estimated that about USD 57 trillion in infrastructure investment will be needed between 2013 and 2030. This investment will be crucial in the emerging economies, such as China, Brazil, India, and Indonesia, for transport, power, water, and telecommunications.[30]

Together, infrastructure and urban development already cover 60 million hectares,[32] an area roughly the same as Ukraine, and will likely expand by a further 100-200 million hectares in the next four decades.[33] Such changes have both direct and indirect impacts on land. Transport infrastructure encourages urban sprawl, replacing natural ecosystems[34] and sealing soils, thus increasing the risks of flooding. In addition, water runoff from urban areas is likely to be polluted, negatively impacting freshwaters[35] and other downstream ecosystem services.[36]

Infrastructure development also changes surface albedo (i.e., reflectivity) and rate of heat transfers from evapotranspiration, thereby altering local weather patterns.[37] The scale of projected infrastructure development is likely to displace productive land uses in some areas and contribute to land abandonment in others.

Outside the urban areas, roads and railways cut through pristine ecosystems, creating immediate damage and, if poorly planned and implemented, encouraging further unplanned conversion.[38] This can lead to the well-known "fishbone effect"[39] when numerous small and unofficial settlers' roads spill out from a new highway running through natural forest or grassland.[40] In the Brazilian Amazon over 20,000 km of federal or state roads are complemented by almost 200,000 km of unofficial roads,[41] often associated with logging,[42] and unpredictable in their development.[43] Over 20 more road building projects through intact forest are underway,[44] many with a significant role in deforestation,[45] and forest degradation.[46] Hydropower projects also change ecosystems, as discussed in Chapter 7, and mining activities cause immediate damage[47] and often longer-term pollution.

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4. Energy production

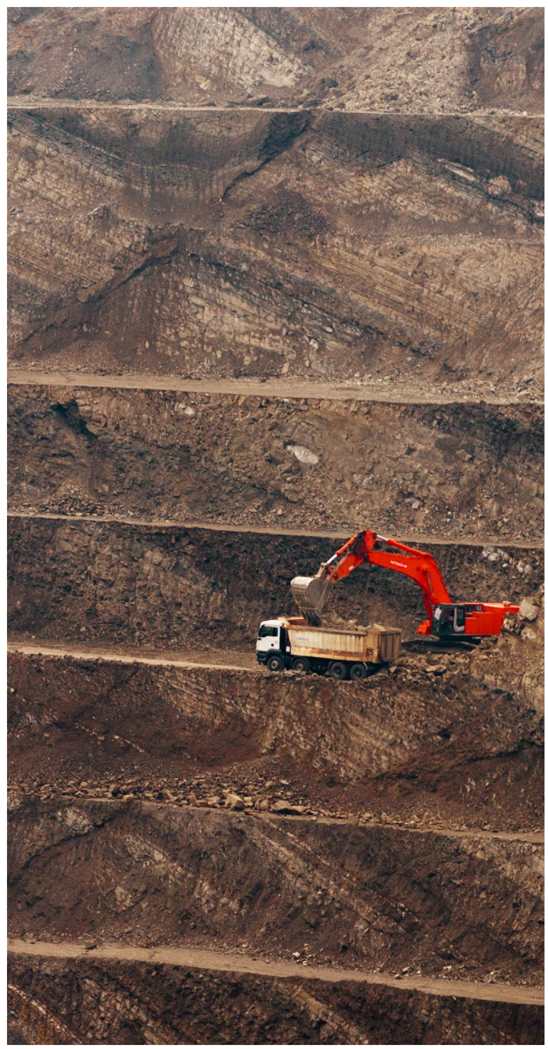
All sources of renewable and non-renewable energy make demands on land resources. In some developing countries, traditional fuelwood energy is a large driver of deforestation, forest degradation, and soil erosion.[48] Oil and gas extraction – in addition to their role in accelerating climate change – affect land condition in situ, encourage further negative land use change, and can cause pollution over large areas. New energy extraction activities, such as hydraulic fracturing ("fracking"), require large amounts of water, pipelines, roads, compressor stations, and evaporation ponds, all of which make demands on land; there are, moreover, documented concerns about the associated health and seismic impacts of fracking.[49] The European Union subsidizes wood and wood waste as an important source of sustainable biofuel. European coal-fired power stations are increasingly burning wood from the United States and Canada, leading to more forest clearance and greenhouse gas releases. Newly planted trees can absorb CO_2, but even with complete tree replacement it takes 20-100 years for the CO_2 to be fully recaptured.[50]

Renewable energy production also impacts land demand, land use, and land degradation. Biofuels require a lot of land, with crops like palm oil and soy encroaching upon forests and grasslands.

Renewable energy production also impacts land demand, land use, and land degradation. Biofuels require a lot of land,[51] with crops like palm oil and soy encroaching upon forests and grasslands.[52] The global area under biofuel crops was estimated at 45 million hectares in 2010,[53] and is expected to double,[54] to roughly 3–4.5 per cent of all cultivated land by 2030.[55] Hydropower developments directly flood large areas, open up new areas for exploitation, and alter hydrology with substantial impacts on rivers, floodplains, and seasonal wetlands.[56] Solar and wind farms also require significant land area and, as with all energy sources, need distribution networks such as electricity grids and powerlines.

5. Mining and quarrying

Recent political and economic changes have led to increased investment in mineral extraction,[57] directly resulting in land and soil degradation from deforestation,[58] vegetation burning,[59] and mining operations, along with more widely dispersed environmental and social damage.[60] Open-cast and mountain-top mining are particularly destructive,[61] while the collapse of underground mines can also lead to problems such as subsidence, soil erosion, and contamination of water resources.[62] The extraction of high-value minerals generates large quantities of waste,[63] in the order of tens of millions of tons per year,[64] causing siltation of water bodies,[65] acid mine drainage, and leaching of toxic minerals. This waste also creates air pollution,[66] which can affect human health[67] and suppress crop production.[68] Mining – particularly when it is illegal and thus unregulated – also creates high levels of pollution; for instance, the use of cyanide and mercury in gold extraction[69] leads to the pollution of surface and groundwater.[70]



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INDIRECT DRIVERS OF LAND DEGRADATION

Over the past two centuries, our demand for land-based goods and services has increased exponentially. The indirect or underlying causes of land degradation are linked to lifestyles, economies, and consumption patterns, a complex mixture of demographic, technological, institutional, and socio-cultural factors.[71] These include international markets and commodity prices, population growth and migration,[72] domestic markets and consumer demand, policies and governance,[73] as well as more local trends such as changes in household behavior.[74]

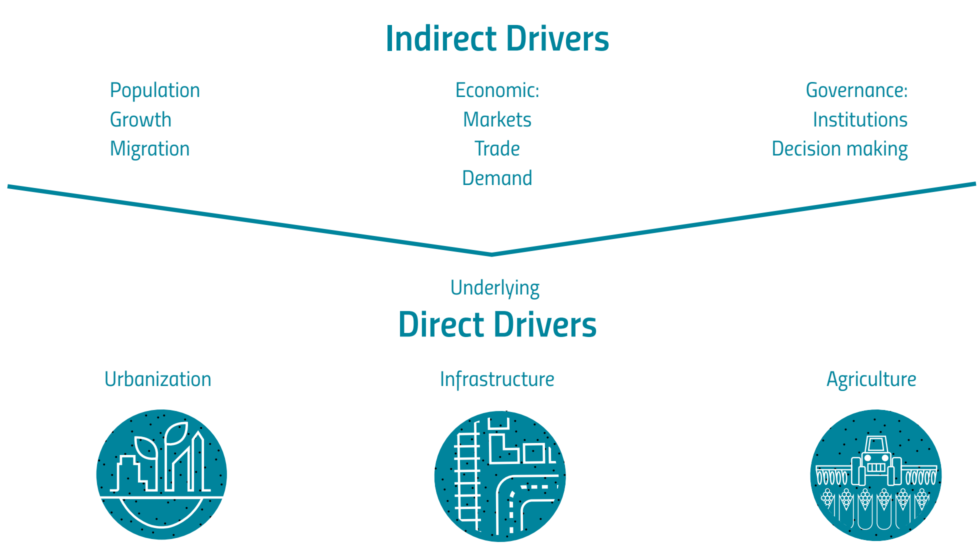
At the national level, weak governance and unstable institutions, the lack of cross-sectoral coordination, low capacity of public agencies, corruption, and illegal activities have all been identified as indirect drivers of forest and grassland degradation. Climate change plays a key role by causing shifts in land use in response to ecosystem change.[75]

Since the 1960s, global agricultural trade has increased ten-fold,[76] and trade in raw wood products, seven-fold.[77] One result is that the competition for prime crop and grazing land has increased. International trade also now includes virtual exchanges of natural resources such as soil, water, and land,[78] thus displacing the environmental impacts of these economic activities.[79] This has resulted in large-scale agricultural expansion[80] in developing countries often under conditions of weak governance.

Many of the underlying drivers are often quite distant from their area of impact. For instance, changes in diet in China, particularly more meat consumption, have increased soy imports from Brazil to feed animals in the pork and poultry sector.[81] Similarly, the growing demand for wood products, coupled with forest conservation programmes in China and Finland, has led to increased pressure on forests in Russia to supply Chinese wood imports.[82] Widespread land abandonment following the collapse of the Soviet Union eventually resulted in increased beef trade from Brazil to Russia, accelerating land use changes in Brazil.[83]

Land consolidation and supply chains: A more recent indirect driver is that land has emerged as a new kind of asset class. As a result, some investors are looking to place their liquidity into rural land holdings, with the expectation of high rents and returns. This raises concerns about large-scale land acquisitions and consolidation as an additional underlying driver of land degradation.[84] Throughout the past decade, the future of small-scale farmers has been threatened by the rise of commercial value chains, driven by the multinational food industry, and supported by consumer demand. The long reach of these supply chains has driven consumer prices down, which is a great help for poor consumers. However, reducing producer margins affects future investment, increases the likelihood of farm consolidation, and places poor farmers on the margins of survival.[85] This may have a profound influence on land degradation in the coming decades as small farmers and their communities disappear, and rural–urban migration intensifies.

Figure 3.3: Indirect drivers underlying direct drivers



CONCLUSION

The drivers of land degradation relate to factors that directly or indirectly impact the health and productivity of land. Direct drivers are either natural or human-induced. Deforestation, overgrazing, and the expansion of agricultural, industrial, and urban areas continue to be the most significant direct causes of land degradation.

Indirect drivers, on the other hand, are far more complex and operate at larger and longer scales and farther from the area of degradation. They include demographic trends, land tenure, changing consumer demand for land-based goods and services, macro-economic policies based on rapid growth, inequitable governance systems, and public policies and institutions encouraging investments that suppress cross-sector coordination. Direct and indirect drivers interact, mutually reinforcing each other and together drive land degradation in many parts of the world.

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Part One CHAPTER 3

Part One

CHAPTER 4

CONVERGENCE OF EVIDENCE

Humans dominate the planet and their influence extends to every part of the world. Over the last 20 years the extent of land area harvested has increased by 16 per cent, the area under irrigation has doubled, and agricultural production has grown nearly three-fold. Yet close to one billion people remain undernourished. There is enormous pressure on global land resources due to rising food demand, a global shift in dietary habits, biofuel production, urbanization, and other competing demands. Landfills, mining, and other extraction activities also contribute to the pressure on land resources. Hence, healthy and productive land is becoming scarce.

It is clear that unsustainable human activities put land at risk and at the same time threaten the ecosystem services on which all humanity depends. In Europe alone, poor land management practices account for an estimated 970 million tons of soil loss due to erosion each year; worldwide, the annual loss of soil is estimated at 24 billion tons. Satellite observations suggest that globally between 2000 and 2012, 2.3 million km^2 of forest were lost, while only 0.8 million km^2 were reforested. The loss of forests and other natural ecosystems directly affects biodiversity and ecosystem services, such as nutrient, carbon, and water cycles and climate regulation.

Agriculture provides food, fiber, and other products that sustain human life. Croplands occupy about 14 per cent of the total ice-free land area on the planet while pastures occupy about 26 per cent. Almost 45 per cent of the world's agricultural land is located on drylands, mainly in Africa and Asia; it supplies about 60 per cent of the world's food production. While increases in food production are essential to feed a growing population, agricultural expansion threatens local and regional ecosystem functions and the vital services they provide to all species.

INTRODUCTION

Measuring the extent of land degradation is difficult; experts disagree about both the status and trends even in well-studied areas like Europe and North America. The World Atlas of Desertification (WAD),[1] a project coordinated by the Joint Research Centre (JRC) of the European Commission with collaboration of the United Nations Convention to Combat Desertification (UNCCD), looks beyond conventional desertification analyses to consider, more generally, the status and trends in global anthropogenic land change processes, with an emphasis on croplands and rangelands. The WAD is further complemented with the large evidence base on forests, water resources, biodiversity, and soil conditions that is summarized in Part Two of this *Outlook*. After summarizing some of the key findings of the WAD, this chapter concludes by contrasting current status and trends in land productivity dynamics with some of the goods and services that widespread land degradation will put at risk.

Considering the drivers and multiple factors underlying land degradation and the need for context-specific responses, developing a single indicator or index to represent or map land degradation represents a big challenge. Thus, the WAD builds on a systematic framework that provides a "convergence of evidence" regarding human-environment interactions. This allows for the identification of thematic pathways and geographically-explicit patterns of coinciding processes that can potentially lead to land degradation.

This approach to providing and combining geospatial information with local level indicators is consistent with the monitoring and evaluation framework of the UNCCD[2] and the application of landscape-level approaches to the implementation of the land degradation neutrality target (SDG 15.3).

By evaluating a reference period of approximately 15 to 20 years, the time since the publication of the last Atlas, and taking account of the findings of the Millennium Ecosystem Assessment[3] in 2005, the WAD global mapping approach is designed to help identify areas potentially affected by persistent land degradation as well as areas that are showing signs of recovering their productive capacity. These maps are overlaid with information on the most commonly documented direct and indirect causes of land degradation, and also include, when available, information on sustainable land use and management practices, such as agroforestry and conservation agriculture.

The WAD implements a systematic and transparent framework to trace where the main human-environment processes and interactions coincide. This geographic convergence of evidence is instructive in that it highlights areas and possible pathways of land degradation as well as responses including the protection, sustainable management, and restoration of land resources. The third edition of the WAD focuses on global datasets that yield discernable patterns in potentially stressed areas. The combination of these stressors is then filtered through a variety of stratifications representing a range of stakeholder interests, such as cropland or rangeland perspectives. As a global scale exercise, the WAD remains limited in its ability to interpret specific local situations, which need to be addressed with contextual information and interpreted based on the understanding of their interactions at that scale. Nevertheless, the WAD convergence framework can be useful in providing background information for more detailed studies at national or sub-national scales.

Decreasing productivity trends do not per se indicate land degradation, or increasing trends indicate recovery. For further evaluation with the aim of identifying critical land degradation zones, an analytical convergence of evidence framework using additional thematic information is required.

Box 4.1: Methodology for assessing the status of land cover

In the past, land degradation maps have been controversial; their value questioned due to the multifaceted nature of the phenomenon, the complexity of processes involved, and the difficulty of interpretation at a global scale. However, progress in the last two decades – the emergence of improved global datasets, a better understanding of underlying processes, and rapidly advancing analytical tools – has improved the accuracy of this type of analysis.

The state of the Earth's vegetative cover and its development over time is a generally accepted representation of land productivity and dynamics, reflecting integrated ecological conditions and the impact of natural and anthropogenic environmental change. The term "land productivity dynamics" (LPD) as used in the WAD reflects the fact that the primary productivity of a stable land system is not a steady state, but often highly variable between different years and vegetation growth cycles due to natural variation and/or human intervention. This implies that land productivity changes cannot be assessed meaningfully by comparing land productivity values of single reference years or averages of a few years, and emphasizes the need for approaches based on longer term trends. Therefore, the LPD dataset relies on multi-temporal and thematic evaluation of long-term global time series of remotely-sensed vegetation indices, allowing for the calculation of equivalents to net primary productivity. These time series datasets coupled with model-derived bio-physical variables are increasingly being provided by existing national and international Earth Observation Systems, such as the Group on Earth Observations.[4,5]

The LPD map used does not provide a numerical measure of land productivity. Rather, it depicts the persistent trajectory of land productivity dynamics during the last 15 years. It provides five qualitative classes of persistent land productivity trajectories from 1998 to 2013: in other words, a qualitative combined measure of the intensity and persistence of negative or positive trends and changes of vegetation cover. The main elements of the LPD dataset processing chain are summarized in Annex 2, considering also aspects of validation and accuracy of the data product.

Land Productivity Dynamics

Land productivity addresses the net primary production (NPP) per unit of area and time. It reflects the overall quality of land and soil that results from environmental conditions and land resource use/management. Persistent decreases in land productivity point to the long-term alteration of the health and productive capacity of the land. Such decreases directly and indirectly impact on virtually all terrestrial ecosystem services, i.e., the benefits that form the basis for sustainable livelihoods and economic growth in all human communities. This indicator relies on multi-temporal and thematic evaluation of global long-term time series of remotely-sensed land productivity measures equivalent to NPP, at high spatial resolution (1 km or better) and operationally addressed by existing Earth Observation Systems.

Table 4.1: Five classes of land productivity dynamics

Class Value	Description
1	Persistent severe decline in productivity
2	Persistent moderate decline in productivity
3	Stable, but stressed; persistent strong inter-annual productivity variations
4	Stable productivity
5	Persistent increase in productivity

The WAD's key message is that land degradation is a multifaceted global phenomenon with distinct variations between regions and across key land cover/land use systems and which cannot be captured by one or a limited set of indicators.

It must be clearly understood and communicated that "land productivity" in the context of the LPD dataset strictly refers to the overall above-ground vegetation biomass productivity. This is not conceptually the same as, nor necessarily directly related to, agricultural income per area unit or "land productivity" as used in conventional agricultural terminology.

The WAD's key message is that land degradation is a multifaceted global phenomenon with distinct variations between regions and across key land cover/land use systems and which cannot be captured by one or a limited set of indicators. A crucial indicator in the WAD framework is the Land Productivity Dynamics (LPD) dataset that refers to the standing biomass productivity, and is derived from phenological analyses of a 15-year time series (1998-2013) of global normalized difference vegetation index (NDVI) observations from SPOT-VGT, composited in 10-day intervals at a spatial resolution of 1 km. The map shows 5 classes indicating areas of negative or positive change or stability and is an indicator of change or stasis of the land's apparent capacity to sustain the dynamic equilibrium of primary productivity in the given 15- year observation period.

Indications of decreasing productivity can be observed globally, with up to 22 million km^2 affected, i.e., approximately 20 per cent of the Earth's vegetated land surface shows persistent declining trends or stress on land productivity. These global trends are evident in 20 per cent of cropland, 16 per cent of forest land, 19 per cent of grassland, and 27 per cent of rangeland (i.e., shrubland, herbaceous and sparsely vegetated areas). For grasslands and rangelands, the global extent of the areas experiencing decreases in productivity exceeds that showing increases. South America and Africa are the most affected by productivity declines in absolute terms, with Australia and Oceania showing the largest proportion of areas affected: approximately 37 per cent for Australia, 27 per cent for South America, and 22 per cent for Africa.

Considering that immense effort and resources are being committed to maintain and enhance the productivity of arable and permanent cropland as well as the fact that there are clear limitations to the further expansion of cropland, these figures are cause for concern and action. This analysis can be further disaggregated according to land cover/land use classification. In the next step of the analysis, the distribution of LPD classes is further broken down to coarse land cover/land use categories at global and continental levels:

- Cropland including arable land, permanent crops, and mixed classes with over 50 per cent crops
- Grassland including natural grassland and managed pasture land
- Rangelands including shrub land, herbaceous, and sparsely vegetated areas
- Forestland including all forest categories and mixed classes with tree cover over 40 per cent

This breakdown reveals significant differences in the respective areas (Figure 4.3) and proportions (Figure 4.4) affected by declining or stressed (i.e., unstable) land productivity dynamics. The overall picture gets more nuanced when disaggregating at continental/regional and sub-regional levels. This is evident in the substantial differences between continents as regards the dimension and extent of potentially critical areas and their association to land cover/land use.

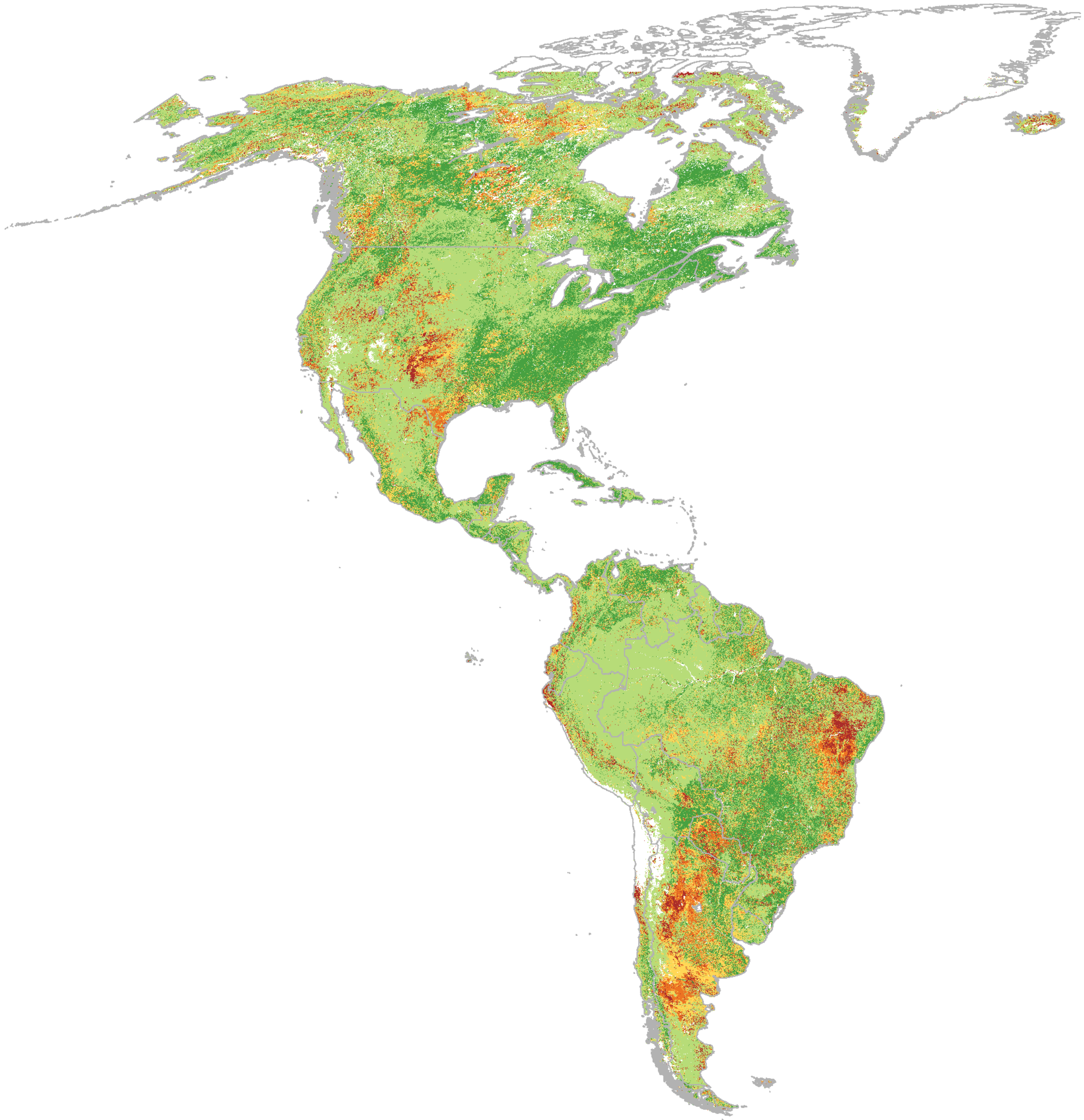


Figure 4.1: Global Land Productivity Dynamics map 1999 to 2013 showing 5 classes of persistent land productivity trajectories during the observation period. Decreasing productivity trends do not per se indicate land degradation, or increasing trends indicate recovery. For further evaluation with the aim of identifying critical land degradation zones, an analytical convergence of evidence framework using additional thematic information is required.

Key

- Declining
- Moderate decline
- Stressed
- Stable
- Increasing

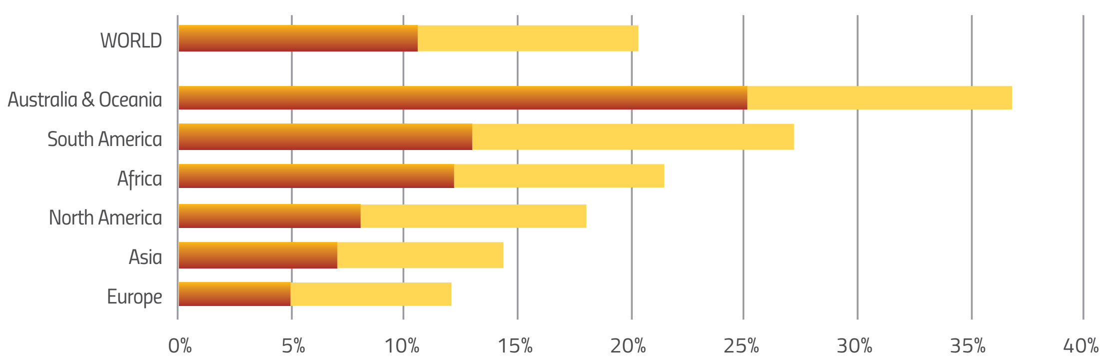


Figure 4.2: Regional groupings refer to a continental classification system (Australia & Oceania includes New Zealand, Papua New Guinea, and Pacific Islands; North & Central America includes the Caribbean).

Key

- Declining and moderate decline combined
- Stressed

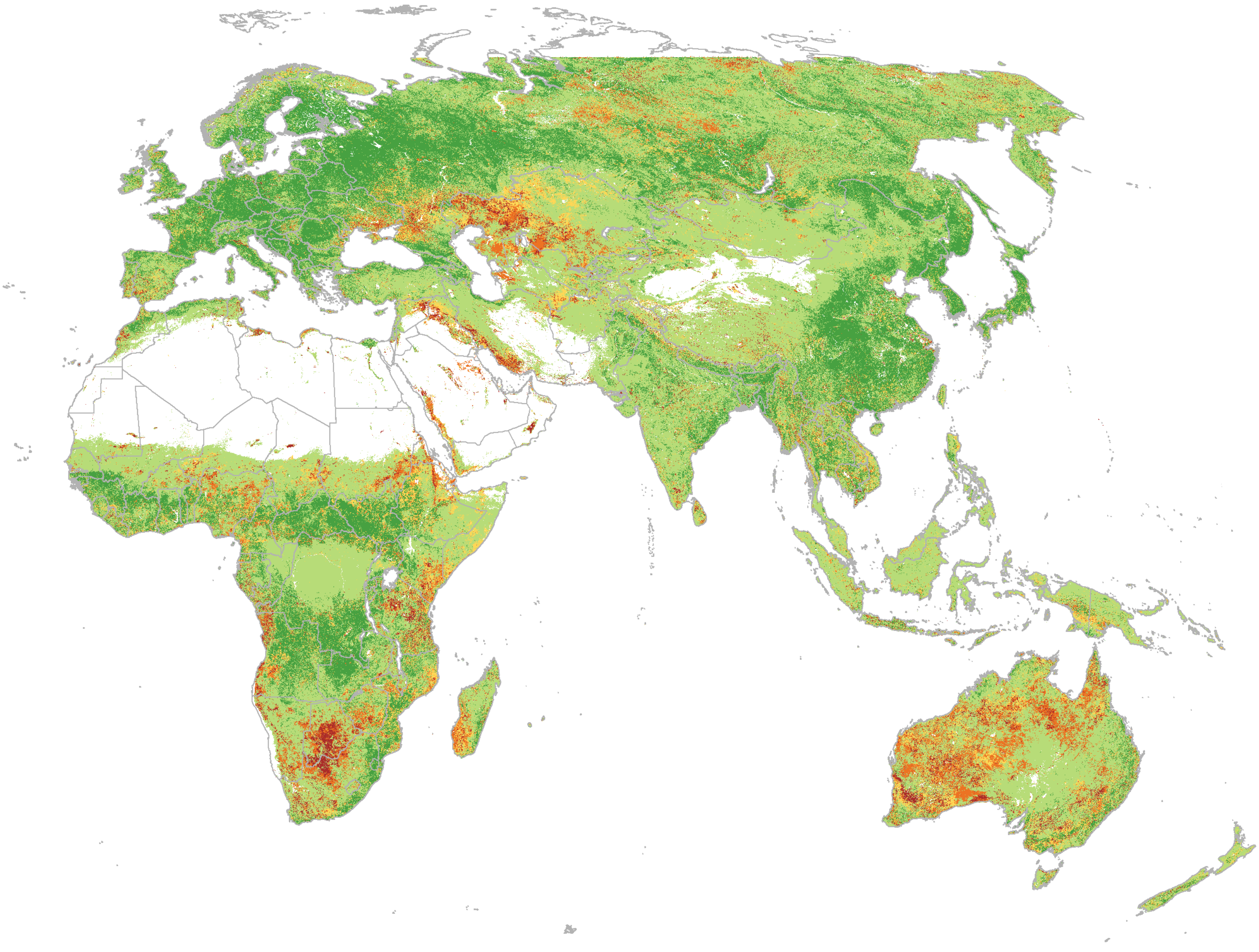


Figure 4.3: Global spatial extent of LPD classes under selected LC/LU categories

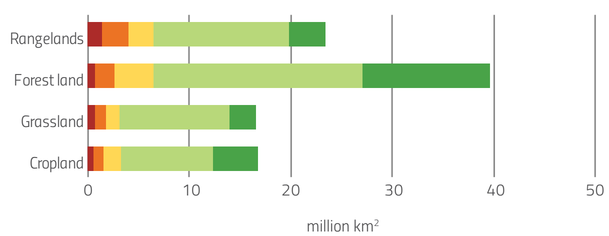


Figure 4.4: Per cent distribution of LPD classes for 4 major LC/LU categories at global level

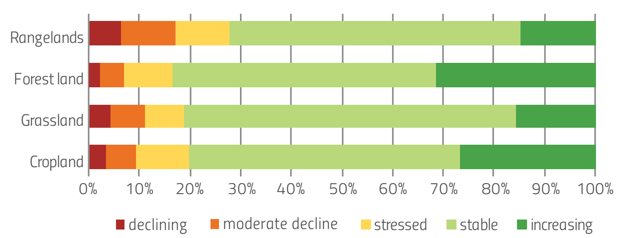
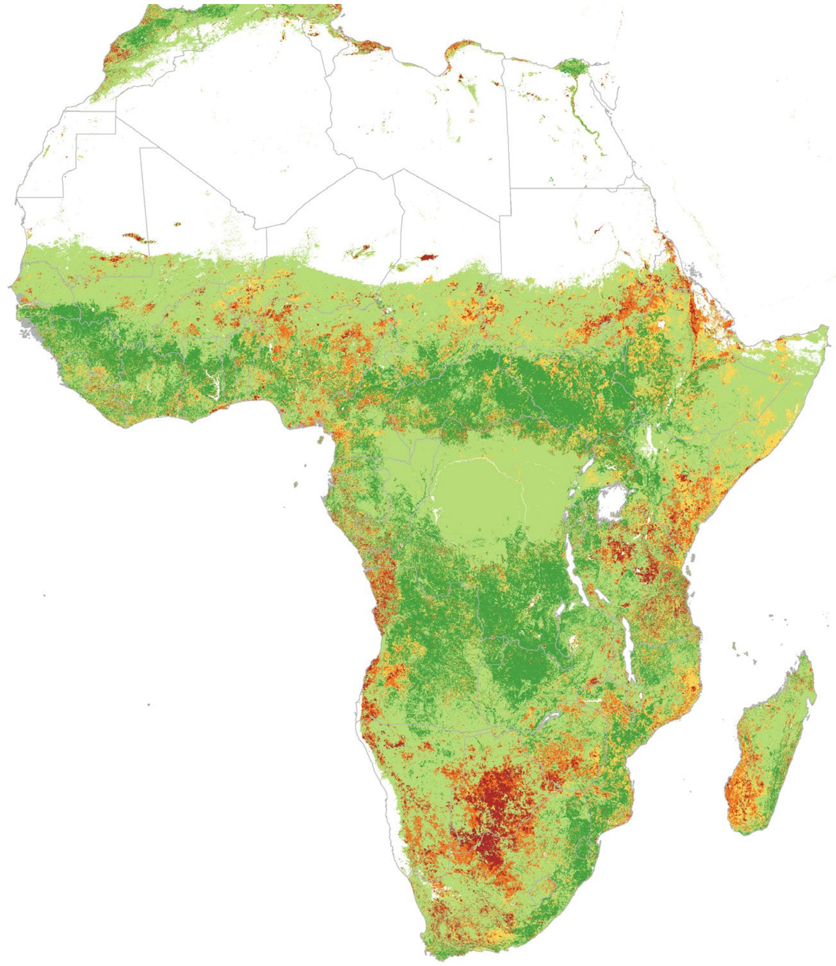


Figure 4.5:
Land Productivity Dynamics map 1999 to 2013 for Africa showing 5 classes of persistent land productivity trajectories during the observation period



Key

- Declining
- Moderate decline
- Stressed
- Stable
- Increasing

Figure 4.6:
Spatial extent of LPD classes in Africa under selected LC/LU categories

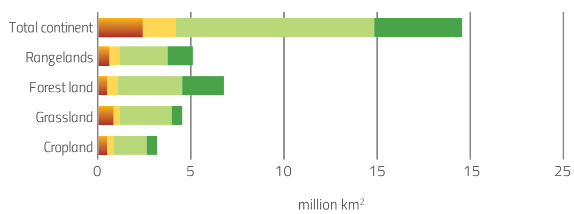
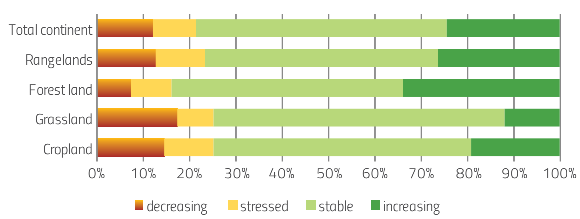


Figure 4.7:
Per cent distribution of LPD classes for 4 major LC/LU categories in Africa



In **Africa**, approximately 16 per cent of the vegetated land surface is assigned as cropland, of which about 23-24 per cent shows signs of decreasing or unstable land productivity. African rangelands and grasslands, an essential resource for livestock production and livelihoods of large parts of the population, are experiencing productivity declines similar to that of affected croplands. The overall expansion of declining land productivity appears to be above global averages and exceeds the extent of areas experiencing increasing productivity or recovery, especially in the croplands and grasslands.

These critically unbalanced land productivity trends in African cropland and grasslands are particularly concerning given expected population growth. Forests in Africa still cover about 7 million km^2, 16 per cent affected by decreasing or stressed land productivity and 34 per cent of the tree covered land showing signs of increasing productivity. This may be a positive signal that programmes stimulating forest protection, afforestation, and tree planting for sustainable agro- and silvo-pastoral land use systems have made some progress in the last 10 to 15 years.

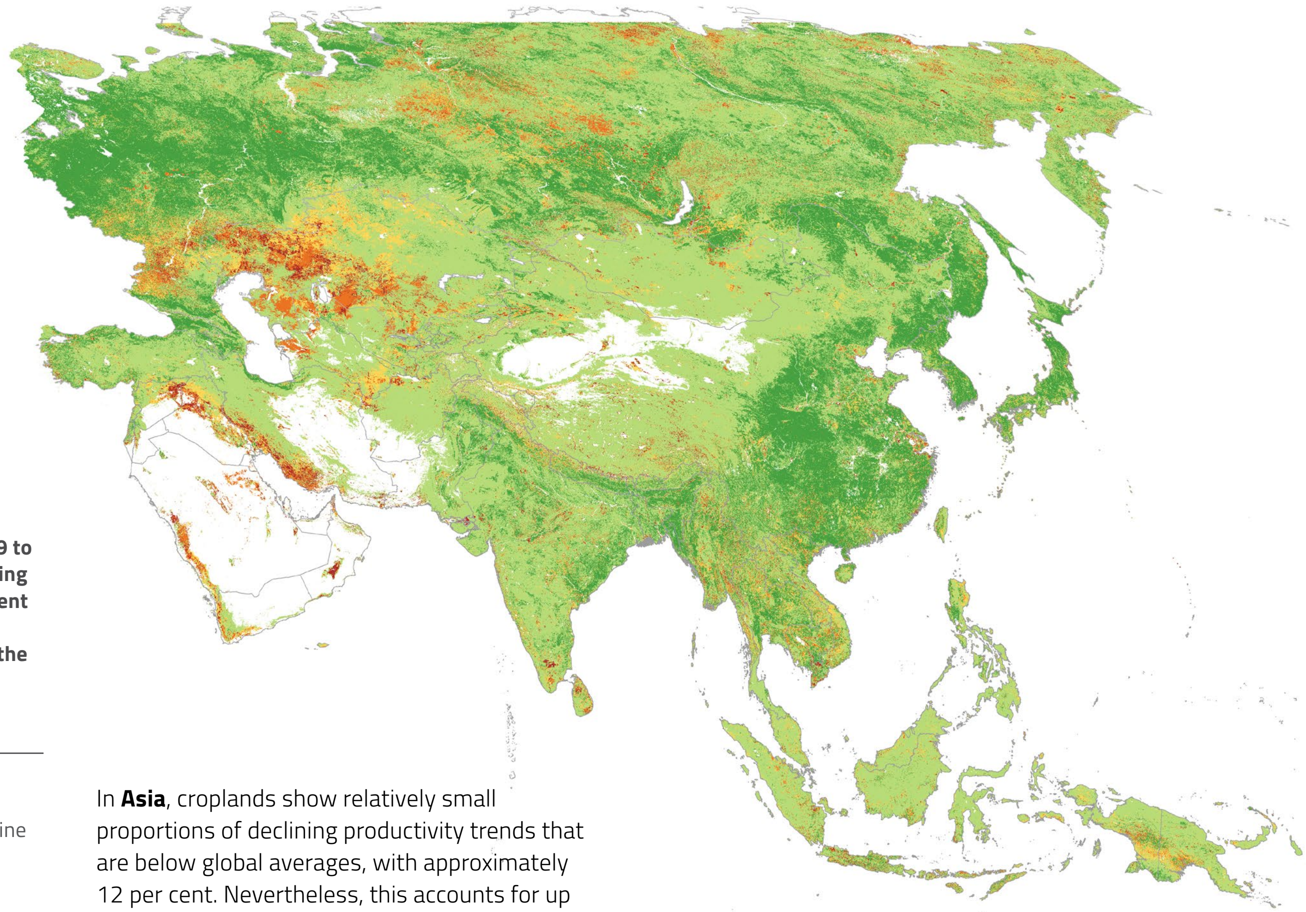


Figure 4.8:
Land Productivity Dynamics map 1999 to 2013 for Asia showing 5 classes of persistent land productivity trajectories during the observation period

Key

- Declining
- Moderate decline
- Stressed
- Stable
- Increasing

In **Asia**, croplands show relatively small proportions of declining productivity trends that are below global averages, with approximately 12 per cent. Nevertheless, this accounts for up to 1 million km² of croplands that appear to be affected. Some critical pressures potentially leading to decreasing land productivity at the ecosystem level may be masked by effects of the relatively recent changes towards more input-intensive agriculture in many Asian countries. Areas where accumulation of anthropogenic pressures exist are identified on the convergence of evidence maps below.

Figure 4.9:
Spatial extent of LPD classes in Asia under selected LC/LU categories

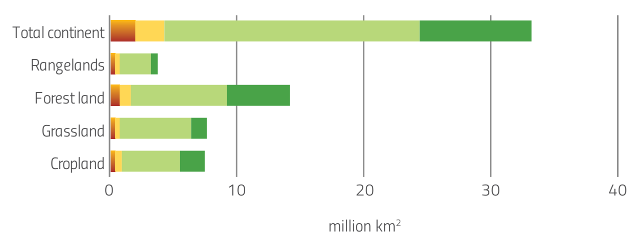
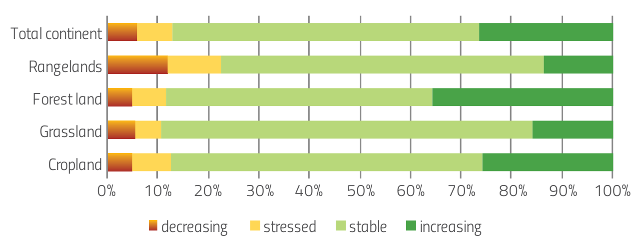


Figure 4.10:
Per cent distribution of LPD classes for 4 major LC/LU categories in Asia



Rangelands are proportionally the most affected by declining land productivity trends (up to 20 per cent), greater than the proportion of increasing or recovering land productivity. This is most apparent in the belt of decreasing land productivity trends across the Central Asian region, which has undergone dramatic changes in land use after the foundation of independent states during the 1990s. In many cases, more sedentary forms of livestock production have led to overstocking and overgrazing of vulnerable rangeland systems while at the same time large-scale collective arable and livestock land use systems were abandoned. About 12 per cent of Asian forest lands show signs of persistent decline or instability in primary productivity while more than 35 per cent experience increasing trends, i.e., recovery. This is evident in around 2 million km², with large patches of cover emerging in Siberia and complex patterns of decreasing and increasing productivity in south and southeast Asia, which reflect the high dynamics of forest transformations in these regions.

Figure 4.11: Land Productivity Dynamics map 1999 to 2013 for Australia/Oceania showing 5 classes of persistent land productivity trajectories during the observation period

Key

- Declining
- Moderate decline
- Stressed
- Stable
- Increasing

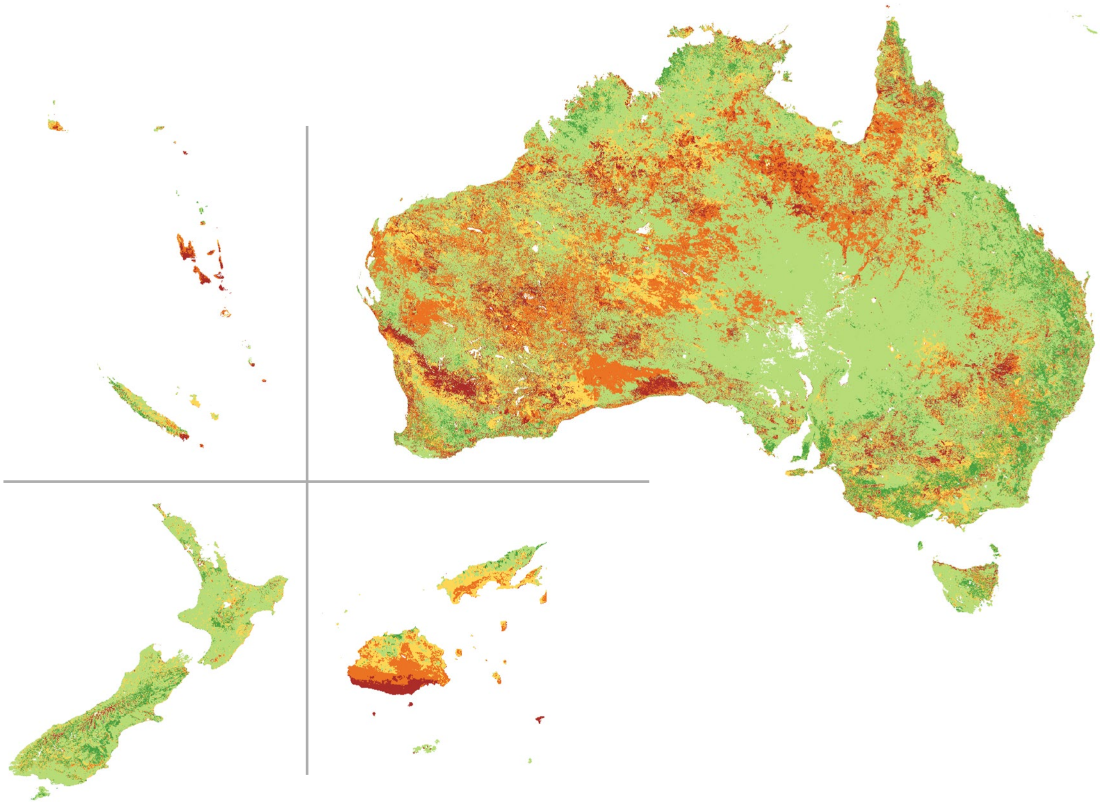


Figure 4.12: Spatial extent of LPD classes in Australia/Oceania under selected LC/LU categories

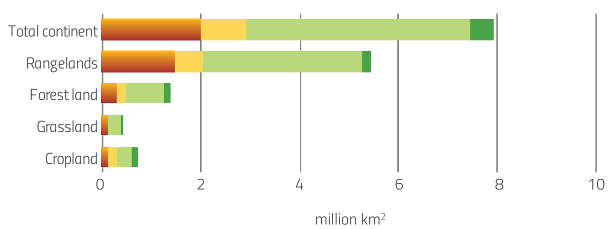
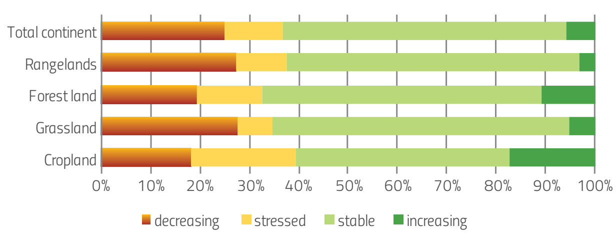


Figure 4.13: Per cent distribution of LPD classes for 4 major LC/LU categories in Australia/Oceania



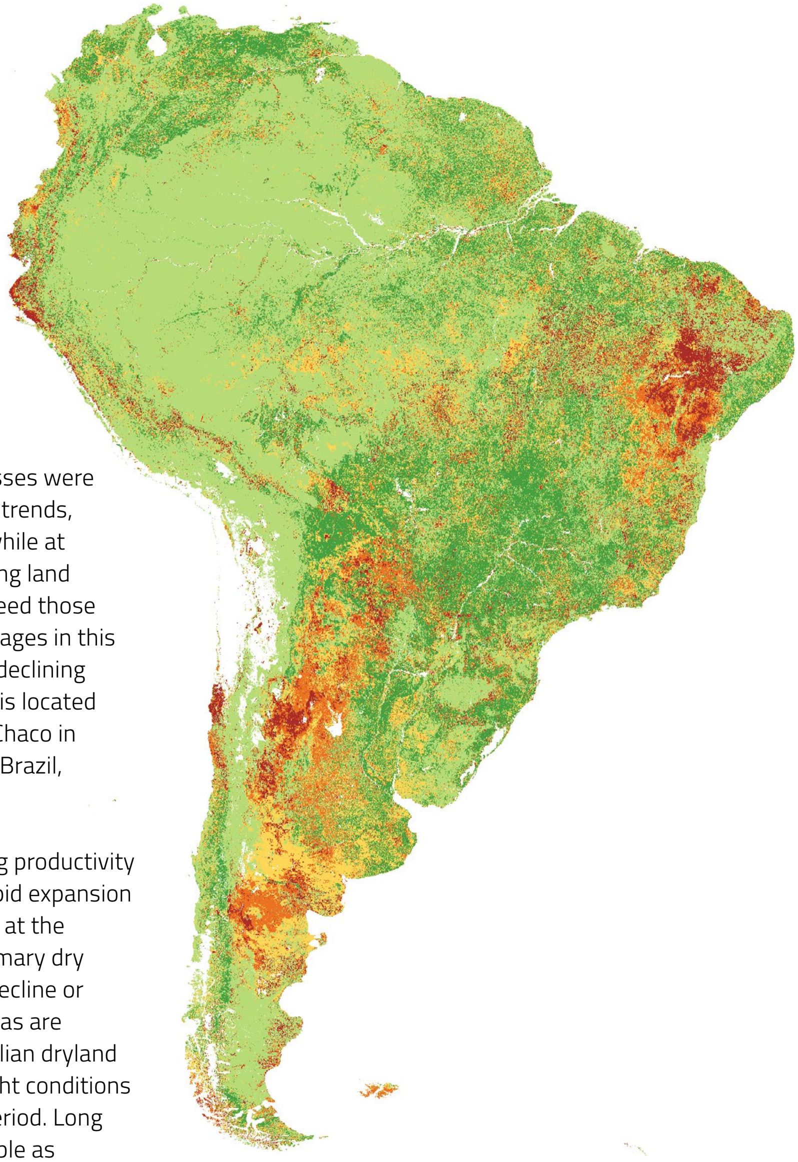
Globally, **Australia**/**Oceania** shows the largest proportion of area under decreasing land productivity trends, which total approximately 37 per cent of vegetated land, clearly above the global average. This primarily reflects the situation on the Australian continent and holds throughout all mainland cover/land use classes; in all classes, areas with decreasing land productivity trends exceed those with increasing trends. This is a result of the specific climate conditions and recurrent drought situation of the Australian continental land mass during the observation period 1999-2013.

These trends are clearly visible on the map depicting an increase in affected areas along a pronounced gradient from East to West following the general aridity gradient of Australia. The northernmost part of Queensland falling in the humid tropical zone is also apparently affected by declining trends of primary productivity, which may be decoupled from the general gradient of aridity and drought. There is evidence that land cover has recovered after significant periods of rainfall in 2015.[6]

Figure 4.14: Land Productivity Dynamics map 1999 to 2013 for South America showing 5 classes of persistent land productivity trajectories during the observation period

Key

- Declining
- Moderate decline
- Stressed
- Stable
- Increasing



In **South America,** all of the LC/LU classes were affected by negative land productivity trends, considerably above global averages, while at the same time the areas with increasing land productivity areas typically do not exceed those declining, remaining below global averages in this regard. One of the main anomalies of declining productivity trends on the global map is located in the vast semi-arid plain of the Dry Chaco in the border region between Argentina, Brazil, and Paraguay.

The spatial distribution of the declining productivity areas generally correlates with the rapid expansion of crop production and cattle ranching at the expense of ecologically high-value primary dry forests. The patterns of productivity decline or instability in the tropical rainforest areas are more diffuse. The north-eastern Brazilian dryland area shows the effect of severe drought conditions towards the end of the observation period. Long term effects of this anomaly, now visible as declining productivity, cannot be estimated yet.

Figure 4.15: Spatial extent of LPD classes in South America under selected LC/LU categories

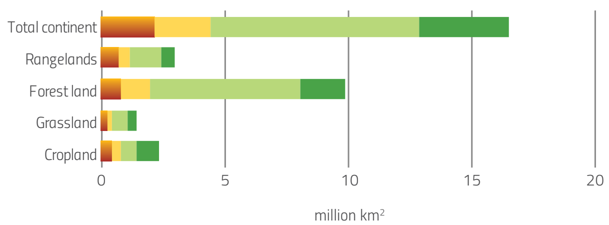
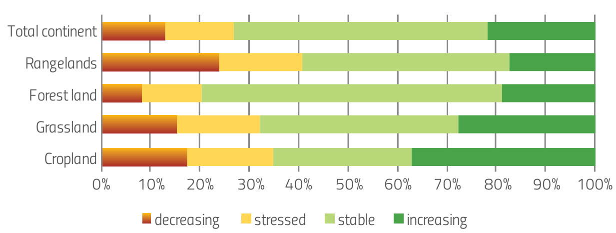


Figure 4.16: Per cent distribution of LPD classes for 4 major LC/LU categories in South America



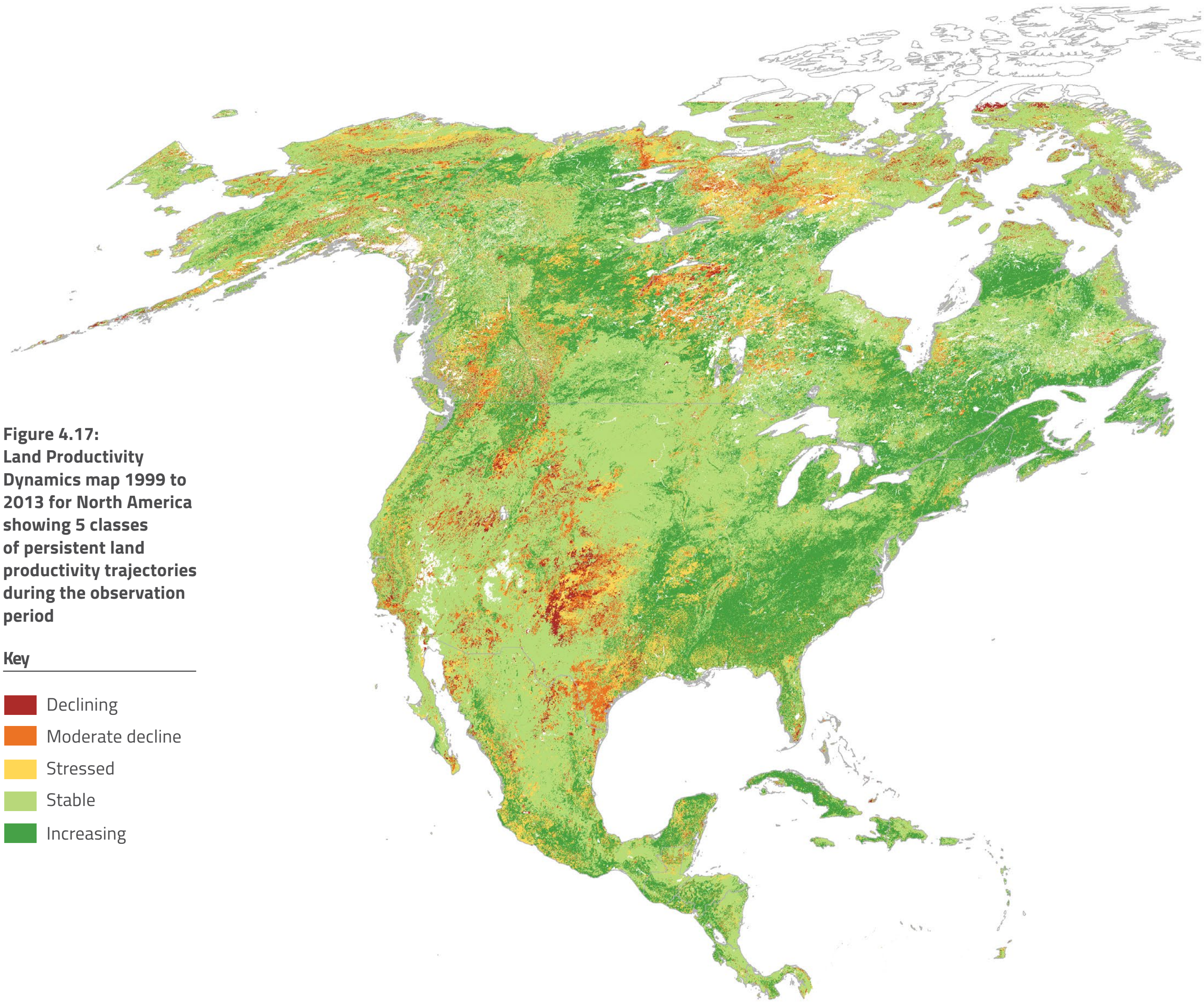


Figure 4.17: Land Productivity Dynamics map 1999 to 2013 for North America showing 5 classes of persistent land productivity trajectories during the observation period

Key

- Declining
- Moderate decline
- Stressed
- Stable
- Increasing

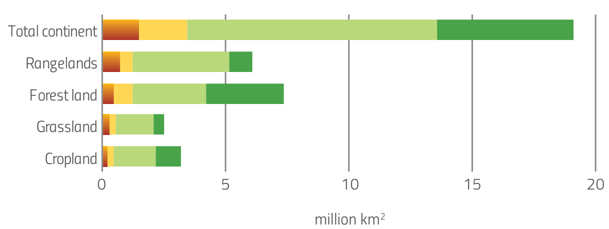


Figure 4.18: Spatial extent of LPD classes in North America under selected LC/LU categories

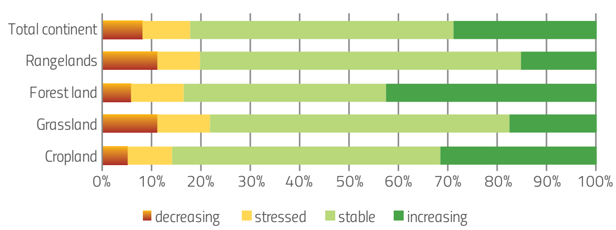


Figure 4.19: Per cent distribution of LPD classes for 4 major LC/LU categories in North America

In **North America**, declining productivity trends within the 4 LC/LU types are typically similar to or below global averages. Grasslands and rangelands appear to be the most affected where the extent of area with declining trends are estimated at 20-22 per cent in both classes, clearly greater than areas showing signs of increasing or recovering primary productivity.

Only 13 per cent of the croplands are characterized by declining trends or persistent instability, nevertheless approximately 500,000 km². The most prominent declining anomaly falls in the southern part of the semi-arid Great Plains in the border region between New Mexico, Texas, Oklahoma, and Kansas, where large areas are dedicated to input-intense, irrigated crops (e.g., cotton in northwest Texas) that depend primarily on fossil groundwater.

Figure 4.20: Land Productivity Dynamics map 1999 to 2013 for Europe showing 5 classes of persistent land productivity trajectories during the observation period

Key

- Declining
- Moderate decline
- Stressed
- Stable
- Increasing

In **Europe**, declining productivity trends within the LC/LU classes are typically below global averages. However, being the continent with the relatively highest proportion of croplands, European farmland is proportionally the most affected when compared to the other land cover types considered. An estimated 18 per cent of the croplands may be subject to significant drivers leading to productivity declines, especially in the south of Eastern Europe where, similar to Central Asia, large-scale collective arable and livestock land use systems have been substantially transformed as a result of the economic crisis.

Some hotspots of declining land productivity in Western Europe, especially in the Mediterranean region, are characterized by agricultural intensification often intermingled with the rapid expansion of infrastructure and built-up areas into croplands. In many European croplands, the impacts of land and soil degradation on productivity may be masked by the sustained capacity to compensate for losses in soil fertility but at a significant cost to biodiversity and quality of freshwater resources.

When disaggregated and viewed by broad land cover/land use categories, the LPD allows for the identification of meaningful patterns of land transformations occurring at continental to national levels. Thus, LPD provides a first approximation and comparison of different regions or even countries according to their capacity to sustain primary productivity in land use systems. In order to substantiate this type of information in the context of underlying causes and drivers of land degradation, the WAD promotes the concept of convergence of evidence.

Figure 4.21: Spatial extent of LPD classes in Europe under selected LC/LU categories

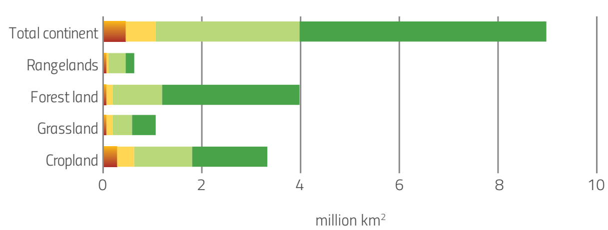
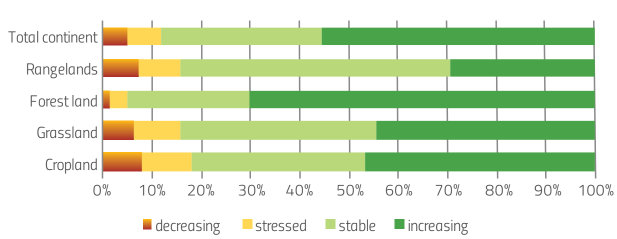


Figure 4.22: Per cent distribution of LPD classes for 4 major LC/LU categories in Europe



Box 4.2: Developing global maps on convergence of evidence

To accommodate the complex interactions and dynamics that trigger land cover/use change, the World Atlas of Desertification (WAD) relies on the concept of "convergence of evidence": when multiple sources of evidence are in agreement, strong conclusions can be drawn even when none of the individual sources of evidence is significant on its own. Convergence maps are compiled by combining global datasets on key processes, using a reference period of 15-20 years. Combinations are made without prior assumptions in the absence of exact knowledge of land change processes at variable locations. Patterns indicate areas where substantial stress on land resource is to be expected.[8]

The resulting convergence maps demonstrate one approach by which these data can be combined, viewed, and analyzed for multiple land use/land cover strata. Convergence is undertaken in two steps: (i) a global land cover/use stratification is compiled representing shares of cropland and rangeland,[9] and tree cover in 2007[10] (other preliminary stratifications could be based on climate, soil, or ecosystem services, depending on the available data); and is partitioned into classes (unsupervised classification); and (ii) for each class, zonal or class statistics are calculated for each dataset or potential issue. The issues are reclassified as being above or below a statistically derived threshold, taking into account their expected effect in terms of land degradation (positive or negative). The resulting layers have values of 0 (no stress) and 1 (potential stress), and are summed together to provide the number of co-existing issues at any geographical position. The method is flexible and can be applied at all scales. Based on the literature,[11] datasets relating to the various issues have been grouped as follows:

Related to the human environment
- changing population densities
- migration and urban sprawl

Related to land use
- agriculture expansion
- agriculture industrialization
- livestock density and practices
- deforestation, fragmentation, and fires

Related to the natural environment
- land productivity
- water availability and use
- soil condition
- changed aridity and drought

Global datasets are now available for most of these issues and the WAD analysis illustrates convergence based on 13 consistent and geographically continuous datasets on socio-economic and biophysical issues. As land degradation in itself is a process, dynamic datasets are ideally to be used, but only a limited number currently provide consistent and harmonized global coverage:

Dynamic data layers:
- Population change (2000-2015)
- Built-up area change (2000-2014)
- Land biomass productivity dynamics (1999-2013)
- Tree loss (2000-2014)

State data layers:
- Population density in 2015
- Gross national income per capita in 2015
- Area equipped for irrigation (2005)
- Nitrogen balance on landscape level (2000)
- Livestock density (2006)
- Fire occurrence (during period 2000 to 2013)
- High water stress (2010)
- Aridity (aridity index 1981 to 2000)
- Climate and vegetation trend anomalies (1982 to 2011)

Global maps on convergence of key issues

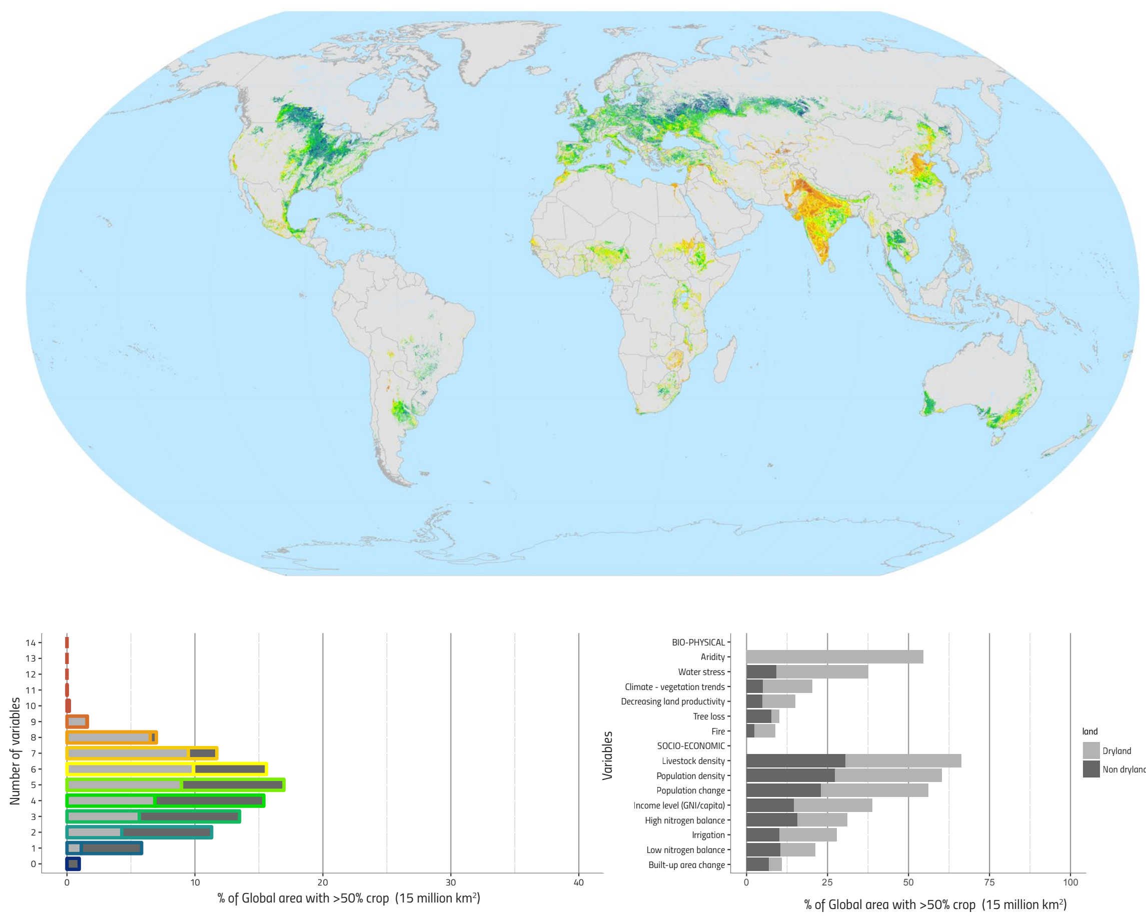
Together with land use and environmental histories, a range of variables influences the occurrence and rate of land degradation, such as interest rates, livestock prices, and agricultural support policies. The progression of this change is guided by slow or fast variables.[7] However, both the pathways towards degradation and the variable interactions that steer them are numerous, volatile, and generally unknown, making it difficult to model land degradation at a global scale. The physically-measurable outcomes that can be observed through the use of satellite data, such as LPD or ground observations (e.g., decreases in biomass, biodiversity, soil organic carbon, or increases in soil erosion or undesirable plant species), cannot be interpreted meaningfully without an understanding of the social and economic conditions at all scales considered.

Maps of the convergence of evidence show where human-environment land change processes are impacting croplands (Figure 4.23) and rangelands (Figure 4.24). They show distinct patterns suggesting areas under different levels of pressure; however, the higher or lower number of concurring issues does not necessarily imply a higher or lower impact or outcome in terms of land degradation. In cropland and rangeland where more potential pressures are present, more attention is generally required in terms of land management and further monitoring of the situation, even though the analysis does not mean that land degradation is currently underway everywhere. As much as possible, interpretation needs to take into account ancillary contextual knowledge and evidence. Paper maps are limited and cannot represent the full depth of data, therefore a digital portal is being developed that will allow for more complete data and information query.

The state of land in the croplands

The analysis shows that approximately 9 per cent (or 1.38 million km^2) of the global area with more than 50 per cent of cropland suffers from potential pressure from 8 to 143 coinciding issues that trigger land change processes that are relevant to land degradation, with practically all occurring on drylands. When a number of related cropland issues combine with a decline in land productivity, this suggests that an observable transformation has happened or is underway. This is observed in 2 per cent of the area (0.3 million km^2) and can be a good proxy for ongoing degradation in those areas. More than half or approximately 60 per cent (8.9 million km^2) of the global area with more than 50 per cent of cropland experiences potential pressure from 4 to 7 concurrent issues that trigger land change processes that are relevant to land degradation, which are evenly distributed over drylands and non-drylands. On 12 per cent of the area (12.4 million km^2), they concur with signs of decline in the land productivity. Just 2 per cent of global cropland, all on non-drylands, does not face any pressure from the 13 issues assessed. In areas where cropland covers 10 to 50% of the land, the proportion of the land that faces more than 8 of the 13 concurrent issues drops to 3 per cent (or 0.6 million km^2) while 69 per cent (11.7 km^2) of the area sustains 4 to 7 coinciding issues.

Figure 4.23: Convergence of evidence of 14 anthropogenic induced and/or biophysical land change processes or issues on the cropland area



Key

Number of concurrent variables

0	7
1	8
2	9
3	10
4	11
5	12
6	13

The main cropland areas facing multiple pressures include, but are not limited to:

- Asia including Indian and Pakistani croplands, agricultural expansion areas in northwest China, and hotspots in the Philippines and Java;
- southeast Australia and small areas in southwest Australia;
- sub-Saharan Africa including Burkina Faso, northern Nigeria, eastern Sudan, south Kenya, Malawi, and Zimbabwe;
- North Africa and the Middle East including northern Morocco, Egyptian Nile area, the Tigris-Euphrates region;
- intense agricultural areas in the Mediterranean and central Europe;
- Central Asia around the Aral sea and croplands in eastern Kazakhstan, Uzbekistan, Kyrgyzstan, and Tajikistan;
- hotspots in Latin America and the Caribbean, including the northeast Brazilian drylands, agriculture expansion areas in the Argentinean Chaco area, central Chile, southern Mexican croplands, and parts of Cuba and Haiti; and
- irrigated areas in the western USA.

The state of land in the rangelands

Approximately 5 per cent (0.5 million km^2) of global rangeland suffers from potential pressure from 8 to 13 concurrent issues that trigger land change processes that are relevant to land degradation, with practically all occurring on drylands. Approximately 52 per cent (13.1 million km^2) of global rangeland experiences potential pressure from 5 to 8 concurrent issues that trigger land change processes that are relevant to land degradation, more than two-thirds of this is on drylands. Again, only 2 per cent of rangelands, all on non-drylands, do not face pressures from any of these issues.

The main rangeland areas facing multiple pressures include, but are not limited to: India; Central Asia; China's Inner Mongolia area; areas of eastern Australia; the fringes of the Sahel; eastern Africa and parts of southern Africa; southwest Madagascar; north-central Chile and southern Ecuador; central Mexico; and south-central USA.

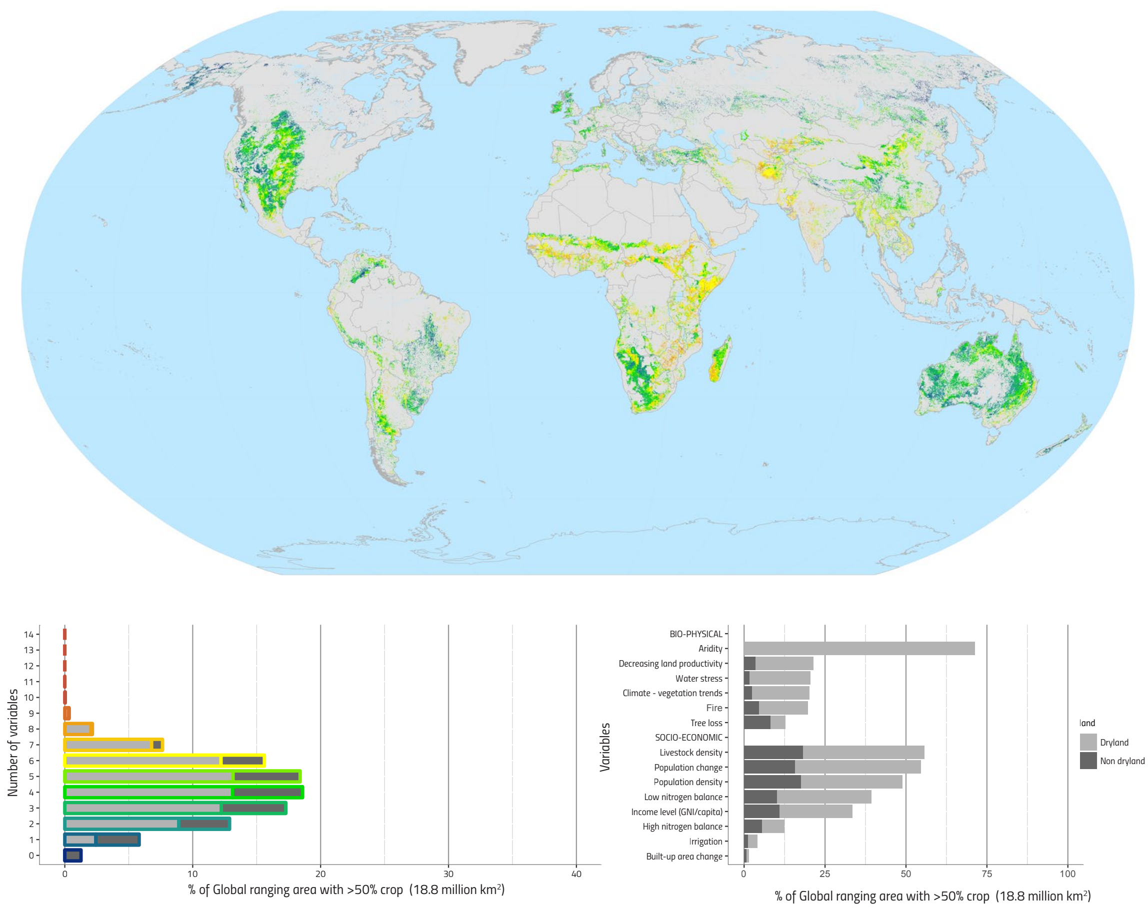


Figure 4.24: Convergence of evidence of 14 anthropogenic induced and/or biophysical land change processes or issues on the rangeland area

Key

Number of concurrent variables

0 1 2 3 4 5 6 7 8 9 10 11 12 13

Regional and national highlights

Middle East and Central Asia A fundamental issue in this area is the scarcity and management of water resources. Over 70 per cent of the global net permanent surface water loss occurred in the Middle East and Central Asia.[12] Irrigation demands combined with intensive agriculture pose unsustainable pressure on the land resource. Livestock numbers remain high and productive pastureland is reduced or fragmented by population increase and agriculture expansion.[13]

India Since the 1700s, high population density has been a major pressure throughout India.[14] India hosts 18 per cent of the world population and 15 per cent of its livestock, but has only 2.4 per cent of the world's land area.[15] Since the 1960s, the portion of cropland available per person decreased three-fold, to 0.12 ha per person; 53 per cent of India is farmland, using an average of 157 kg/ha of fertilizer with more than 36 per cent under irrigation; annual freshwater withdrawal is one of the highest globally at 761 billion m^3. This suggests a significant pressure on cropland. Land productivity dynamics, however, show a stable state during the last 15 years. Some areas, but not all, overlap with the detailed national assessment of ongoing degradation that is based on identification of biophysical processes observed by satellite data.[16]

China Biomass land productivity status, observed by satellite from 1999-2014, is mapped as stable or increasing over most of China. However, in the Beijing-Hebei-Shandong area, dense population combined with intensive, mostly irrigated, agriculture is leading to water stress and poor land quality. The introduction of agriculture in marginal lands traditionally used for grazing sheep and cattle has caused erodible soil surfaces, a process known as "sandification," in large areas of northern China, especially Inner Mongolia and western Xinjiang.[17] In Inner Mongolia, government policies aiming to settle nomadic pastoralists and privatize collective grasslands have increased pressure on rangeland resulting in large-scale degradation.[18] From 1980, the privatization of farmland and introduction of state incentives increased productivity in northern China, largely driven by groundwater irrigation and fertilizer use. Together with legal access regulations and restrictions, the expansion of cropland into environmentally-sensitive rangelands has been slowed, and moving dunes and sand sheets partially stabilized. However, this has been accompanied by the rapid depletion of groundwater resources where smallholder irrigation systems have increasingly been replaced by large-scale pivot irrigation schemes. These schemes tend to lower water tables and today many lakes and wetlands have disappeared as seen in satellite images.

Sahel In the past 50 years, an increase in sedentary human presence and activities, together with climatic variability, has caused major environmental changes in the semi-arid Sahelian zone. The accumulation of land change processes over vast stretches of the Sahel's croplands is significant, considering that water resources are limited,[19] population is still growing, domestic food demands are increasing, and cropland resources are scarce and managed by smallholders with limited means and income. Cultivation is mainly rainfed (except in parts of Ethiopia) and, in general, on rather poor soils with medium or low soil organic matter. Smallholder systems are mainly low-input farming systems mixed with high livestock densities and increasing pressure from a growing sedentary population.

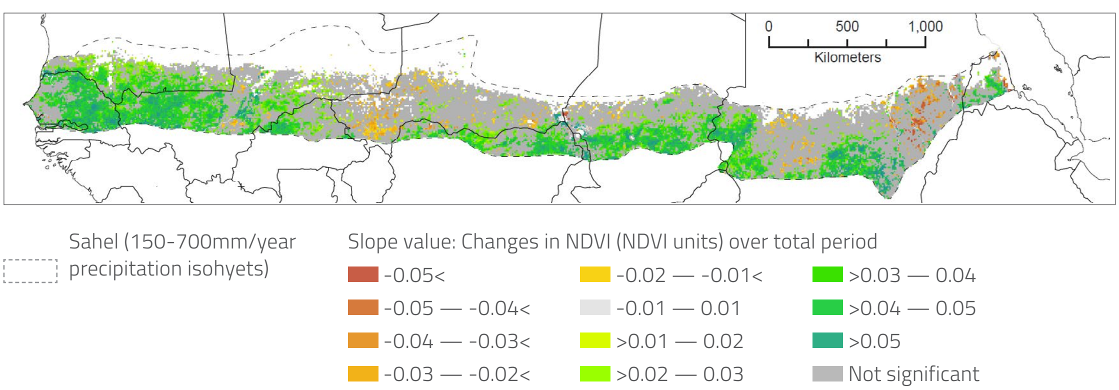


Figure 4.25: Recent Earth Observation studies show a positive trend in rainfall and vegetation index over the last decades for the majority of the Sahel – known as the re-greening of the Sahel.[24] This has been interpreted as an increase in biomass, and contradicts prevailing narratives of widespread degradation caused by human overuse and climate change. Yet observable areas of decreasing productivity, e.g. in Niger and Sudan, indicate that the re-greening process is not uniform across the entire Sahel.

The degradation of arable lands has been a major concern for livelihoods and food security in the Sahel, but despite decades of intensive research on human–environmental systems, there is no overall consensus about the severity of land degradation.[20] Earth observation data suggest an overall increase in vegetation greenness that can be confirmed by ground observations. However, it remains unclear if the observed positive trends provide an environmental improvement with positive effects on people's livelihoods.[21] While there is no widespread decrease in biomass productivity over the last 15 years, pockets of biomass decline can be seen.[22] Long-term assessments of biodiversity at finer scales highlight in some cases a negative trend in species diversity.[23] The Sahel underlines the need to monitor land dynamics by combining long-term information from Earth observation with in situ observations that improve the understanding of the site specific impact of changes in land use and observed land cover trends

Brazil/Argentina Input-intensive farming schemes on prime quality land, using large quantities of water and fertilizer, for short-term economic gain put land resources at risk by depleting and/or polluting soil and water.[25,26] Deforestation with subsequent irrigated farming is, for instance, a threat to land resources in the vast Chaco area in Argentina, Paraguay, and Bolivia, where the native vegetation, particularly dry forests, is undergoing one of the highest deforestation rates in the world (see Figure 4.26). This is attributed to rapid agricultural expansion and intensification, especially for crop production (e.g., soy, maize) and cattle ranching.[27]

Land transformations driven by cultivation have resulted in significant losses of biodiversity, landscape fragmentation, and a reduction in essential ecosystem services,[28] which will likely lead to further land degradation.[29] Monitoring is essential to identify biophysical, social, political, and economic drivers of changes and to develop land use planning and management policies that mitigate or reverse land degradation trends.

As in other countries where tropical and subtropical climate predominates, agriculture in Brazil was initially developed using traditional inversion tillage, based on farmers' experiences acquired in temperate regions of the Northern Hemisphere.[30] In this climate, the potential for land degradation arises from a combination of soils highly vulnerable to erosion, high pressure on land use, and intense rainfall when soils are most susceptible to erosion.[31] Annual soil losses were estimated at 0.8 billion tons in areas under crops and pastures.[32] Off-farm costs of erosion were estimated at USD 1.3 billion.[33]

United States and Europe Input-intensive food production systems are driven by mechanization and high fertilizer applications that have made farmland dependent on continuous inputs of nutrients to ensure high yields. This is a risky balancing act, but favorable economic situations have so far made it possible to keep the land resource mostly in equilibrium. Local farming practices often result in water and wind erosion and other degradation phenomena that, however, cannot be captured universally at the scale of analysis with the current datasets available.

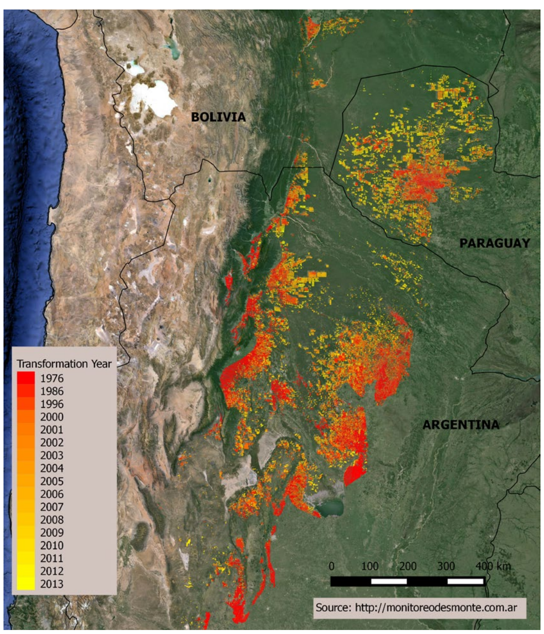


Figure 4.26: Between 1976 and 2012, 20 per cent of the whole ecoregion has been transformed, with an exponentially growing annual transformation rate in Paraguay. Areas colored from red (transformed in 1976) to yellow (transformed in 2013) show the extent and rapid pace of transformation of Dry Chaco into crops or pastures.

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WHAT WE STAND TO LOSE: THE IMPORTANCE OF ECOSYSTEM SERVICES

Land condition, including its productivity, plays a key role in the potential of any given area to deliver multiple goods and services; it is clear that declines in LPD directly undermine their quantity and quality. The key role that a healthy land base plays in the delivery of ecosystem services is a fundamental tenet of the *Global Land Outlook*, yet the preceding analysis supports other studies that suggest that the quality of ecosystem services is in decline. To put this into perspective, in this section, we outline the main terrestrial ecosystem services, many of which we take for granted and which are now threatened by land degradation and/or declines in productivity.

Ecosystem services are the goods and services produced by or in conjunction with natural capital that directly and indirectly benefit humans. Land degradation and the subsequent loss of biodiversity leads to a reduction in many vital ecosystem services and thus greater food and water insecurity.[34] The impacts of land degradation can be seen in lower crop yields, the reduced ability of agricultural systems to resist exotic pests and pathogens,[35] and a general decline in the resilience of ecosystem functions.[36] This has negative consequences for everyone, but generally impacts the vulnerable and poorest people most severely.[37]

Natural ecosystems are increasingly recognized as important places that promote physical and mental health and wellbeing.

Ecosystem services are defined and categorized in several ways. For example, the Millennium Ecosystem Assessment suggests a simple typology to summarize the various services from natural capital, dividing them into supporting, provisioning, regulating, and cultural services.[38] There are countless ecosystem services associated with thousands of species and ecological interactions. Some are only known to a small group of people who recognize their value, such as the medicinal benefits of a particular plant. As our societies become more homogeneous, much of this traditional ecological knowledge is being lost. Other ecosystem values are much more widely recognized, affecting whole communities, cities, countries, or acting at a global level. Some of the key land-based ecosystem services affected by land degradation are:

- Food security
- Water security
- Physical and mental health
- Disaster risk reduction
- Mitigating and adapting to climate change
- Cultural values
- Tourism including particularly ecotourism
- Raw materials

Many of these services are discussed in more detail in Part Two of this *Outlook* (e.g., food, water, energy, and climate) and only touched on briefly here; others are discussed in slightly greater detail. The concept of actively managing land resources to ensure the delivery of ecosystem services (i.e., benefits to humans) is increasingly being recognized, often under the umbrella term "nature-based solutions."[39]

1. Food security

Agriculture is dependent on a range of ecosystem services (see Chapter 7): supporting services like nutrient cycling and soil formation; and regulating services such as water purification, atmospheric regulation, and pollination.[40] In addition, an estimated 150 million people rely directly on wild harvested food, including plants, fodder, game, and fish.[41] In southern Africa, the value of wild resource consumption was estimated at USD 800 million per year in 2005.[42] Ecosystem services contribute directly to food and nutritional security. Insects and birds provide pollination services that are vital for agriculture and currently estimated at having a total economic value of USD 160 billion annually,[43] albeit under threat.[44]

A wide range of genetic variation is needed for crop breeding to help species adapt to changing environmental conditions, including new pests and diseases. Agronomists draw on two sources for the genetic materials to help develop crop resilience and adaptability: the variation that exists in traditional varieties of crops, known as landraces, and that from closely-related wild species, known as *crop wild relatives* (CWR). Given the multitude of crop threats, both landraces and CWR are vital resources that will help ensure future food security.[45] It was estimated some time ago that the introduction of new genes from CWRs contributed approximately USD 20 billion towards increased crop yields per year in the US alone and USD 115 billion worldwide.[46] Yet these values are often under-recognized and many centers of crop diversity – places where a disproportionate number of the world's crop species originated – are poorly conserved.[47]

2. Water security

Resilient, functioning ecosystems play a critical role in water security, maintaining the quality and in some cases the quantity of water as well as regulating flows. Natural vegetation and healthy soil can help maintain water quality and in some circumstances increase the quantity of water available (see Chapter 8).[48] Today most of the world's population lives downstream of forested watersheds:[49] these offer higher quality water supply than watersheds under alternative land uses, which tend to be more disturbed, have increased soil erosion, and are likely polluted by pesticides, fertilizers, or toxic waste.[50]

Some ecosystems, such as cloud forests and the *paramos* vegetation of central South America absorb water droplets from clouds and increase net water flow. For example, the cloud forests of La Tigra National Park in Honduras provide more than 40 per cent of the water supply to Tegucigalpa, and in Ecuador 80 per cent of Quito's population receive drinking water from two protected areas.[51] Over a third of the world's 100 largest cities draw a significant proportion of their drinking water from protected forests.[52] In some cases, the effects may be felt hundreds or thousands of miles away from the ecosystem supplying the service. Water vapor from the Amazon travels thousands of miles south to provide rainfall for some of the richest agricultural area on the continent, which without these so-called "flying rivers" would be far more arid.[53]

3. Physical and mental health

Natural ecosystems are increasingly recognized as important places that promote physical and mental health and well-being. Much of modern medicine is derived from or replicated synthetically from natural sources. Locally-collected traditional medicines are a major resource for primary health care needs in Asia, Latin America, and Africa,[54] with more species of medicinal plants harvested than any other natural product.[55] India and China harvest 90 per cent and 80 per cent respectively of their medicinal plants from the wild.[56] Natural medicines are traded internationally, with a market estimated at over USD 50 billion annually.[57] Wild species also provide raw material for pharmaceutical development; forests are particularly important sources of medicinal compounds[58] and some companies pay for the right to explore in protected areas or other high biodiversity regions.

More fundamentally, spending time in nature is recognized as a critical factor in maintaining mental and physical health. It has been calculated that, in the United States, every USD 1 invested in physical activity leads to a saving in medical costs of USD 3.2,[59] and people with access to attractive public spaces are likely to walk more.[60] A growing number of countries are encouraging walkers, runners, and cyclists to use nature reserves as places to exercise, also known as the green gym concept. In Scotland, the health benefits of woodlands have been estimated at between USD 17.6- 23.6 million per year (at 2006 prices) by helping to avoid premature deaths and morbidity through increased physical exercise, reduced air pollution, savings in mental health costs, and reduced absence from work.[61] Natural environments help people recuperate from mental fatigue and can enhance the ability to recover from illness and injury, and cope with stress.[62]

4. Disaster risk reduction

Natural and well-managed ecosystems are important for mitigating the impacts of extreme weather events and the progression into full-fledged disasters. The worst disasters, in terms of loss of human life and economic costs, are often in those places where natural defenses have been degraded or destroyed.[63] Forests protect against floods, avalanches, typhoons and hurricanes, desertification, droughts, and landslides; wetlands can mitigate flooding; and coral reefs and mangroves help to protect against storm surges, tsunamis, and flooding.[64,65]

Some key benefits of ecosystem services in terms of disaster risk reduction (DRR) are outlined in Table 4.2. Ecosystems that are healthy, functioning, and diverse are more resilient to these hazards. After the Asian tsunami of 2004, a study in Sri Lanka found that an area with a diverse landscape of sand, mangrove-fringed lagoons, coconut plantations, scrub forest, and home gardens, was much less seriously affected than areas that had been cleared of natural vegetation, as these ecosystems absorbed much of the energy of the waves.[75] Conserving natural ecosystems is increasingly seen as a way of protecting against hazards from weather or severe events.[76]

Box 4.3: Ecosystem services in the Mekong delta

Inland fisheries in the Mekong watershed yield an estimated 2 million tons of fish a year,[66] for example contributing almost 80 per cent of animal protein for people in Cambodia.[67] Rising human populations put these resources under threat. Protected areas help regulate off-take: 60 per cent of fish caught in the region come from Tonle Sap Lake, a UNESCO Man and Biosphere reserve,[68] and the Ream National Park in Cambodia produces an estimated USD 1.2 million a year to local residents from fishing.[69] In Lao PDR, Fish Conservation Zones are co-managed for fisheries; villagers report significant increases in stocks of over 50 fish species.[70]

Ecosystem services are an important form of disaster risk reduction. Low-lying land and frequent storms open the Mekong delta to coastal damage, a situation likely to increase under climate change. Natural barriers such as mangroves and corals are increasingly valued. In Sri Lanka and Thailand, mangrove species were found to be effective barriers.[71] The storm protection value of mangroves in Thailand has been estimated at USD 27,264-35,921 per hectare.[72] Restoring mangroves can be a cost-effective option for improving coastal protection. A USD 1.1 million mangrove restoration scheme in northern Vietnam provided effective protection during typhoons and saved an estimated USD 7.3 million a year in sea dyke maintenance.[73]

Poorer people still rely on collecting natural products from the forest. In Nam Et National Biodiversity Conservation Area in Lao PDR, 81 village communities depend on non-timber forest products with a value estimated at USD 1.88 million/year (30 per cent cash income and the rest subsistence), providing villagers in the region with a higher than average per capita income.[74]

5. Climate change mitigation and adaptation

Healthy forests, grasslands, wetlands, and the soil and sedimentation beneath them hold carbon stocks and sequester atmospheric carbon, thus playing a key role in climate change mitigation (see Chapter 10): for example, wetlands hold approximately 33 per cent of the planet's carbon.[78] Conversely, their destruction and release of carbon is one of the factors leading to accelerating climate change. Carbon flux management is an important argument for persuading governments to conserve natural ecosystems, although current compensation schemes under Reducing Emissions from Deforestation and Forest Degradation (REDD)+ are not usually enough on their own to make up for the values forgone in development. The climate mitigation values of natural ecosystems have also now been reflected in the role of protected areas.[79]

Natural and well-managed ecosystems also help society to adapt to changing climate by maintaining the ecosystem services that are critical for survival: for example, protecting shorelines from rising seas, watersheds against flooding caused by heavy rain, and wild food sources often help communities to survive periods of emergency created by droughts or other weather events.[80]

6. Cultural values

Natural ecosystems are not devoid of human influence. Many contain important archeological sites, historic buildings, pilgrimage routes, and traditional or sacred land uses. In the same way that iconic buildings, writers, and football teams can embody the heart of a nation or region, so too can heritage landscapes and their species. Natural areas often contain sacred sites or landscapes that are cherished by local communities, such as sacred groves, waterfalls, and mountains. Iconic national parks like Yellowstone, the Blue Mountains outside Sydney, the Lake District in the UK, and the Japanese Alps have inspired artists and writers for generations. On a more local scale, these natural habitats provide rich sources of ideas and energy for poets, painters, musicians, and other artists.

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Table 4.2: Role of natural ecosystems in disaster mitigation[77]

Event	Role of Ecosystems
Flooding	Providing space for floodwaters to dissipate without causing major damage Absorbing the impacts of floods with natural vegetation
Landslide	Stabilizing soil Packing snow Slowing earth, rock, and snow movement and limiting extent of damage
Storm surge, tsunamis, erosion	Corals and mangroves creating a natural barrier to the force of waves Roots stabilizing wetlands
Droughts and desertification	Reducing pressure (particularly grazing pressure) thus reducing desert formation Maintaining populations of drought resistant plants to serve as food during droughts
Fires	Limiting encroachment into the most fire-prone areas Maintaining traditional management systems that have controlled fire Protecting intact natural systems better able to withstand fire
Hurricanes and typhoons	Mitigating floods and landslides Buffering communities against impacts of storm events (e.g. storm surge)
Earthquakes	Preventing or mitigating associated hazards including landslides and rock falls

7. Tourism

Tourism is a major source of income**,** generating USD 7.2 trillion (or 9.8 per cent of global GDP) and 284 million jobs (1 in 11 jobs) to the global economy in 2015.[81] For many countries, natural or semi-natural landscapes have allowed the development of ecotourism, defined as "*Responsible travel to natural areas that conserves the environment and improves the well-being of local people.*"[82] Global spending on ecotourism has been increasing by 20 per cent a year, about six times the industry-wide rate of growth.[83] In Kenya, an estimated 80 per cent of the tourism market is centered on wildlife, with the overall tourism industry generating a third of the country's foreign exchange earnings.[84] Ecotourism depends on maintaining the quality of land resources; a degraded landscape or disappearing wildlife will no longer be attractive to visitors.

8. Raw materials

Many raw materials are collected from the wild, often in huge volumes, including timber, fuelwood, resin, rubber, grass, rattan, and minerals, with many communities dependent on these for their livelihoods. Examples are shown in Table 4.3 below.

Estimating the value of natural ecosystems

While provisioning services, such as food, fuel, and fiber, have market values, the value of other benefits from natural ecosystems can be assessed at three levels: *qualitative*, *quantitative*, and *monetary*.[85] Qualitative valuation focuses on non-numerical values, for example by describing the role of a particular mountain or landscape in defining local culture and identity. Quantitative indicators of value focus on numerical data, such as the number of visitors to or quantity of carbon stored in a national park. Monetary valuation reflects service values in monetary terms, for example, by calculating

Table 4.3: Examples of materials collected from natural ecosystems.

Typology	Value	Example
Materials for construction or for physical protection (including timber, reeds, bamboo, and grasses)	Housing	In Mexico's Yucatan peninsula, the value of palm thatch for roofing material is estimated at USD 137 million per year.[85]
Materials for grazing livestock (e.g. grasses, plants)	Food (livestock)	A significant percentage of India's 471 million livestock are sustained by forest grazing or fodder collected from forests.[86]
Fuels (e.g. timber, fuelwood)	Fuel (cooking and heating)	In developing nations, 2.4 billion people – more than a third of the world population – rely on wood or other biomass fuels for cooking and heating.[87]
Materials for handicrafts (including grasses, reeds, seeds, wood, bamboo, etc.)	Income	In Namibia's Caprivi Game Reserve, one of the few sources of income for local women is through the sale of palm baskets to tourists. By 2001, these producers had grown from 70 in the 1980s to more than 650.[88]
Materials collected and **sold** (either as such or as inputs into other products) to provide income (including corals, sea shells, rubber, cork, honey, etc.)	Income	Matsutake mushrooms collected from China's Baimaxueshan Nature Reserve have helped to increase incomes 5 to 10-fold in 70 villages.[89] A kilogram of these mushrooms can bring more income than the average annual wage in Yunnan Province.[90]
Materials with traditional, cultural, or spiritual value	Cultural/ spiritual	In the Nordic region NTFPs such as mushrooms, herbs, and berries are extremely important culturally as well as economically.[91]

the revenue generated by fish caught in a river system or the value of carbon stored in a peatland assuming there are markets for these services. It is primarily the provisioning services that can be captured through monetary indicators. Therefore, a comprehensive assessment of benefits is likely to build on a combination of all three.

An estimate for the total global ecosystem services in 2011 was USD 125-145 trillion per year.[86] The challenge is how to incorporate these values in decision-making: for an individual land owner or someone using a natural resource, it is often more profitable in the short term to degrade the resource even though the cost to the wider society is much greater. Payment for Ecosystem Service (PES) schemes is an attempt to address these issues by making direct payments to those who maintain and restore ecosystem services. How these values benefit the poorest people is a more complex question and depends on issues such as governance quality, rule of law, degree of corruption, and the willingness of decision-makers to support poverty reduction programmes.[87]

Box 4.4: Assessing the value of national parks systems in Eastern Europe

In the Dinaric Arc region of Europe (the countries of former Yugoslavia and Albania), an assessment was carried out in 2013 and 2014, using a standardized methodology,[88] of ecosystem services in all the national parks in the region. Workshops provided an insight into local cultures and traditions and raised awareness on the range of benefits provided by the park. Some clear patterns emerged across the region of how protected areas can better promote conservation, protect local culture, and develop sustainable funding strategies: in 96 per cent of protected areas, stakeholders receive economic benefits from tourism, and commercial water use has a major economic value in over half, while 60 per cent of protected areas have local food values. There is potential in developing branding for local/regional products from protected areas (e.g. honey, mushrooms, medicinal plants, cheese). Protected areas were a major employer in regions that had suffered rural decline, making their future important to local politicians. A bottom-up assessment system, involving over a thousand people in 58 national parks, provides clear information about the values of ecosystem services, even if many of these had not been calculated in economic terms.[89]

CONCLUSION

Maintaining or improving the productive capacity of land and its associated resources requires us to maintain and surpass a position of "no net loss" of land quality. This is a matter of preserving or enhancing the ability of soil, water, and biodiversity to support the necessary ecosystem functions and services to meet the demands of today and the needs of the future.

More sustainable management of land resources can help close yield gaps, increase resilience to stress and shocks, and thus support human health, well-being, and security in the long term. The WAD provides a useful global overview of status and trends in the condition of our land resources as well as the potential human impacts. By identifying those areas under stress, decision-makers can be empowered to take remedial actions and create a supportive environment for stakeholders to do the same.

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Part One

CHAPTER 5

LAND RESOURCES AND HUMAN SECURITY

This chapter looks at some of the wider human security issues related to the condition of land. Many of the underlying pressures on land resources are not immediately obvious. Considerable evidence suggests that people are more likely to use land sustainably if they have secure tenure. Yet insecurity remains high in many countries and the growing phenomenon of "land grabbing" is making it worse.

Gender inequalities put many women and their families at increasing risk, leaving them among the most vulnerable. Yet in practice they are expected to take responsibility for land management as a growing number of men migrate in search of employment.

Income growth simultaneously creates large middle classes with new consumption patterns that drive unsustainable land use and heighten the existing massive inequalities in wealth. Conflict over scarce resources can generate additional local and sometimes global pressures. One result has been greater rural to urban migration, primarily within states or between neighboring states. Increasingly, longer distance migration is contributing to social and political tensions with ramifications throughout the world.

INTRODUCTION

The interplay of ecology, climate, and the human management of land resources has shaped the world for millennia. It is almost 9,000 years since the early settlement of Ain Ghazal, now Amman, Jordan, was partially abandoned seemingly due to land degradation caused by tree felling and intensive goat husbandry.[1] Similarly, the periodic cooling of the climate has wreaked havoc with farming communities, leading to their disintegration and the abandonment of once-fertile areas. In Britain, upland areas that had been farmed for thousands of years were deserted during colder periods at the end of the Bronze Age and only a few have been resettled.[2] Even if the climate remains stable, the mismanagement of natural resources can lead to the loss of essential ecosystem services, potentially followed by the collapse of human societies dependent on them.[3] Humans do not always have a proud history of land management with examples from virtually every part of the world, from earliest history to the present day.[4] The wave of colonization originating in Europe in the 16th century led to the massive over-exploitation of land resources by those who had little interest in their long-term status.[5]

It is simplistic and usually inaccurate to assume that land degradation is a primary cause of major social upheaval, migration, discord, or conflict. Human cultures are complex, and societies evolve as a result of multiple interacting social, political, economic, and environmental factors. But it is increasingly recognized that the availability of and access to land resources are contributing factors to some of these social upheavals.[6,7] There are connections between the health and stability of managed and natural ecosystems, e.g., the degree to which they ensure food and water security, and the overall security of human communities, their resilience to stress and shocks, and eventually to issues of migration or risk of conflict.

Box 5.1: Easter Island – ecocide, genocide, or epidemic?

Rapa Nui or Easter Island is one of the world's most remote inhabited islands, in the middle of the Pacific Ocean a thousand miles from its nearest neighbor, and famous for hundreds of massive stone heads (moai) carved by the inhabitants for reasons that are not fully understood. Rapa Nui suffered an ecological collapse with the extinction of many native species (including all land birds); the destruction of what may have been one of the world's largest seabird colonies; almost complete deforestation and the extinction of several tree species; and widespread soil erosion. But who is to blame?

Debates about Rapa Nui show the difficulty in identifying cause and effect, and the dangers of simplistic explanations. Polynesian people settled the island a long time ago[8] and are thought to have gradually cleared the forests over a 400 year period. It is hypothesized that the introduction of rats may have increased the rate of loss,[9] although the pollen records show no evidence of a rat invasion.[10] Some researchers argue that they literally ran out of space and fertile soil and suffered societal collapse, leading to inter-tribal conflict and cannibalism; by the time European settlers arrived only remnants of the population remained.[11] Others argue that while Polynesians definitely caused widespread ecological damage, their society was viable until the Europeans arrived and were then devastated by diseases for which they had little resistance.[12] Still others point to the impacts of Peruvian slave traders, who captured many people in the 1860s.[13] Widespread sheep farming led to the final stage of degradation[14] causing some species to go extinct in the 20th century. Was the society on a course of self-destruction when the Europeans arrived, or could they have stabilized the soil and maintained agriculture? Agriculture in some parts of the island had apparently been abandoned long before European arrival.[15] Did Europeans exacerbate or precipitate society collapse? What role did climate play? These are some of the recurring questions when working out exactly how humans and environment interact.

This chapter looks at some of the wider human security issues related to land degradation and the convergence of evidence described in Chapter 4:

1. **Land tenure:** sustainable use is heavily influenced by the security of people's rights to land resources
2. **Gender issues:** traditional, usually patriarchal, societies disadvantage women
3. **Resource shortages:** are adding to global insecurity, in terms of the amount of land resources and materials needed
4. **Increasing inequality:** the drive towards rapid economic growth is further disadvantaging the "have-nots," who are as a consequence often forced into unsustainable land management approaches
5. **Migration and security:** is partially attributed to ecological changes in many parts of the world

1. LAND TENURE

Who owns land, who has rights to use land and natural resources, and how secure those rights are significantly influence the way that land is managed. Shifts between various forms of public, private, and communal governance are driven by wider social and political changes that are often well beyond the control of people living in any one place. Ownership is distinct from tenure and most states ultimately "own" the land, in that they reserve the right to supersede individual rights.

Sustainable Development Goal target 2.3 aims to "*double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.*"

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Box 5.2: Types of tenure

Nationalized land tenure: the state has full ownership where individuals have use rights only. The central government may pass on authority to regional governments.

Freehold land tenure: considered to provide strong ownership rights, implying the right to own, control, manage, use, and dispose of property, although most states also have controls over what can be done on freehold land. Rights can also be overridden by state expropriation. Freehold may be conditional, for example when payments or developments have been completed.

Leasehold land tenure: based on the notion of rentals for varying periods. Land belonging to one entity – either the state or an individual – is, by contractual agreement, leased to another entity. Such leases can be long or short. In practice, 99-year leases are considered as secure as freehold land tenure.

Rental: rental occupation of state-owned or privately owned land.

Cooperative tenure: land is owned by a cooperative or group in which members are co-owners.

Customary land tenure: land is owned by indigenous or local communities and administered in accordance with their customs. Ownership is vested in the tribe, group, community, or family. Land is often allocated by customary authorities such as chiefs. Customary land rights are location-specific and often flexible, overlapping, and include dispute resolution mechanisms and individual as well as group rights to use local land resources.[19]

Tenure – the conditions under which land is held and occupied – is more significant than ownership. Clearly defined and secure tenure and access to land and other natural resources provide the basis for long-term stewardship as well as mechanisms for reconciling competing claims made by different users and interest groups. Secure land tenure is recognized as being an important factor in sustainable land management and in reducing the risk of environmental degradation; for example secure tenure is linked with reduced deforestation.[16] However, land degradation can sometimes continue to take place under conditions of secure tenure, such as in many parts of Europe, reinforcing the fact that tenure needs to be supported by clear policies and regulations if degradation is to be avoided.

Land tenure systems differ widely between and within countries. They are a product of historical and cultural factors, comprised of the customary and/or legal, statutory rights to land and related resources as well as the resulting social relationships between the members of society.[17] Tenure can be defined as the way land is held or owned by individuals and groups, or the set of relationships legally or customarily defined among people with respect to land.[18] Tenure systems have evolved gradually and often continue to change over time. In some cases, they have been influenced by revolutionary processes, such as the turnover of existing land tenure systems through redistributive land reform or forced land collectivization as in the various revolutions of the 20th century. In some countries, policy makers have strengthened the role of the state in allocating and managing land, often through the nationalization of non-registered lands held under customary tenure or conversely through more formalized tenure that gives individuals and communities greater control of their land. Although many countries have restructured their legal and regulatory frameworks related to land and in some cases harmonizing statutory law with customary arrangements, insecure land tenure and property rights remain prevalent, particularly in the developing world.

During the 19th century, colonialism introduced new dimensions to land ownership and titling in many parts of the world, based on freehold and leasehold, and usually ignoring or overriding existing forms of customary land tenure. The drive to establish private property continued throughout the 20th century and was subsequently embraced by many governments at the time of independence. As a result, tenure systems are increasingly based on formal, statutory rights that include private freehold and leasehold rights alongside more informal, customary rules and arrangements.

This range of tenure possibilities forms a continuum, each providing a different set of rights and different degrees of security and responsibility. There are various forms of religious tenure as well as temporary or informal tenure systems, including illegal occupation.[20] Additionally, a study of 64 countries found that 10 per cent of the land is owned by indigenous people and local communities, with a further 8 per cent designated for or "controlled by" these groups.[21] Some forms of tenure may only relate to certain kinds of uses, or particular times of the year.

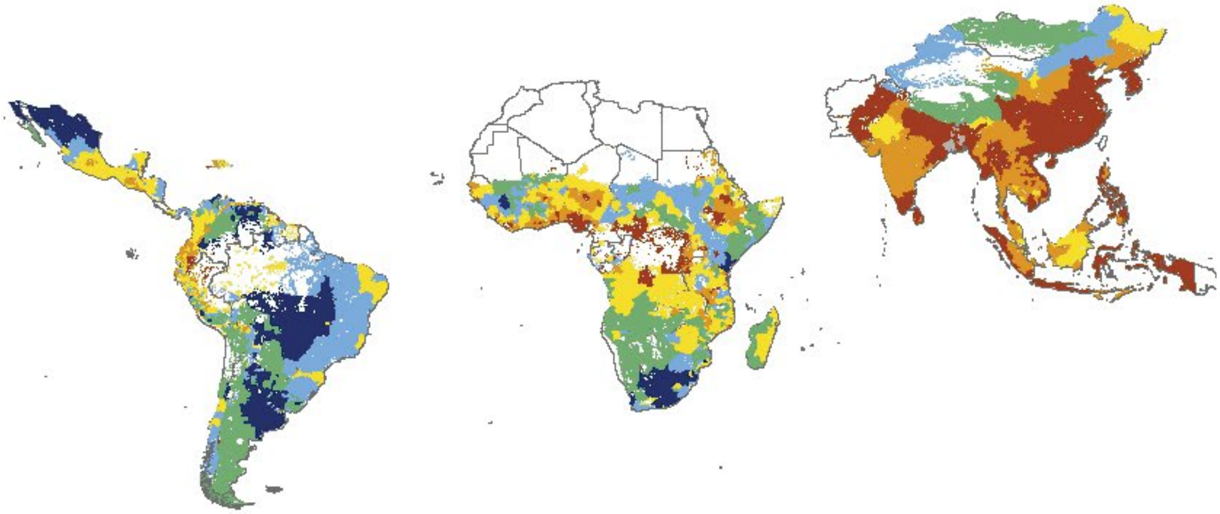

Figure 5.1: Size of agricultural concerns in the developing world: Used with permission[23]

Key

- Urban
- Extensive grazing (mean > 15 ha, > 90% pasture)
- Very large (mean > 50 ha)
- Large (mean 15- 50 ha)
- Medium (mean 5- 15 ha)
- Small (mean 2-5 ha)
- Very small (mean < 2 ha)

The dominant role that agriculture plays in rural land use means that farmers control and manage much of the land. It is estimated that there are 570 million farms worldwide, of which the large majority are small; for example 410 million are less than a hectare in size and 475 million less than 2 hectares. Despite the numbers, smallholders farming less than 2 hectares only occupy 12 per cent of total agricultural land, with the remainder held by significantly larger farms.[22]

While some governments have, to varying degrees, recognized a range of tenure arrangements as legitimate, "secure tenure" still tends to be strictly defined in terms of legal, statutory forms of tenure, such as individual land titles. However, this fails to reflect realities on the ground, and severely reduces the number of people who can afford or access such "formal" tenure, particularly women and rural poor in developing countries. Formalization can also have perverse impacts in that poor people may be tempted to sell land to make ends meet, or it can erode and displace existing social networks and arrangements that potentially offer greater security.[24] The problems are especially acute in sub-Saharan Africa, where the majority of the population remains landless. In South Africa, for example, 80 per cent of farmland was still owned by the white minority in 2013.[25] Overall in Africa only about 10 per cent of rural land is registered, leaving 90 per cent informally administered.[26] Similar land tenure issues extend around the world; India has the largest population of landless people on the planet.[27]

Today, systems of land tenure and property rights are changing quickly, as evidenced by the growing incidents of land expropriation and land-related conflicts,[28] in part due to speculation and the high value placed on good agricultural land.

Land tenure, registration, and dispute resolution

In countries where tenure systems remain informal or are in flux, one common response has been to introduce a land registry initiative: recording land rights in the form of deeds or through the registration of title. In these cases, there are two important elements to consider: the registry, which records the rights to land and the cadastre, which provides information on the location, boundaries, use, and values of land parcels. This approach is being introduced by many governments in developing countries to provide land users with greater security,[29] with the aim of enhancing land-related investments[30] and fostering the development of financial markets; efforts to date have met with varying success. While sometimes useful in addressing long-term tenure problems, new land registration systems often institutionalize inherent inequalities.

Most titling systems have been conceived in terms of individuals and often ignore those with informal use rights, such as women, children, migrants, Internally Displaced Persons (IDPs), pastoralists, hunters and gatherers, and other minority groups. In addition, collective land rights, such as family land rights, have not been adequately addressed, nor have issues relating to the legal position of community lands, including forest, wetlands, and grazing lands, which are usually under customary management. Land titling can be a lengthy and expensive process, particularly if community owners of land are not clearly defined and if new formal entities have to be established.

Land disputes often center on the demarcation, ownership, custodianship, and inheritance of land, or originate from the infringement of customarily held rights. Land disputes have led to social tensions and open conflict in many countries. In Latin America, the conflicts are primarily between the landless and large landholders, and between the landless and indigenous communities. The key drivers of land conflicts include a combination of inequitable access to and control over land, natural resource degradation, historical grievances, and demographic pressures, exacerbated by weak governance and political corruption.

Inequitable distribution and lack of access/control of land and its resources can be key drivers of poverty, food insecurity, and land degradation. The reallocation of rights to establish a more equitable distribution of land can be a powerful strategy for promoting both economic development and environmental sustainability, but there is no direct link between formalizing land rights, security of tenure, economic development, and peace.

As mentioned, standard approaches to formalizing land tenure, which focus solely on private and/or individual property rights, can create problems because they do not take account of collective rights. Other approaches seek to build land governance regimes that encourage cooperation between the central administration, local government, and customary authorities. Elements of successful processes include reconciling legality and legitimacy; building consensus; defining a realistic and adaptable implementation strategy; and ensuring financial viability for the stewardship of land services.[31]

While there is a general consensus on the need to redistribute land in many countries, there is often controversy about how to do so peacefully, equitably, and legally, without invoking rampant corruption, political interference, rent seeking, or social conflict.

A number of mechanisms have been developed to resolve disputes at a national or local level. In Ghana, a council of elders and land allocation committees are expected to help the customary trustees.[32] In Tanzania, the Land Commission recommended participation of the elders (Wazee) in the courts to ensure equitable land dispute resolution.[33] In Colombia, a quarter of the land became indigenous territory when a new constitution came into force in 1991.[34]

While there is a general consensus on the need to redistribute land in many countries, there is often controversy about how to do so peacefully, equitably, and legally, without invoking rampant corruption, political interference, rent seeking, or social conflict.[35] There are frequent contradictions between formal and informal tenure rules and institutions, which lead to conflicts and inefficiencies. One aim of land reform policies is to find ways of combining these different systems so as to ensure equal rights for both women and men to hold and use property as a cornerstone of social and economic progress.

Land grabs and virtual land

"Land grabs" are a growing phenomenon in Central and South America, Africa, the Pacific, and south-east Asia[36] and refer to the acquisition by outside interests of rights to harvest timber or establish large-scale commercial farms, plantations, or livestock operations on lands in developing nations where tenure has historically been collective, communal, or customary in nature.[37] Although the best known cases involve large investment companies based in the Middle East, Asia, North America, and Europe acquiring farmland in sub-Saharan Africa, land grabs are more commonly initiated by domestic investors supported by their own governments.[38] Such abrupt changes in control over large tracts of land are a modern reflection of a historical phenomenon, including chronic territorial wars, colonization, socialist collectivization, and the dispossession of indigenous people.

Land grabs are often either illegal, in that they contravene the law, or irregular, in that they exploit loopholes in the law, inconsistencies between laws and tenure systems, or take advantage of corruption or low levels of government coordination and capacity. However, completely legal land grabs can exhibit many of the same problems.

Wealthy countries unable to meet their own food and water needs have been acquiring lands in developing countries with abundant arable land and water resources, in some cases to hedge against food and water shortages at home. During 2004-2009, land was acquired by foreign investors in 81 countries;[40,41] however, many transactions are conducted without public notice. It is estimated that in the period 2000-2011 around 200 million hectares changed hands with the average size of land deals around 40,000 hectares. Approximately two-thirds of these acquisitions were estimated to have occurred in Sub-Saharan Africa, where over USD 2 billion has been invested. Almost 10 per cent of the total area under cultivation, and 35 per cent of the remaining potentially-available cropland in Africa has been acquired by large entities, with over 70 million hectares allotted for biofuels.

It is estimated that over 12 million people worldwide experience the loss of household income as a direct consequence, with significant impacts being felt for instance in Gabon, Liberia, Malaysia, Mozambique, Papua New Guinea, Sierra Leone, South Sudan, and Sudan.[42] Scientists have also raised alarms about the volume of water captured and used by these powerful new concerns in dryland countries and about high deforestation rates in land-grabbed

Box 5.3: The Tirana Declaration[39]

Large-scale land acquisitions or concessions are defined as land grabs if they are characterized by one or more of the following:

- Violations of human rights, particularly the equal rights of women;
- Not based on free, prior, and informed consent of the affected land users;
- Not based on a thorough assessment or are in disregard of social, economic, and environmental impacts, including the way that they are gendered
- Not based on transparent contracts that specify clear and binding commitments about activities, employment, and benefits sharing;
- Not based on effective democratic planning, independent oversight, or meaningful participation.

Examples from Tanzania, Kenya, and Madagascar confirm that land grabs often occur against the will of existing inhabitants, that corruption is rife, and that local socio-economic divisions increase after the land grab is implemented.

areas in south-east Asia and Brazil.[43] Land grabs tend to be a small percentage of the total available agricultural land but cluster in places where fertility, transportation, and access to water and markets are especially good.[44] Although little empirical data is available, it seems likely that this is causing considerable displacement and involuntary migration.[45] Examples from Tanzania, Kenya, and Madagascar[46] confirm that land grabs often occur against the will of existing inhabitants, that corruption is rife, and that local socio-economic divisions increase after the land grab is implemented[47] Land grabs can also increase tensions and the potential for conflict within communities and between affected groups and governments.[48]

Food security concerns are important driving forces behind countries outsourcing land resources abroad either indirectly or through foreign direct investment via large-scale land acquisitions[49] Most new cropland expansion globally can be linked to the production of crops for export, especially commodity crops in tropical countries. Other important drivers include the recent economic recession and biofuel targets linked to climate mitigation strategies. An analysis of 1,204 concluded deals, covering over 42.2 million hectares of land, showed that food and non-food crops play the most significant role, both in terms of number of land deals and their area along with growing demand for liquid biofuels by the EU and many other countries.[50] Malaysia, the United States, the UK, Singapore, and Saudi Arabia constitute the top five investor countries and account for 45 per cent of global lands under contract and 37 per cent of all global land deals.[51]

However, there is evidence of increasing large-scale acquisitions through cross-country investments within developing country regions: for example, Libya's investments in Mali; Mauritius's investments in Mozambique; and Egypt's in Ethiopia.[52] In Africa, governments often act as joint venture partners in some of these land deals. Furthermore, government policies can stimulate private capital to invest in foreign land acquisition, and deals have been stimulated by the World Trade Organization, domestic policies on food, agriculture, and trade, and the rolling out of commercial land markets.[53,54]

Pervasive tenure insecurity exacerbates the problems created by land grabbing. Small-scale farmers and pastoralists often have no formal title to land even though they have customary land tenure,[55] and compensation is paid in only one third of cases to people or communities who lose access to land.[56] Supporters of large-scale land investments argue that it offers opportunities for increasing productivity on land which has not yet been intensively cultivated. At the same time, those who oppose these investments contend that while such investments offer opportunities for development, the rural poor are being evicted or losing access to land, water, and other related resources[57] or being trapped in poorly paying contract farming agreements. Almost half the existing land deals analyzed involved land formerly owned by communities,[58] pushing people into cities, marginal areas, or remaining natural forests.[59] In the Democratic Republic of the Congo, large-scale agricultural investment has apparently pushed local farmers into a national park.[60]

A more fundamental criticism of the modern manifestation of land grabbing is that it is predicated on the assumption that large-scale monoculture agriculture is the only realistic way forward, closing the door on alternative approaches.[61] Mixed farmland that provides ecosystem services and supports biodiversity along with many families is replaced with monocultures, which supply none of these additional benefits.[62] Olivier de Schutter, UN Special Rapporteur on the Right to Food, has argued that "what we need is not to regulate land grabbing as if this were inevitable, but to put forward an alternative programme for agricultural investment."[63]

More secure and equitable tenure

Addressing land tenure issues requires a number of clear steps, which will vary depending on the stage of development within a given country. The FAO has established Voluntary Guidelines on the Responsible Governance of Tenure, which provides a strong framework for action.[64] Key elements include:

1. Policy and legal frameworks: policy and legal reform is often needed to ensure security of land tenure for smallholder farmers, rural communities, and indigenous people. This entails developing pro-poor land policies and laws, along with capacity-building programmes that empower traditional rights holders to use the law and make informed decisions about their land.

2. Conflict or dispute resolution: respected conflict resolution mechanisms are essential at both local and national scales. The nature and scope of land conflicts must be thoroughly understood before any intervention. Decisions and adjudications need to be enforced and resolution mechanisms viewed as legitimate by citizens.

3. Redistribution: sources of available land must be identified if redistribution is to be an option, although this is controversial and often difficult to achieve. Land purchase and redistribution by governments, directly by beneficiaries, or by land trust funds should support the livelihoods of marginalized groups. Funds are needed for compensation and the provision of rural infrastructure.

4. Land administration: improvements in efficiency are needed for registration and titling systems, formalizing and securing land transactions and regulation of land markets, including the establishment of local administrative bodies to define rules and maintain information systems and regular land valuation.

5. Land use planning and the conservation of natural resources: development of a new long-term integrated approach to land use planning and the conservation of natural resources, including building resilience of vulnerable communities to environmental degradation and climate change.[65] Planning should be intergenerational, inspirational, participatory, involving all relevant stakeholders, and based on efficient, comprehensive data gathering and processing.

6. Land protection: the issue of land grabbing is complex and requires a territorial vision that 1) recognizes the rights of local communities to use, manage, and control land and other natural resources as a basis for community-driven development and building equitable and just societies; and 2) encourages models of investment in agriculture and other rural land-based activities that are socially, economically, and environmentally sustainable.

2. GENDER ISSUES

Gender dynamics and community relationships with the environment determine the ability of women and men to manage livelihoods and the land. Women in many developing countries often do not have ownership, tenure, or control over land, natural resources, or commercial production. Women, whose rights are facilitated by their husbands, brothers, or fathers, become even more vulnerable as they can lose their property or tenure rights following migration, widowhood, divorce, or desertion.[66] Tenure is often seen as a positive element contributing to sound land management practices, higher agricultural output, and greater influence in community decision-making.[67] As societies change, more men migrate in search of work or experience higher mortality rates, which may leave women as the responsible heads of households.[68]

The proportion of women farmers is gradually increasing in many places and a feminization of agriculture is taking place in many countries that will continue to change the way in which women's farming roles are perceived.

Women play an important role in many forms of land management, including food production, but are often seriously disadvantaged because of entrenched gender-specific rights, roles, and responsibilities, reducing the quality of life for them and their children. Women are believed to make up 43 per cent of the world's agricultural labor force, with significant regional differences (on average less in Latin America and more in Africa).[69] Many women work as unpaid laborers on family farms rather than as farmers. In Europe, women make up 41 per cent of farm laborers but this masks large differences between countries.[70] In the United States, less than 3 per cent of "commercial" farmers operating stable, successful businesses are women, and the average male farmer makes 17 times more than the average female farmer.[71] There is still no accurate estimate about the proportion of food produced by women[72] and some researchers believe the number of women farmers has been exaggerated,[73] but the importance of their role is not in doubt.

Female farmers generally have lower output per unit of land[74] and are less likely to be involved in commercial activities[75] than male farmers. This is a result of women tending to have smaller farms on more marginal lands; less access to technical information and credit facilities; facing social constraints and family responsibilities that hamper productivity; and often having more dependent relatives and relatively less labor to help with work. Extension services normally target men and in some societies cultural norms present additional barriers for male extension service providers to work with women farmers. Yet if these constraints are removed, women farmers are on average found to be as productive as or more productive than men.[76] Closing the gender gap in the use of inputs and technologies could increase yields for women farmers by 20 to 30 per cent, and raise total agricultural output in developing countries by between 2.5 to 4 per cent.[77]

Gender differences also exist with respect to livestock rearing, although much less is known about the relative productivity of women and men in this area.[78] Women have been estimated to make up two-thirds of poor livestock keepers, and are likely to keep poultry and other animals around the home.[79] However, as livestock enterprises scale up in size, the role of women often declines.[80]

However, gender roles in agriculture are changing. Male out-migration from rural areas in search of jobs is a significant factor in not only increasing women farmers' workloads but also in triggering new roles for women. Out-migration compels women to carry out some of the work previously done by men, such as tending to farm animals[81] and engaging in income-generating activities, in addition to their farm production and household activities.[82] The proportion of women farmers is gradually increasing in many places and a feminization of agriculture is taking place in many countries that will continue to change the way in which women's farming roles are perceived.[83]

Particularly in the developing countries, women's traditional roles make them responsible for many other aspects of land use and management, including the collection and preparation of fuelwood, water, fodder, medicinal herbs, fruits, and seeds.[84] It has been estimated that women in parts of Kenya can burn up to 85 per cent of their daily calorie intake just fetching water.[85] Women are predominantly responsible for fuelwood collection in dry tropical forests except where there are social constraints such as purdah (female seclusion).[86] Environmental degradation increases the burden on women: for example, the time required for firewood collection in the Himalayas has increased by around 60 per cent in the last quarter century because of the declining productivity of the forest; women and children undertake virtually all this work.[87]

Rural women are at the frontline of marginalized groups impacted by land degradation, making gender-responsive land degradation neutrality policies and their implementation an imperative at the local and national levels. If rural household land becomes degraded, the burden on women is increased because they need to find additional ways

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Box 5.4: Understanding gender roles and the land

Various theoretical frameworks exist for examining gender roles. *Ecofeminism* covers a "variety of different feminist perspectives on the nature of the connections between the domination of women (and other oppressed humans) and the domination of nature..." along with "theories and practices concerning humans and the natural environment that are not male-biased."[93] *Human vulnerability analysis* can be applied, for instance, to the positioning of parties towards land degradation and what role the state may be playing in conferring privilege and favor to men to the detriment of women. *Vulnerability analysis* emphasizes the importance of taking a life-cycle approach to societal problems, with special attention paid to the needs that arise from roles, responsibilities, and life-stage.[94] While ecofeminism focuses on the patriarchal approach to nature, vulnerability analysis considers how governments might usefully respond. Vulnerability analysis calls for the recognition of hidden tasks relating to reproduction and caretaking in the family, primarily undertaken by women; this caretaking role extends to the land, where women farmers' subsistence roles are not valued and are thus excluded from the Gross Domestic Product. In the context of land degradation, the approach is to examine how gender inequality places women farmers in a less resilient socio-economic position, with respect to maintaining or increasing land productivity and responding to climate change.

Under the agrarian reform programme in the Philippines, over half of the land certificates issued still do not include the name of the wife, despite a longstanding order to include the names of both spouses.

to supplement their declining food production while maintaining their reproductive and caretaking roles. These activities typically include selling their labor to wealthier farmers or petty trading just to buy enough food for their own families.[88]

One way in which women manage multiple roles is through the formation of women's groups where they assist each other with both production duties (e.g., tilling, sowing, harvesting), childcare, and other forms of cooperation, such as financial services assistance. Such groups are found in many countries in Africa,[89] Asia,[90] and the United States.[91] Climate change and its impacts amplify existing gender inequalities, putting additional pressure on "already fragile, undervalued and precarious gender roles at the community level, which shape the nature and extent of exposure, sensitivity and impacts."[92] The vital role women play as producers of goods and services makes them an important strategic partner both in the realization of the SDGs and the climate change agenda.

Traditional systems of inheritance and property transfers, especially of agricultural land, are predominantly patrilineal; however, an increasing number of countries now recognize women's land rights in their constitutions and laws. In Laos, a married woman is entitled to one-half of any property acquired during marriage;[95] Rwanda has recognized women's land rights under law.[96] Where women farmers already have informal or customary land rights, formal title can sometimes be acquired through the conversion of customary title to freehold title registered with the state or through statutory recognition and codification of customary title in the government registry.[97] However, in most developing countries women still only have access to land and related natural resources through their husbands or male relatives. This is particularly important for a woman if she becomes the de facto head of household as a result of male migration, abandonment, divorce, or death. In both urban and rural settings, independent property rights under these circumstances can mean the difference between dependence on family support or charity and the ability to form a viable, self-reliant, female-headed household.[98]

Change comes slowly and legal reforms do not always equal changes in reality on the ground for communities faced with the most severe land degradation. Even when reforms are made, customs and tradition can slow the uptake and rate of change. Under the agrarian reform programme in the Philippines, over half of the land certificates issued still do not include the name of the wife, despite a longstanding order to include the names of both spouses.[99]

Box 5.5: Gender strategies for achieving land degradation neutrality

Sustainable Development Goal target 5.c states "*Adopt and strengthen sound policies and enforceable legislation for the promotion of gender equality and the empowerment of all women and girls at all levels*." These strategies should be geared towards ensuring gender equality, which can mitigate the unjust effects of the patriarchal norms and attitudes that still prevail in many rural communities around the world, including:[100]

- Recognizing and engaging women as land managers in various aspects, including as farmers, not just farm helpers[101]
- Ensuring that all initiatives undertaken to rehabilitate and restore degraded land are gender sensitive and responsive to the interests and needs of women farmers and land managers
- Sharing best practices and where necessary changing legislation to enable women to overcome the obstacles they face in securing land tenure and resource rights
- Addressing perverse laws and policy incentives that hamper the efficiency and development of women in food production activities
- Ensuring that agricultural extension services include women and address gender-specific needs of women as well as men,[102] through for example training women extension workers, changing teaching practices, peer-to-peer initiatives, re-training, etc.[103]
- Ensuring that women farmers have direct access to resource inputs and financial services, such as micro-finance schemes that are not mediated through their husbands[104]
- Strengthening the voices of women land users at all levels in policy processes through reforms, capacity building, and incentives
- Increasing female participation in agricultural research and development[105]

3. RESOURCE SHORTAGES

Conflict over scarce resources can generate additional local and sometimes global pressures. Ever since the Club of Rome published its report Limits to Growth in 1972,[106] concern about the eventual exhaustion of the Earth's natural resources has received increasing attention. Price volatility and localized competition over limited natural resources can be the precursors to future instability and conflict. While many of the early studies were accurate in their recognition that the world was reaching limits in terms of available resources, the timeline was often overly pessimistic; the world has already survived many of the predicted tipping points for the availability of food, minerals, and energy. But for how much longer?

So far, when shortages have emerged, they have often been issues of politics in the case of both[107] energy and food,[108] or a combination of factors[109] rather than real resource scarcity. Past mistakes also highlight just how difficult it is to estimate resources on a global scale.

Estimates of the remaining stocks of minerals and other materials distinguish between reserves and resources: reserves are reasonably well known and accessible using current technology while resources are less fully known (including their quantities) and perhaps not viable due to the high economic or environmental costs involved in extraction. Some analysts include a third category of "undiscovered" reserves, which are inferred from a general understanding of geology and landforms. Our knowledge of global resource stocks is less exact than is often assumed. In 2004, the oil company Shell shocked the financial market by downgrading its own oil reserves by about one-third, a "loss" of over 4 billion barrels. Table 5.1 summarizes the state of knowledge on some important resources while the rate of their consumption is increasing. Annual global extraction of raw materials grew from 22 billion tons in 1970 to around 70 billion tons in 2010, with non-metallic materials used for buildings showing the steepest increase; over this period there has also been an overall decline in material use efficiency resulting in even greater extraction than the statistics suggest.[110]

Table 5.1: Global outlook for key natural resources

Natural resource	Estimated availability
Land	The availability of good farmland per capita is declining due to rising populations, urbanization, increasing demand for food and non-food crops, and land degradation, leading to the use of marginal areas and the continued conversion of natural ecosystems. See Part Two.
Food	Most analysis concludes that rising population and consumption levels will strain the ability of agronomists and farmers to maintain productivity increases that are large enough to keep pace. Under these circumstances, global shortages could be addressed by reducing waste and changing diets, particularly reducing the proportion of animal products eaten. See Chapter 7.
Water	The amount of water is constant but its availability in different parts of the world is changing and growing problems of water scarcity are expected in many places. See Chapter 8.
Oil and natural gas	Some analysts believe that oil supply has peaked and the world will face energy shortages;[111] others disagree.[112] Many believe there are sufficient supplies of oil and natural gas to see a transition to renewable energy sources; it assesses supplies to be abundant but most are classified as resources rather than reserves, which means that they are not fully known, or present technical difficulties in extracting them in an economic or environmentally sound manner.[113] See Chapter 10.
Coal	In theory, there are hundreds of years of supply left but concentrated in a few countries; some analysts predict the end of cheap coal and a peaking towards the middle of the century due to a variety of factors including pollution and climate concerns.[114]
Timber	There are sufficient supplies of industrial timber. Currently, 1.2 billion hectares of forests are managed for production, half in high-income countries but only 8 per cent in low-income countries: removals in 2011 were around 3 billion m^3, less than one per cent of the growing stock.[115] Sustainable forest management is still severely lacking in many tropical countries, although the area recognized as sustainably managed is increasing.[116] Access to some high-value native tree species, particularly tropical hardwoods, is declining leading to damaging impacts on remaining natural forests. In 2004, around half the tropical timber traded was estimated to be illegal.[117]
Fuelwood	Localized shortages exist which have important social and ecological impacts.[118]
Nitrogen	Industrial ammonia synthesis through the Haber–Bosch process converts atmospheric nitrogen and hydrogen, usually from natural gas, to ammonia, thus facilitating the large-scale and unlimited production of nitrate fertilizers, provided the cost of energy remains low.
Phosphate	Primarily mined from phosphate rock; current global reserves will be depleted in 50-100 years, with some projections of a peak around 2030.[119] Global supplies are uncertain and rest heavily on very large inferred reserves in Morocco.[120] At the same time, phosphate recycling technologies are increasing.[121]
Potassium	Potassium reserves remain large, although concentrated in a few countries, particularly Canada (Saskatchewan) and Russia.[122]
Iron	The US Geological Service estimates global iron reserves at 800 billion tons of crude ore, containing 230 billion tons of iron; sufficient for 200 years of production at current levels.[123]
Copper	Copper reserves are thought to amount to 680 million tons[124] and copper resources are currently estimated at 2,100 million tons known with an estimated 3,500 million tons undiscovered.[125]

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Box 5.6: Sand mining[126]

Sand and gravel account for the greatest amount of materials, by volume, mined in the world. Global production in the year 2000 was estimated to exceed 15 billion tons. Coastal sand with high silica content has been used in glass manufacture, however, due to the ecological and hazard regulatory functions of dunes, its removal is now generally prohibited. Sand from fluvio-glacial drift and fluvial channels, lakes, lagoons, and backwaters is used for building construction. Marine dredged sand forms an important component of aggregate supply, particularly in north-western Europe. River sand has been so extensively mined in some areas that it is in short supply in many parts of the world. Continued and indiscriminate sand mining can cause irreversible damage to ecology and economies by transforming habitats and associated biodiversity, damaging civil construction structures attached to river environments, reducing important ecosystem services, reducing ground water supplies, and impacting drinking water quality. The environmental costs of extracted sand seldom figure in the cost-benefit analysis or environmental impact assessment of the extractive industries, making extraction more profitable than other alternatives. A lack of information on the adverse impacts presents a major problem when developing suitable regulatory systems for wise use. Although some countries have mechanisms to address sand extraction in situ (e.g., Australia and Malaysia) which are proving successful in the protection of river and other sand producing systems, many developing nations need to strengthen their policy to move legal mining to more sustainable levels and to tackle illicit sand mining operations.

Making sand use more sustainable requires, in brief:

- River sand to be used for construction and not for land filling and reclamation.
- New building technologies with reduced sand requirements.
- New technologies for the use of all grades of sand in construction.
- Alternatives to concrete and cement–sand mix in building technology.
- Penalties for illegal and overuse of sand.

4. INCOME INEQUALITY AND UNSUSTAINABLE CONSUMPTION PATTERNS

Income growth and inequality affect the land base in two major ways. First, a general increase in the middle classes in many countries creates a larger pool of people with disposable income, which generates higher consumption levels, and in some cases a demand for resources that are in short supply or are disproportionately land-intensive. Second, an unprecedented increase in income inequality is occurring, forcing poorer people onto marginal land where degradation is more likely, as are the risks of civil conflict.[127]

Sustainable Development Goal 10 aims to "*Reduce inequality within and among countries*" and target 10.1 encourages countries to "*progressively achieve and sustain income growth of the bottom 40 per cent of the population at a rate higher than the national average*."

The huge increase in the fashion industry and the rapid turnover of clothing has resulted in a boom in cotton production, which is one of the heaviest pesticide users, responsible for almost a quarter of the world's pesticide usage.

Increasing consumption patterns are stressing land resources: soil, water, biodiversity, and minerals. The global economy is based on people consuming more, a phenomenon recognized a generation ago[128] and still accelerating. Consumption levels have impacts that are more complex than simply an increase in products used. For example, the huge increase in the fashion industry and the rapid turnover of clothing has resulted in a boom in cotton production, which is one of the heaviest pesticide users, responsible for almost a quarter of the world's pesticide usage.[129] The explosive demand for land-intensive, high-protein foods discussed in Chapter 7 has meant, among other things, huge forest losses to grow soybeans and create grazing land for cattle. Rising middle classes in some developing countries are also financing an increase in bushmeat trade,[130] the killing and selling of wild animals: most notoriously in the case of large predators like the tiger but also new markets for wild mammals, birds, and reptiles, which is threatening whole species with extinction. Other wildlife product markets, such as elephant ivory[131] or rhino horn used for medicine,[132] are also creating a crisis for conservation management.[133]

Income inequality is even more complicated. The richest one per cent of the world's population now own more than the rest of us put together; just eight men hold the same amount of wealth as the poorest half of the world. Over the last 30 years, income growth of the poorest half of the world has been zero while the incomes of the top one per cent have grown 300 per cent.[134] Direct causal links between poverty and land degradation are contested, although the balance of evidence suggests that social inequality is bad for the environment, which may in turn explain why societies with more inequality appear to be less healthy.[135]

5. MIGRATION AND SECURITY

An estimated 244 million people live and work outside the country of their birth;[136] many more migrate within their own countries. Migration takes place for many reasons, including the desire for a better life, to escape repressive regimes, or to move away from difficult environmental conditions. When things get tough, people have two options: to stay put and try to sort things out in place, or to move somewhere else. Many people opt for the latter although the poorest and most vulnerable may be unable to do so. Mobility and the ability to migrate are important livelihood strategies, especially among rural populations that depend on land-based goods and services, but also among the rich and educated who are prepared to move for career or economic opportunities.

Sustainable Development Goal target 10.7 encourages countries to "*Facilitate orderly, safe, regular and responsible migration and mobility of people, including through the implementation of planned and well-managed migration policies*."

Three forms of human mobility can be distinguished: migration by people moving within or beyond their country for socio-economic reasons; displacement, usually referring to forced movement due to conflict or disaster; and planned re-location, the movement of communities to a safer place in response to irreversible environmental changes. While migration can be a positive adaptation strategy, displacement can increase vulnerability and planned relocation often has mixed results, moving people out of immediate harm but sometimes leading to new vulnerabilities.[137]

As a response to land resource pressures, some migration takes place because regions are over-populated, while in other areas depopulation and land degradation are a contributing factor. Migration is more likely to be a strategy to address climate change in vulnerable ecosystems, such as drylands, mountains, and low-elevation coastal zones.[138] Rural–urban migration, when people move from the countryside to towns and cities, is the most common direction of movement. In some countries, governments encourage migration from crowded peri-urban areas to less developed natural frontiers, encouraging the clearance and conversion of forests and increasing land degradation in new areas: the Indonesian transmigration programme is a well-known example of this approach with mixed results.[139]

Most migration takes place within countries and international migration mainly occurs between contiguous countries.

Most migration takes place within countries and international migration mainly occurs between contiguous countries. Long-distance international migration from low to high-income countries averages just over 4 million people per year, making it a relatively small contribution to the more than 200 million international migrants worldwide,[140] although the numbers of "forced migrants" are currently rising.[141] Migrants tend to move to places where people like them have gone before, using family or social networks to help with the journey and getting established at their destination.[142] Migration preferences change over the course of a person's life, with young adults typically the most mobile people in any society, although retired people also migrate, often returning to their place of origin.[143]

Migration can be temporary or permanent and can take place in an orderly fashion or suddenly because of natural disaster, political repression, or conflict. The connections between land degradation and migration are complex, influenced by social, economic, political, demographic, and environmental processes that operate at local to global scales. Most land degradation-associated migration occurs not under conditions of absolute distress but as households take advantage of opportunities to generate new income sources and reduce their exposure to risks and hazards associated with land production activities. While migration may be voluntary or forced, most often decisions are a combination of both.

The global number of forced migrants (i.e., refugees and displaced persons) and stateless people is estimated to be 65 million,[144] two-thirds of whom are internally displaced persons.[145] Voluntary migrants are sometimes enticed by economic benefits such as labor markets, commodity prices, housing costs, and valuation of workers' skills,[146] but also as a way for households to reduce and diversify their exposure to economic uncertainty and unexpected difficulties.[147] For example, rural populations in West Africa use migration strategically to cope with the inherent seasonality of the climate,[148] sending young adults to the cities in the dry season to reduce the demands on household food supplies and in the hope they may earn money.[149] In many poorer countries, the money sent back from overseas migrants represents a large proportion of household incomes;[150] but, as the poorest people are often unable to migrate, this can further increase inequality. Migration can be an important factor in sustainable livelihood strategies, particularly in the drylands.[151]

How environmental change affects migration

The term "environmental refugee" was coined to describe people displaced by famines and other disasters,[152] including people forcibly relocated to make way for the construction of dams and other infrastructure.[153] Millions of environmental refugees were forecast.[154] The United Nations has been prominent in linking human movement and conflict to resource issues, including an analysis of civil wars over the past 70 years that indicate that at least 40 per cent are linked to the contested control or use of natural resources, such as land, water, minerals, or oil.[155] However, many analysts are cautious as to the reality of environment as a direct driver for human movement,[156] with a split between "alarmists" and "sceptics."[157] Scholars have been wary of drawing links between environmental change and human migration due to fears of being accused of geo-determinism,[158] and argue that estimates are exaggerated,[159] yet policy makers, the military, and governments are increasingly treating this phenomenon as a perceived reality.

The terms *environmental refugee* and *climate refugee*, used by social campaigners, have no status under international law, which confines the term refugee to those moving across national borders to escape political or religious persecution. This has led to environment and climate often being neglected in the discussions about migration. International law remains limited in its capacity to address climate- and environment-induced population movements, although the fact that the Cancun Adaptation Agreement acknowledges migration, displacement, and re-location as adaptation strategies is an encouraging development.[160] More recently, vulnerability to climate change has been recognized as a driver of migration,[161] being seen as one way in which people cope with and adapt to environmental change.[162,163]

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Land degradation and migration

Growing human populations put stress on the carrying capacity of land. Sometimes these pressures can be offset, at least for a while, with innovation, intensification, and/or collaboration in food production:[164] in the Machakos region of Kenya, an area that once suffered severe soil erosion, was rehabilitated by conservation practices which were in fact stimulated in part by a growing population.[165] However, in other cases, an imbalance between population and the carrying capacity of the land can lead to large displacements, as in sub-Saharan Africa in the 1980s and early 1990s.[166] Innovation is more likely when people have secure land tenure and a stake in remaining in place,[167] with numerous examples of both.[168]

Migration out of rural areas has typically been a last-resort strategy for households experiencing the loss of crops or livestock due to drought.

Land degradation can cause migration and vice versa; sometimes the two take place simultaneously. Land degradation and migration are thus often closely interconnected processes, which are also influenced by population growth and the conversion of traditional or communal land tenure rights to private ownership. There are currently no reliable statistics about the number of people globally who may have been induced directly or indirectly to migrate because of land degradation.

Rough estimates suggest that at present the total is already in the millions, likely tens of millions of people each year, most of whom live in rural areas.[169] Some project that as many as 200 million people will be displaced for environmental reasons by 2050.[170,171] Others recognize environmental factors as important secondary drivers,[172] or threat multipliers,[173] with hotspots identified in the Sahel, the Middle East, central Asia, and coastal regions of east, south, and southeast Asia.[174]

Small-scale dryland farmers use seasonal labor migration strategically to cope with the general variability of precipitation.[175] Longer-term migration processes within countries, particularly the accelerating trend toward rural-urban migration, is driven primarily by social and economic processes,[176] but gradual land degradation is also a contributing factor. A key driver of land degradation in traditional pastoral regions is land enclosure and the conversion from communal to private tenure in order to facilitate commercial development and the intensification of livestock and agricultural production. In East Africa, some pastoralists, increasingly confined to smaller areas, are obliged to keep more animals on degrading pastures and must purchase supplemental fodder or graze their herds in areas that put them into conflict with other land users.[177,178] Pressures are increased by larger stock numbers and can be exacerbated by government efforts to settle nomadic farmers. This combination of factors creates a growing need for cash which spurs the outmigration of young people to urban centers.[179] A similar process is taking place in the Andes, where the collective campesino model of land management is being undermined by governments,[180] fragmenting grazing lands and resulting in higher stocking rates,[181] land degradation, and out-migration.[182] A self-reinforcing process of settlement, wage labor migration, and greater integration of formerly pastoral peoples into the market economy has emerged.

Much of this migration may be temporary. In Ethiopia, most migration has traditionally been within the drought-prone rural areas, including:

Box 5.7: Common characteristics of land degradation-associated migration

- Most land degradation-associated migration, as with all forms of migration, takes place within countries, or between contiguous countries
- Precipitation variability, extreme temperatures, deforestation, overgrazing, and drought are important influences on migration in many dryland areas
- The most prominent type of migration is labor migration, used strategically to overcome the risks associated with living in a challenging environment
- Migration generally but not always tends to flow out of areas with higher rates of land degradation to areas with lower rates
- Migration rates are high in places where governments are unable or unwilling to provide responses to land degradation
- Social networks facilitate migration, making them less costly and channeling migration to particular destinations
- Migration is gendered, usually with a disproportionate number of women, children, and older people left behind
- Land degradation and migration can aggravate existing societal tensions
- Climate change will impact migration, likely increasing flows out of drought-prone and degraded areas
- Measuring and monitoring migration is improving but reliable data remain scarce, particularly for internal migration

temporary, seasonal, and indefinite migration.[183] Migration out of rural areas has typically been a last-resort strategy for households experiencing the loss of crops or livestock due to drought.[184] In Mexico, a proportion of migration is linked to drought although another important motivation is the pursuit of additional income to remit home.[185] While most migration occurs within Mexico, a proportion of young men also migrate to the United States,[186] with an increase usually coming a couple of years after drought[187] underlying the importance of migration as an adaptation strategy for dryland farmers;[188] conversely when precipitation is above average and agricultural productivity is better than usual, migration to the US drops sharply.[189] China has a floating population of an estimated 120 million undocumented migrants living primarily in coastal cities with booming economies, many of whom come from poor households in degraded dryland regions.[190]

Alongside discussions about where migrants come from is the equally important question of where they go;[191] a sudden influx of people can cause further environmental degradation elsewhere. In Ethiopia, human migration is both caused by and a cause of deteriorating environmental conditions.[192] In tropical regions, forest loss is increasingly being driven by the exploitation of forests by outside commercial interests using unsustainable harvesting practices,[193] often leading to higher rates of degradation than where small-scale forestry is conducted.[194] Cleared areas are often replaced with commercial farming or grazing, displacing local and indigenous communities. Commercial forestry companies often actively avoid employing local people, preferring to bring in migrant workers.[195]

In many rural areas of Central and South America, south and southeast Asia, and sub-Saharan Africa, artisanal mining attracts migrants to areas where the activity is unregulated or carried out clandestinely.[196] An estimated 10-20 million people are engaged in artisanal mining worldwide.[197] Artisanal mining is a significant driver of environmental degradation, which can include deforestation,[198] erosion,[199] water pollution, and contamination of soils and groundwater by mercury.[200]

When migration results from the loss of agricultural land, the causes may sometimes be deliberate, or as a result of some major disaster. In 2000, it was estimated that between 20 and 40 million people worldwide had been displaced by dam projects.[206] The Three Gorges dam project in China, completed in 2012, alone displaced an estimated 1.3 million people.[207] Many of the new lands to which farmers were relocated were on steep slopes and prone to erosion,[208] causing on-migration to cities.[209]

Mega-disasters that have caused widespread migration include the desiccation and salinization of the Aral Sea by poorly planned irrigation projects,[210] which were clearly deliberate but with unforeseen consequences. The Aral Sea shrank dramatically, exposing sediments heavily laden with agricultural chemicals and other toxins, and the region's population subsequently experienced chronic respiratory illnesses and renal problems well above national averages.[211] Farmland became increasingly unproductive, and groundwater contaminated, leading to widespread migration and impoverishment of the remaining population,[212] problems that will take at best decades to overcome.[213]

Box 5.8: Migration in China

China has land use controls and a household registration (*hukou*) system that make migration patterns distinctive. The use of agricultural land is regulated by the state, and recent decades have seen growing intensification as well as large areas of agricultural land being consumed by infrastructure projects and urban expansion, with an estimated 50 million people directly displaced in this way.[201] In western and central China, large areas of dry forests and grasslands have been degraded by overgrazing and conversion to cultivated land.[202] In Xinjiang and Gansu provinces, governments actively encouraged agricultural expansion in marginal drylands.[203] In the grasslands of Inner Mongolia and Tibet, governments have actively relocated and resettled pastoralists and rural populations to towns or other rural areas, often citing overgrazing as a reason, with mixed results in terms of the welfare of those relocated.[204] Households use migration as a means of adapting, either legally in the case of richer families, or illegally as undocumented migrants living primarily in coastal cities.[205] The nature of institutional arrangements in China means that government has a disproportionate role in managing both land degradation rates and population flows relative to other countries. The results have been mixed; sometimes migrants' remittances home help take pressure off the land, while in others depopulated lands undergo a domestic land grab and production is intensified.

In the future, climate change will influence the dynamic interactions of land degradation and migration by exacerbating natural phenomena that influence soil, water, and biodiversity, such as precipitation variability, droughts, and extreme weather events, and by affecting agricultural productivity, which in turn affects household incomes and the price of food. Some traditionally productive areas will become less so, while productivity will increase in others; the net balance in terms of food security is hard to predict.

Drought, land degradation, conflict, and migration

There is a complex and poorly understood relationship between land degradation, droughts, migration, and violent conflict. While academics continue to debate the links between land degradation, migration, and conflict, businesses are quietly organizing. While politicians still discuss the reality of climate change, those with a responsibility for security such as the military, have for years been analyzing the implications and are planning responses.[214] Conflicts, particularly between rival factions within states, for example in Africa, are thought to have been exacerbated by drought, migration, subsequent competition with other groups, and resulting social tensions.[215,216]

Slow onset disasters, such as those associated with drought and desertification, can increase tensions between resources users like pastoralists and farmers, which can lead to violent conflict although usually on a local scale.[217] In Sudan, farmers burned grasslands and destroyed water sources to deter nomadic grazers;[218] tensions can also rise between pastoralists if one group is forced to move into the territory of another.[219]

However, the processes leading to violent conflict are invariably complex[220] and in some places land degradation and drought conversely lead to greater cooperation and resource sharing.[221] The current consensus is that resource scarcity, land degradation, and sudden climatic changes do not cause conflicts on their own,[222] but are "threat multipliers" increasing the risk of violence breaking out in areas where tensions are already high.[223] Areas of Ethiopia prone to rebel activity and communal conflicts experience an upswing in activity during droughts and extreme rainfall events,[224] while across the Horn of Africa, scarcity in vegetation can exacerbate existing conflicts among pastoral groups, especially when other non-environmental influences are concurrently strong.[225] However, it should be noted that persistent conflicts also occur in areas with no particular environmental stresses.

In the majority of cases environmental scarcity is managed in a peaceful way, where broadly accepted rules lead to cooperative outcomes of one kind or another.[226,227,228] Having said that, there is evidence that getting land governance and management right can help to reduce tensions and avoid conflict.[229,230] Such forms of governance can potentially be initiated in places where the state is failing to mitigate conflict through its own institutions. The establishment of transnational peace parks for example (i.e., protected areas in former conflict zones) is a proven way of building community stability following periods of unrest and violence.[231] In the same vein, evidence from Ethiopia showed that while a large refugee influx and population pressures led to localized conflict over natural resources, effective management regimes were able to ameliorate these tensions.[232]

Migration is likely to continue and even to increase in the near future. The current debate convulsing Europe, where boatloads of migrants from Africa and the Middle East are daily making their way across the dangerous waters of the Mediterranean, are mirrored by the increasingly protectionist policies emerging in a number of powerful economies. Some countries have practiced policies excluding other nationalities for many years. Others, including some of those where the issues are most controversial, rely heavily on migrant labor to keep their economies growing. In general, migration policies have been less restrictive.[233] The presence of a tiny proportion of terrorists among the migrants creates fears leading to the rejection of people fleeing war and persecution, thus worsening existing humanitarian catastrophes.

A new approach to migration is urgently required, one which is closely linked with many of the other issues discussed here. People often migrate because they feel they have to. From the perspective of the land, this is likely because crops are failing, they have insufficient access to land and resources, poor security of tenure, or because the climate is changing and they can no longer produce adequate amounts of food or income. Most of these issues can only be addressed by decision makers far from the affected areas, although often in the same country. A scale shift from rural to urban areas is underway with a smaller but more visible shift from poor to rich countries. Migrants need to be once again welcomed for the diversity and skills that they bring to their new homes but, at the same time, migration out of desperation requires larger-scale political and environmental responses.

CONCLUSION

Humans have always had an intimate relationship with the land, and settlements have ebbed and flowed, appeared and disappeared, partly as a result of the interaction between natural resource management and climate conditions. These relationships are complicated and easy explanations usually misleading.

Today, many ecological problems are made worse by a range of social, economic, and political issues. Too many people are either landless or have no security of tenure, desperately poor and without any safety net to withstand climate change or other stressors. Social relationships and gender inequity further hamper progress towards food, water, and overall human security. Most of the issues that create the largest challenges for the poorest and most vulnerable members of society are completely outside of their control. At the same time, everyone, rich or poor, is vulnerable to future shortages on a planet of finite resources. Competition for dwindling resources risks destabilizing communities and countries. One result is a rapid increase in migration, with millions of people on the move. Some of the outcomes have been positive, while others increase pressure and add to regional tensions.

The result is a general increase in economic, political, and social insecurity, with established social and political orders breaking down, often leaving a vacuum. People are feeling anxious, frightened, and looking for scapegoats. While we have stressed that making a simplistic link between land degradation and human insecurity is precarious, the catalytic effect of these factors is becoming increasingly clear. The fact that peace and security are often expressed in other terms – such as religious or ethnic intolerance – should not distract us from the massive destabilizing impacts of soil loss, crop declines, desertification, and water scarcity. Addressing these fundamental land issues can help relieve a host of societal and political tensions.

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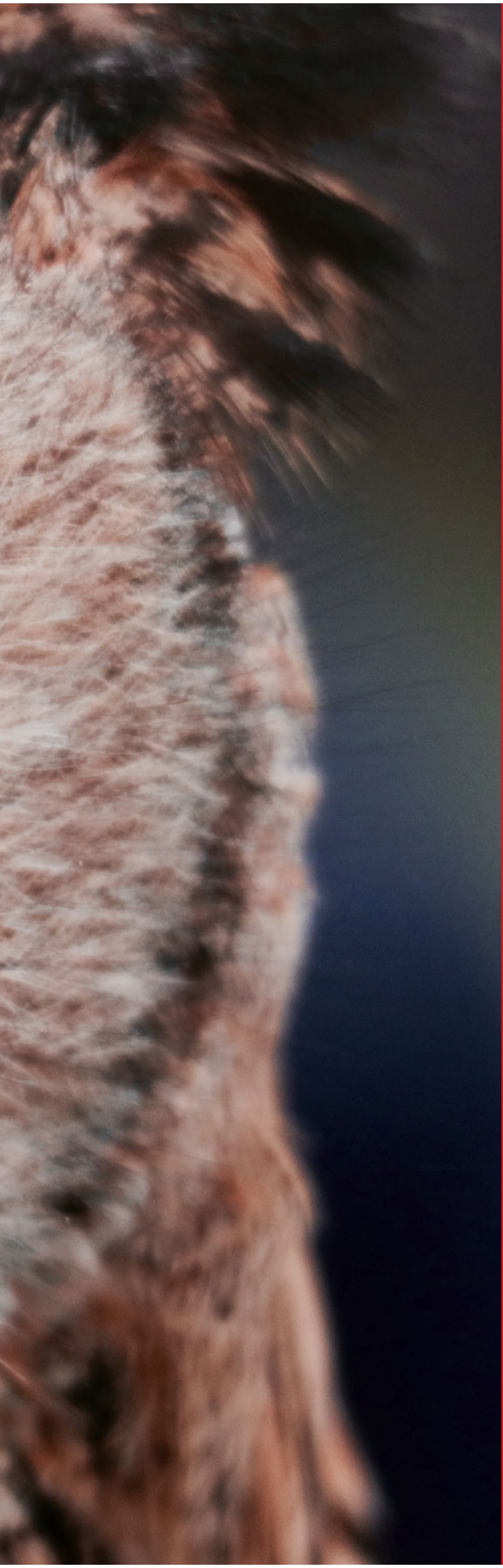


Part Two
THE OUTLOOK

An outlook is a vantage point, a platform, a perspective; it broadens our vistas and allows us to examine our prospects, both present and future. It is within this broader frame of thinking that the *Global Land Outlook* aims to present a unique perspective on one of the Earth's most precious assets: land. As we grapple with the current state of our land resources – a sober reminder of past misuse and mismanagement – Part Two presents both grounds for concern and opportunities for action. It provides a brief overview of how land resources are used today and assesses likely scenarios for how we can sustainably meet the demand for land, and its goods and services, in the future. It focuses on broader policy and practice, the cardinal issues long requiring attention, as well as the emerging concerns that need to be considered in the global public policy agenda.

Part Two

CHAPTER 6

SCENARIOS OF CHANGE

Given growing demands on land and emerging challenges from land degradation and climate change, policymakers require information on the possible consequences. This chapter explores trends up to 2050, through the Shared Socio-economic Pathways scenarios, based on the report '*Exploring the impact of changes in land-use and land condition on food, water, climate change mitigation and biodiversity: Scenarios for the UNCCD Global Land Outlook*'.[1]

Different scenarios point to large differences in future land-use, but Sub-Saharan Africa, the Middle East and North Africa, South Asia and, to a lesser extent, Southeast Asia are the regions that will bear the brunt of growth in population and overall consumption, and rapidly increasing pressure on the remaining land resources. Under all scenarios, the strongest regional land-use change is expected in Sub-Saharan Africa; however, the best land is already in use and expansion will increasingly take place on less productive lands, resulting in lower yields. Several regions have little land left for agricultural expansion or only more marginal land, such as in South Asia.

Future changes in the condition of land resources are also projected to be extensive as a result of continued land-use change and the deterioration of soils, land cover, and biodiversity. Biodiversity loss, in terms of mean species abundance, is projected to continue by 4 to 12 per cent point up to 2050, depending on the scenario, and will continue well into the second half of the 21st century. Changes in land cover and soil quality affect the probability of flooding and drought. The effects are amplified in drylands, which also face above-average population growth. Almost 20 per cent of the Sub-Saharan African land area shows declining productivity when corrected for climate effects, in most other regions this is between 5 and 10 per cent. On a global level, by 2050, there may be an additional 5 per cent expansion in cropland to compensate for these productivity losses.

To date, global soil organic carbon has been reduced by 176 Gt compared to the natural, undisturbed state. If current trends continue, anthropogenic land-based carbon emissions from soil and vegetation will roughly add another 80 Gt of carbon to the atmosphere over the 2010–2050 period, equivalent to about 8 years of current global carbon emissions from fossil fuels. Abating these projected land-based emissions would leave more of the available global carbon budget of 170–320 Gt C intact (i.e., the amount in CO_2 emissions that can still be emitted without jeopardizing the target of keeping average global temperature increase below 2°C). The global potential to store carbon in soils is considerable but requires the development of agricultural systems that combine high yields with close-to-natural soil organic carbon levels.

INTRODUCTION

Global scenarios on land-use change and land degradation represent potential storylines, descriptions, and evaluations of how the future may unfold, e.g., the possible future state of land resource use, demand, and condition. The scenarios presented here are a tool to explore uncertainties associated with possible future development pathways focused on the relevant human and environmental dimensions.[2] The increasing demand for food, water, energy, housing, and other land-based goods and services, and the resulting impacts on the quality and productivity of the land, is at the heart of these scenarios.

The primary aim of a scenario in this context is to help decision-makers to explore and shape the future and realize a long-term vision of sustainable development for all. In Part Three of this *Outlook*, scenarios that reduce pressure on our land resources are translated into broadly understood principles and response pathways. By analyzing the various pressures and forces that drive land-use change and land degradation, scenarios also allow a range of stakeholders at various scales to test how well the expected demand for and management of land resources will help achieve the Sustainable Development Goals (SDGs) and their targets, specifically SDG target 15.3 on land degradation neutrality.

Shared Socio-Economic Pathways

Global modelling requires an agreed methodology, which relies on the development of consistent storylines, followed by transparent modelling.[3] Most recently, the Shared Socio-Economic Pathways (SSPs) have been developed to provide a framework for scenario analysis, considering multiple driving forces of economic development, population, technological development, land-use, and international cooperation.

The SSPs represent alternative characterizations of possible societal futures for use by different research communities, including narrative descriptions of future trends and quantitative information for some of the key elements. This chapter is based on the scenario analysis[4] being undertaken by the PBL Netherlands Environmental Assessment Agency, in cooperation with Wageningen University, University of Utrecht, and the Joint Research Centre of the European Commission, and with the support of many experts from different fields and organizations. It shows the results of three explorative scenarios (SSP1–3) and one variant on the SSP2 scenario (the SSP2 productivity decline scenario) to estimate the order of magnitude of global changes in land-use, and condition up to the year 2050 under different societal development paths.

Table 6.1: Assumptions embedded in the three SSP scenarios.

	SSP1 Sustainability	SSP2 Middle of the Road	SSP3 Fragmentation
Globalization of trade	High	Medium	Low
Meat consumption	Low	Medium	High
Land-use change regulation	Strict	Moderate	Little
Crop yield improvement	High	Medium	Low
Livestock system efficiency	High	Medium	Low

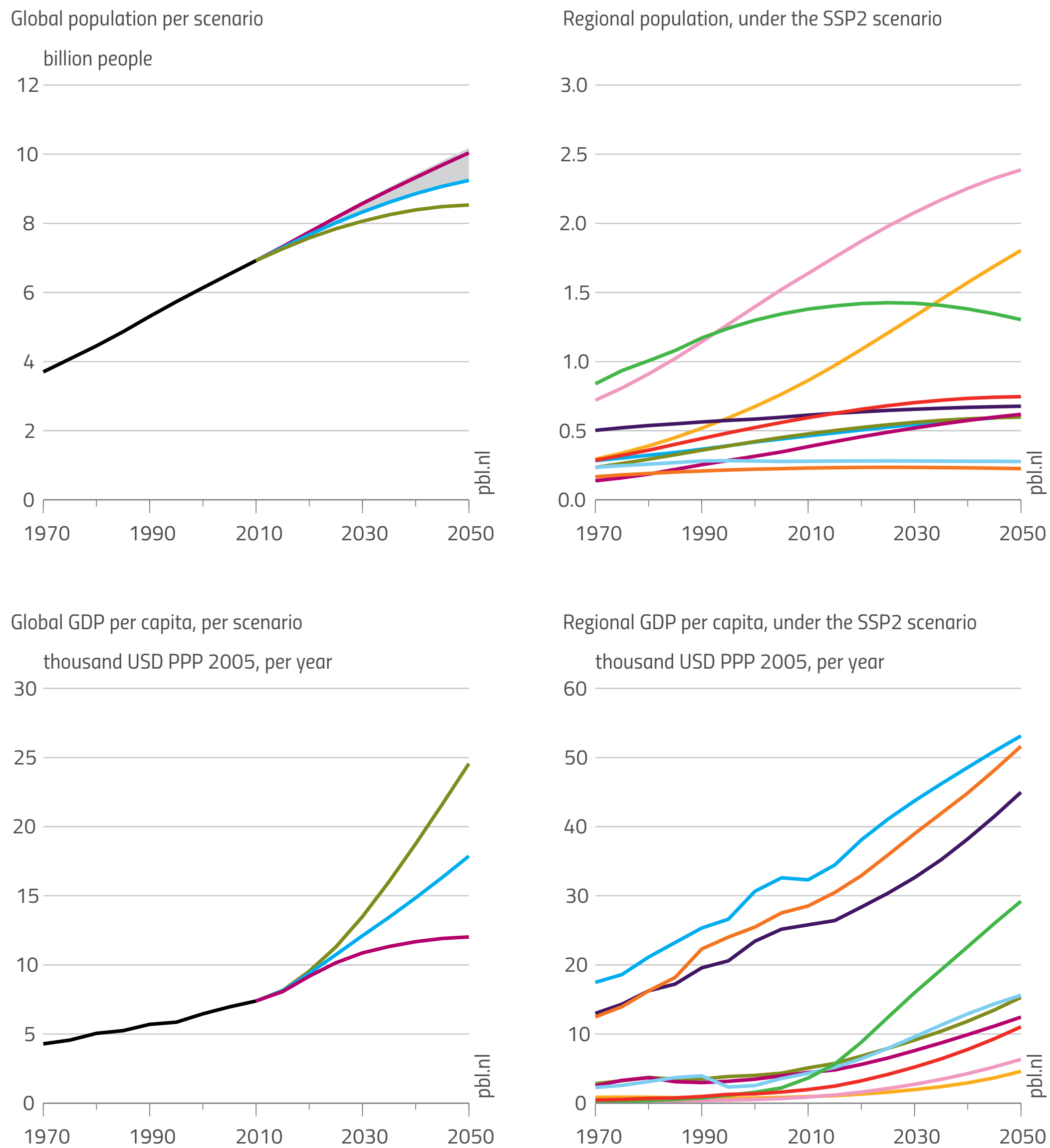
These quantitative scenarios embed a set of internally consistent assumptions within a coherent storyline. The 'Middle of the Road' scenario (SSP2) is characterized by the continuation of current trends (business as usual); the 'Sustainability' scenario (SSP1) depicts a more equitable and prosperous world striving for sustainable development; and the 'Fragmentation' scenario (SSP3) portrays a divided world with low economic development, high population growth, and limited environmental concern.

In order to explore the impact of changes in land condition, a variant of the SSP2 scenario was created. The scenario 'SSP2 productivity decline' includes, in addition to SPP2, the impact of a decline in productivity, land cover and/or soil quality from poor land management. It assumes the continuation of the net primary productivity decline between 1982-2010, as observed by remote sensing techniques and corrected for climate effects, up to 2050. In order to discern the magnitude of changes in land condition from poor land management rather than that of climate change, the data have been corrected for climate change effects over the same period.

While all scenarios are potential futures, their storylines differ widely. This helps to explore the potential range of future developments in land-use, demand, and condition. These ranges then give decision-makers sufficient bandwidth within which they can expect changes to take place and challenges to materialize. Table 6.1 lays out the major differences in assumptions made for each of the three SSP storylines. These scenarios are elaborated with the IMAGE model,[5] by applying quantitative projections for populations,[6] urbanization,[7] and economic development,[8] and by quantifying model parameters to reflect the storylines as described above. The scenario results span the energy system, food production, land-use, GHG emissions, climate change, biodiversity, and impacts on water and soil properties. In assessing the trends in biodiversity, soil properties, and hydrological systems, both land-use change and climate change are important drivers that are accounted for in the modelling. For land-use patterns and the agro-economic system, however, climate change impacts are not included due to the large uncertainties and the experimental design.[9] The change in soil properties, biodiversity, and hydrological systems are elaborated with the S-World model,[10,11] GLOBIO model,[12] and PCR GLOB WB model[13,14] respectively.

The Shared Socio-Economic Pathways describe plausible alternative trends in the evolution of society and natural systems over the 21st century at the level of the world and large world regions. They consist of two elements: a narrative storyline and a set of quantified measures of development.

Figure 6.1: Socio-economic drivers (GDP and population) quantified for the SSP scenarios (PPP is purchasing power parity).
Source: PBL/IMAGE



Population and Economic Growth

In all three scenarios, past population growth patterns will continue to 2050, yet at different rates (Figure 6.1). Global population growth is assumed to start levelling off in SSP2. The world population reaches about 9 billion people in 2050 but continues to grow rapidly in Sub-Saharan Africa with population doubling within 40 years; high growth rates are also projected for North Africa, the Middle East, and South Asia. Other regions show clear signs of levelling off or even declines in population. In SSP1, population growth is slower, peaking at about 8 billion in 2050, primarily due to lower growth rates in Sub-Saharan Africa, South and Southeast Asia.

In SSP3, population growth continues at its current rate and reaches more than 10 billion in 2050, primarily due to higher growth rates in all regions but especially in Sub-Saharan Africa and South and Southeast Asia.

Economic growth follows historical trends in SSP2, is assumed higher than historical trends in SSP1, and lower than historical trends in SSP3, especially in less developed regions. As a result, trends in population and economic growth partly compensate for each other in SSP3 with respect to food demand due to a larger but less affluent population. In SSP1, despite higher incomes, lower population numbers and attention to environmental concerns keep food demand below SSP2 levels.

Figure 6.2: Land currently in use (dashed line), in 2050 and the potential of remaining suitable land for agriculture under the SSP2 scenario.
Source: PBL/IMAGE

Key

Land area used in 2050

Crops

Pasture

Potential of remaining land suitable for agriculture

Very high

High

Moderate

Low

Land area used in 2010

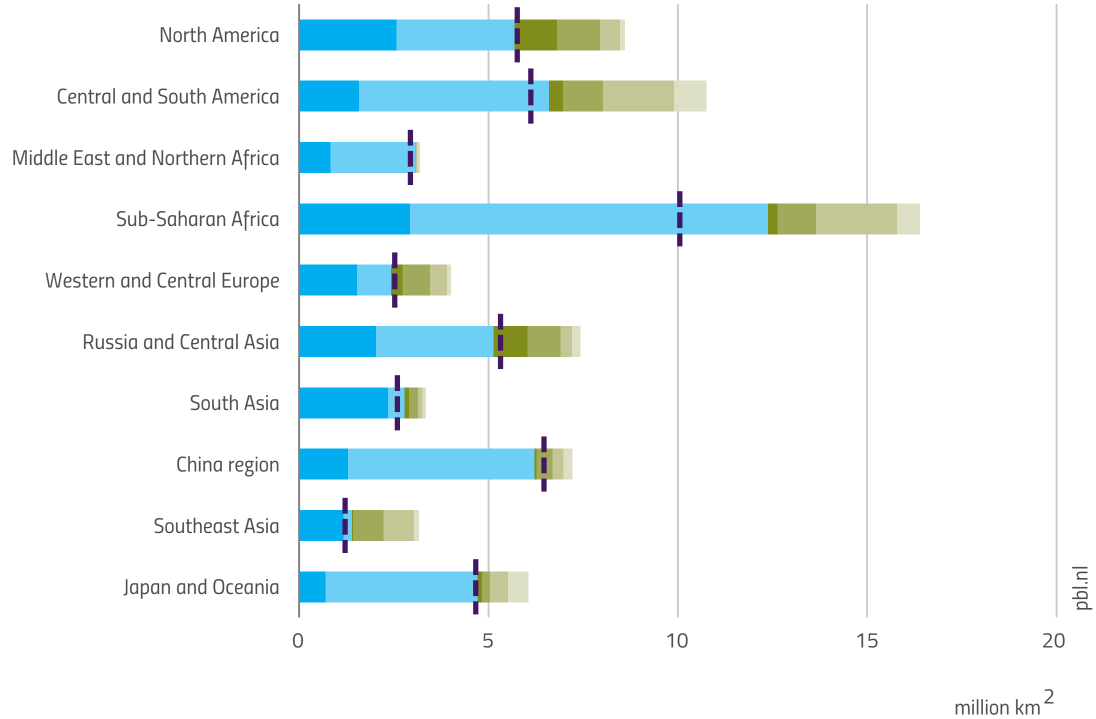


Figure 6.3: Land productivity potential of newly converted agricultural area.
Source: PBL/IMAGE

Key

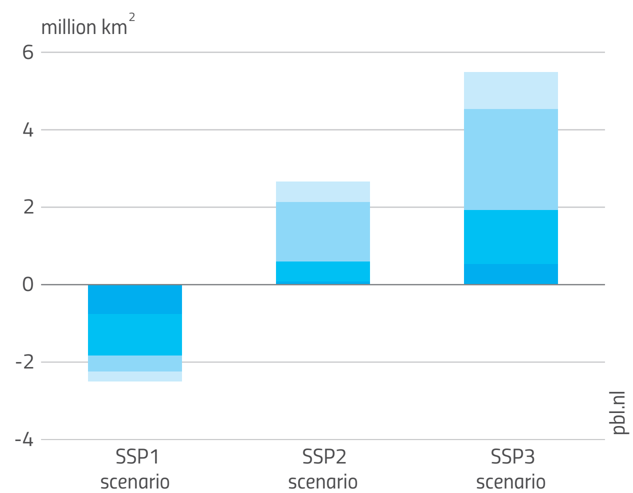
Crop productivity class of converted land

Low

Moderate

High

Very high



Results from PBL's scenario analysis

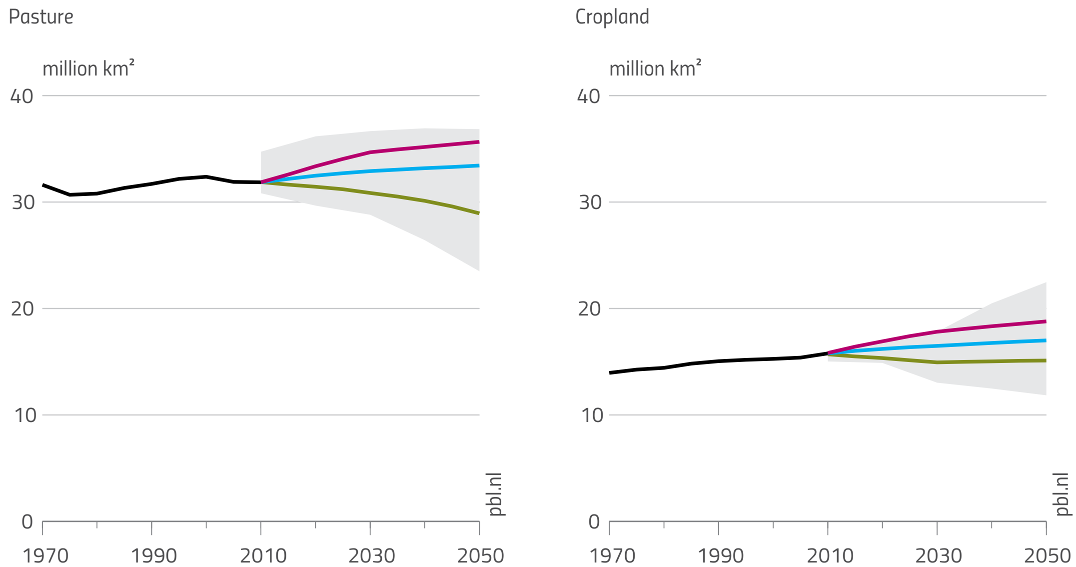
In all three scenarios, the demand for land-based goods and services will continue to grow rapidly over the coming decades.[15] This includes agricultural products (e.g., food and fodder), fiber (e.g., cotton and timber for construction and paper), and fuel (e.g., fuelwood, biomass, liquid biofuels). In addition to the demand for land-based products, cities, villages, and infrastructure are built on land, and the conservation of forests and other natural areas for biodiversity, ecosystem services, and climate mitigation and adaptation all require land.

Overall, the scenario findings are robust as the overall linkages between food, fodder and their respective land-uses are well understood and rely on a broad empirical base. The key uncertainties in future land-use dynamics are the change in demand for agricultural products and trends in crop yields

Figure 6.4: Global trends in land-use for the SSPs (colored lines) and the range in other models[16] (grey area) for 2010–2050.
Source: PBL/IMAGE

Key

- History
- SSP1 scenario
- SSP2 scenario
- SSP3 scenario
- IAM model range for scenarios SSP1, SSP2 and SSP3



and livestock production systems. All global models indicate for the Middle of the Road scenario SSP2, and even more so in SSP3, that the century-old trend to convert forested areas into agricultural land will continue at least until 2050. Not only will forests be affected by future land-use demands from agriculture but so will savannas and grasslands. As a consequence, we can expect continued habitat loss and the associated biodiversity impacts. The following sections reflect the following chapters in Part Two of the Outlook which present in more detail the evidence and potential future policy issues.

Agriculture

The remaining natural land suitable for agriculture is limited, with expansion increasingly taking place on more marginal lands. With much of the land potentially available for agriculture already in use, either for crops, livestock, or urban areas, additional land for agriculture has to expand to areas that are less productive (Figure 6.2). Using less productive land requires more area and/or inputs for the same output. Moreover, marginal lands are often more difficult to manage and more prone to degradation: they may be on slopes, have thin and less fertile soils, be more difficult to work, or restricted by water shortages or climate factors. Farmers thus require more effort and inputs, on top of having conditions that are less favorable than elsewhere. In various regions, smallholders are more likely to be pushed into marginal areas whereas larger producers maintain control over more fertile land.

Two out of the three scenarios project an increase in agricultural land-use: approximately 50 per cent (in SSP3) and 80 per cent (in SSP2) of that increase is estimated to take place on land of low or moderate productivity (Figure 6.3). In contrast, in the SSP1 scenario, the net global agricultural area will decrease as a result of the combination of low population growth, more attention to sustainable consumption and production (e.g., lower levels of meat consumption and food waste), and increased efficiencies in crop and livestock systems. In Europe and Russia, accounting for a large fraction of the world's most fertile lands, even highly productive land will face land-use change or abandonment. From the perspective of global efficiencies in land-use, more trade in land products would help allocate production to regions according to their comparative advantage. Still, there are many other concerns, such as domestic food self-sufficiency and the cost of transport, and CO_2 emissions due to long-distance transport.

Global land-use change is expected to continue in the SSP2 scenario, with the expansion of cropland from 15 million km^2 in 2010 by about 0.9 million km^2 in 2030 and 1.2 million km^2 in 2050, with an additional 1.4 million km^2 for energy crops in 2050. Pasture area (including grassland area for livestock) is projected to increase by about 1.6 million km^2 by 2050 (Figure 6.4).

Figure 6.5: Change in land-use and natural areas, globally (left) and regionally (right)
Source: PBL/IMAGE

Key

- Other natural land
- Forest
- Pasture
- Energy crops
- Food and feed crops
- Built-up area
- Range between scenarios SSP1 and SSP3

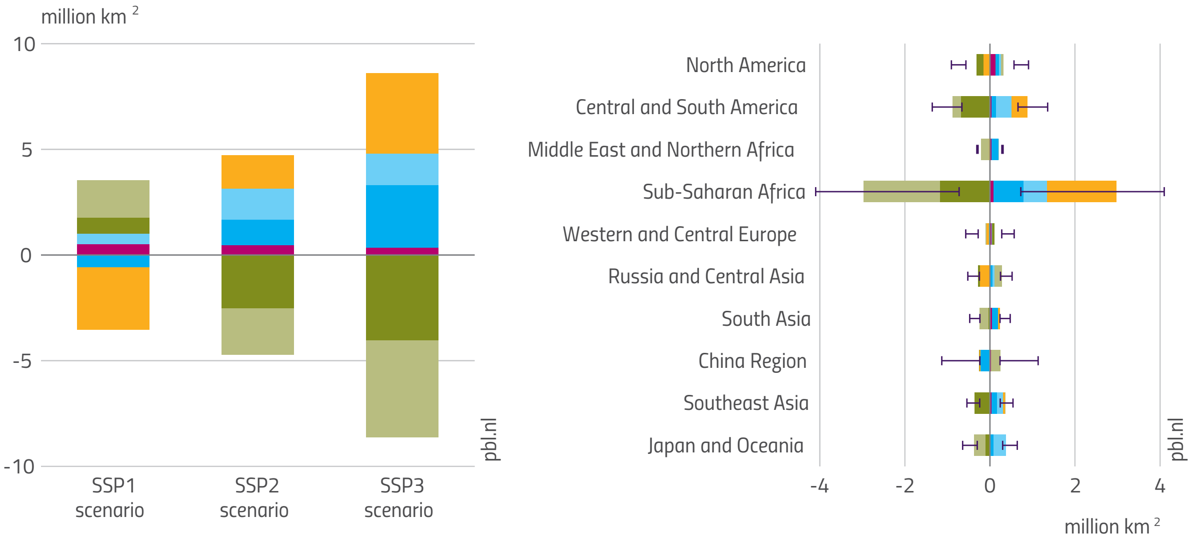


Figure 6.6: Land-use change over the 2010–2050 period: green indicates expansion of natural areas; purple indicates expansion of agricultural land/built up areas.
Source: PBL/IMAGE

Key

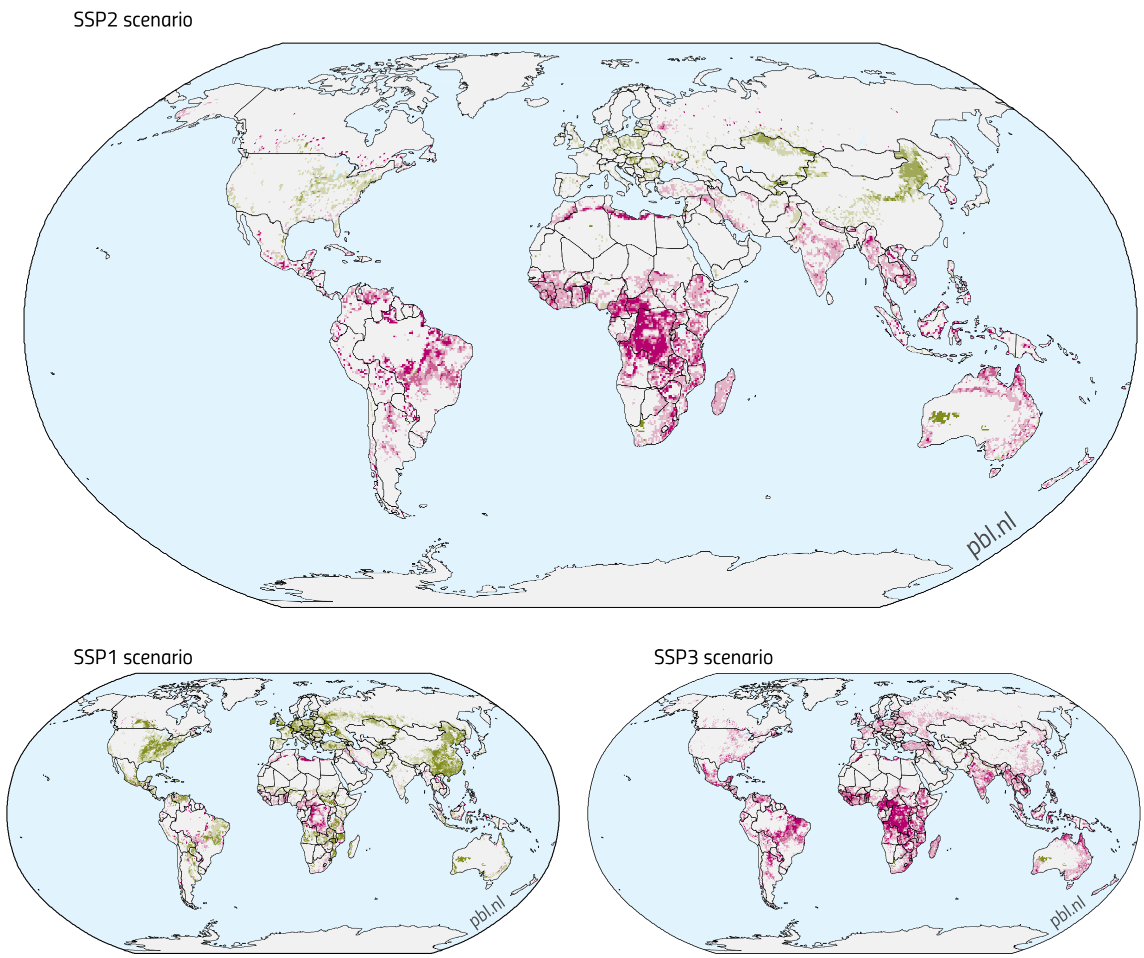
Deforestation and conversion of other natural land (% change per grid cell)

5 30 50 100

Reforestation and abandonment of agriculture to other natural land (% change per grid cell)

5 30 50 100

No or small change (less than 5%)



The SSP3 scenario shows larger expansions for cropland, bioenergy, and pasture than SSP2, mostly due to slow technological development. In the SSP1 scenario, a net decrease in agricultural area is projected globally due to small increases in population, more sustainable consumption and production, and increased efficiency in crop and livestock systems, thus requiring less land. The expansion of agricultural land is greatest in Sub-Saharan Africa due to high population growth and increasing demand for food and fodder, which cannot be met completely by increases in efficiency. Also in SSP1, despite a net decrease at the global level, agricultural land-use expands in Sub-Saharan Africa; in SSP3, expansion is about 40 per cent higher than in SSP2 due to slow improvements in crop yields and livestock system efficiency (Figure 6.5 and 6.6).

Land-use change is driven by the continued increase in the demand for food, fuel, and fiber. Global demand drives agricultural and timber production increases of 27 to 77 per cent until 2050, under the various scenarios and depending on population and income projections. This is in line with the range across the literature.[17] In the developing regions, the increase in production is moderate, as the growth in demand is levelling off, but large increases are expected especially in Sub-Saharan Africa (more than 150 per cent), South and Southeast Asia and Latin America (more than 70 per cent), driving agricultural land-use change. Part of the increasing regional demand is also met via production in other regions and trade.

In the SSP1 scenario, the increase in demand is much smaller in most regions or even constant. Changes in food demand in SSP3 are often similar to SSP2 at both global and regional levels as higher population and lower economic growth compensate each other: SSP3 has higher population, which would lead to more demand, but also less income, which would lead to less demand when compared to SSP2. In driving land-use change, agricultural intensity (crops and livestock) makes up the difference between these two scenarios. Timber production remains at high levels in developed regions in all scenarios and shows some increase in Latin America, Africa, and Southeast Asia, often via increased forest plantations.

Nitrogen and phosphorus fertilizer use is expected to increase rapidly in countries where use is currently low, improving land-use efficiency, but risking adverse environmental effects. Much of current market-oriented agricultural production has become reliant on artificial fertilizer, with naturally occurring soil nutrients not able to sustain current yield levels in many locations. In the SSP2 scenario, the rapid increase in food production will lead to increases in nitrogen and phosphorus fertilizer use, especially in regions where fertilizer use is currently low. Earlier comparable scenario projections estimate a 36 per cent increase in global nitrogen fertilizer use and 44 per cent in the use of phosphorus between 2005 and 2050, but with a quadrupling of phosphorus fertilizer use in Sub-Saharan Africa.[18]

All SSP scenarios show significant expansion of agriculture on tropical soils that are vulnerable to erosion. Soils under tropical forests are generally poor and weathered, with a long history of abundant rain and high temperatures having leached out most nutrients. The high productivity of natural vegetation is sustained via a near-closed cycle in which the majority of nutrients are found in the biomass and in the layer of dead and decomposing matter on the forest floor. The largest cropland expansion is projected in the Congo basin as a result of large increases in demand in Sub-Saharan Africa, even under the relatively optimistic assumption of around 200 per cent increase in agricultural productivity in that region under the SSP2 scenario. Without sustained and effective soil management systems, clearing these lands for agriculture could result in quickly declining agricultural production due to a lack of nutrients and exposure to water erosion.

Globally, continuing productivity loss in particular areas may require additional cropland expansion as compensation by 2050. Assuming local negative trends in net primary productivity as a proxy for land-based productivity declines in croplands allows for a first estimate of the additional cropland required to compensate for that loss. According to this SSP2 productivity decline scenario, this would result in a 5 per cent larger cropland area by 2050, on top of the 8 per cent expansion under the SSP2 scenario which was based on growth in food demand only. Regions that show the most additional expansion under these assumptions are North Africa, the Middle East and North Africa, Russia and Central Asia, Sub-Saharan Africa, and Japan and Oceania.

Water Resources

Future water security faces a multitude of risks from a scarcity perspective. These risks relate to the robust increase in water demand, uncertainties on non-renewable groundwater depletion, reductions in water quality, and changes in rainfall patterns as well as changes in soil depth, soil texture, and soil organic carbon. With the decline in soil condition, the ability of soils to hold water declines. Water holding capacity is especially relevant for rain-fed agricultural production in drylands, where rainfall can be erratic and the buffering function of soils to store water is used by plants to survive longer dry spells. Low yields in dryland systems are often ascribed to excessive water evaporation from soil surface, where higher amounts of organic mulching can – although not in all situations – improve water infiltration and storage, and therefore increase productivity.[19] When more water can be stored in the soil (e.g., due to mulching), the delayed release of moisture to groundwater systems can have a smoothing effect on river discharge.

Under the SSP2 scenario, the total global water demand increases from 2,056 km^3 to 2,445 km^3. Southeast Asia and Sub-Saharan Africa show the largest increase in water demand, due in large part to the demand by industry and households. Water scarcity refers to its limited availability given the total demand of different users. Water scarcity, now and in the future, is prevalent in densely populated regions such as India, Asia, the western United States, and Spain (Figure 6.7). These regions consist of large arid and semi-arid areas. Figure 6.7 also shows the regions that will experience an increase in water scarcity. Among others, in the east central coast of Africa, the Great Plains of the USA, around the Mediterranean Sea, and in parts of the Yangtze basin, water scarcity may slow down economic growth.

The extent to which local water scarcity will become problematic also depends on local storage, the pumping of groundwater from aquifers, or measures upstream to prevent shortages downstream.
The scenarios explored here only sketch the risks and do not include these potential mitigation and adaptation measures.

In the SSP2 scenario, many river basins with higher precipitation levels due to climatic changes show increases in runoff that are larger than expected based on the increases in precipitation alone; land cover change appears to reduce the ability of ecosystems to buffer water flows and thus leads to a higher runoff rate. The effects are amplified

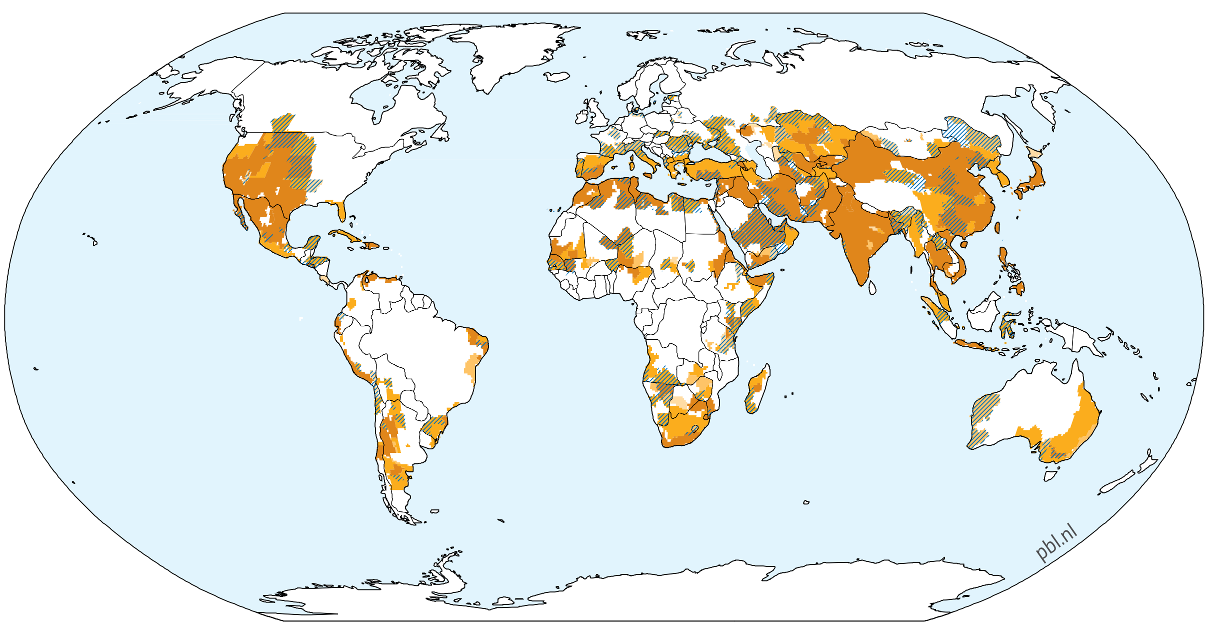


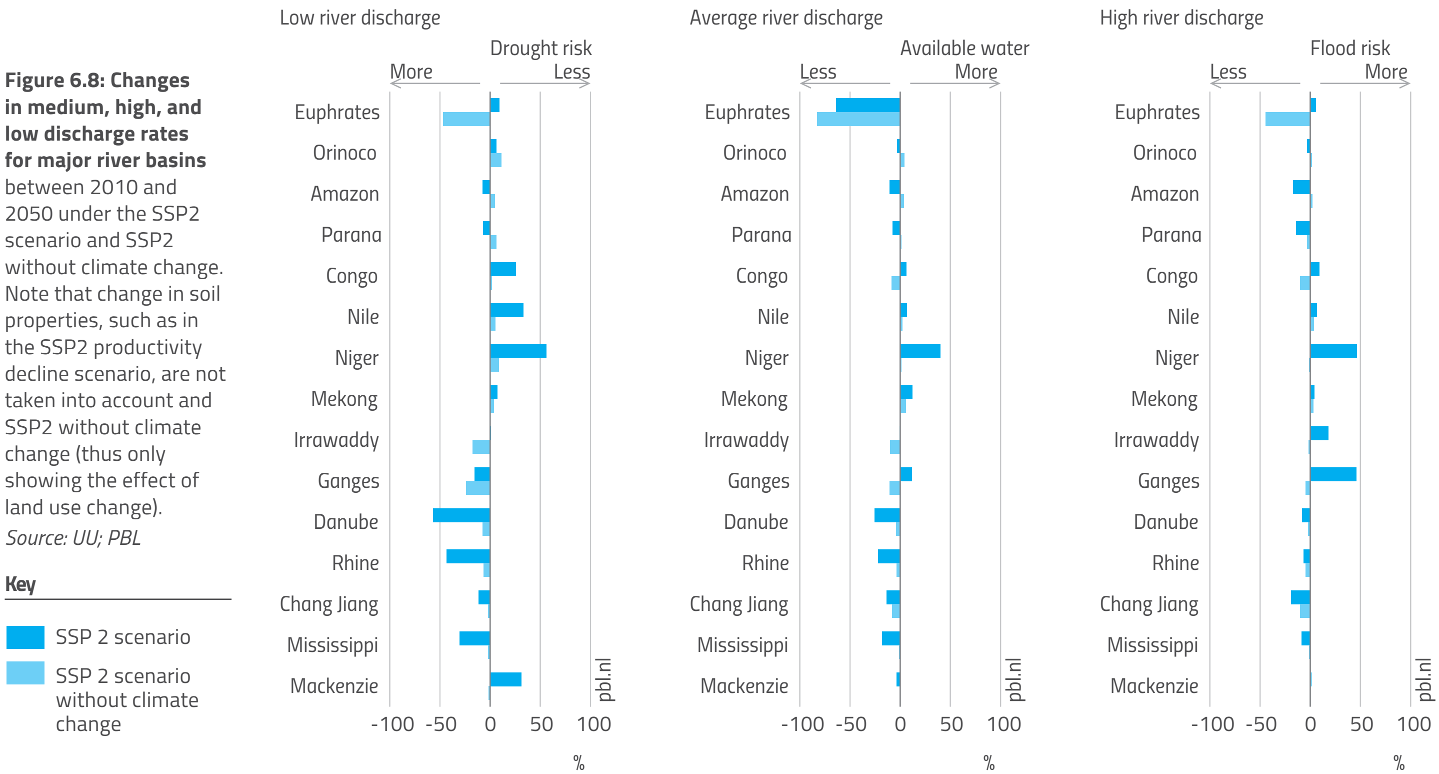
Figure 6.7: Global projections of dynamic water scarcity, between 2010 and 2050, under the SSP2 scenario: the dynamic water scarcity index map is based on a monthly timescale and accounts for how often and how persistent water scarce conditions occur in a year. *Source: UU*

Key

- Low (0.1-0.2)
- Moderate (0.2-0.4)
- High (0.4 -0.8)
- Very high (0.8 or more)
- No water stress (less than 0.1)
- Projected increase in water stress, compared to 2010

Figure 6.8: Changes in medium, high, and low discharge rates for major river basins between 2010 and 2050 under the SSP2 scenario and SSP2 without climate change. Note that change in soil properties, such as in the SSP2 productivity decline scenario, are not taken into account and SSP2 without climate change (thus only showing the effect of land use change).

Source: UU; PBL



in dryland regions, where for many small basins just a little intensification in land-use can cause a significant change in runoff.

Climate change and land cover change result in changes in runoff which influence river flow volumes. Based on average discharge, river basins may get wetter or drier. But as river discharges generally show a high natural variability, high and low discharge volumes rather than average discharge levels provide more information about the hazards of flooding and drought. Figure 6.8 shows the relative change in low, average, and high discharge volumes for the SSP2 scenario, with and without climate change, for some of the larger river basins of the world. Several developments may amplify or moderate one another and the extent varies per river basin, depending on the local situation. A negative change in low discharge means that their volumes will become smaller, indicating that a river basin will be more susceptible to hydrological drought. For high discharges, it is the other way around.

Biodiversity

Biodiversity loss, as measured by mean species abundance (MSA), is projected to increase from 34 per cent in 2010 to 38, 43, and 46 per cent under SSP1, 2, and 3, respectively (Figure 6.9). In SSP1, the rate of loss is slowed down by halting the expansion of cropland although this leads to a higher impact from forestry. This is a typical example of trade-offs between different sector developments; the forestry area has to expand more than in SSP2 and SSP3 to compensate for the absence of timber production from forests cleared for cropland expansion. SSP2 and SSP3 show the biggest biodiversity losses as a cumulative effect of the increase in cropland, also including bio-energy crops, infrastructure, and encroachment from human settlements, forestry, and climate change. These scenarios would continue or even accelerate the rate of loss recorded in the 20th century. In all scenarios, the loss in biodiversity continues well beyond 2050 while the impacts from climate change accelerate in all scenarios.

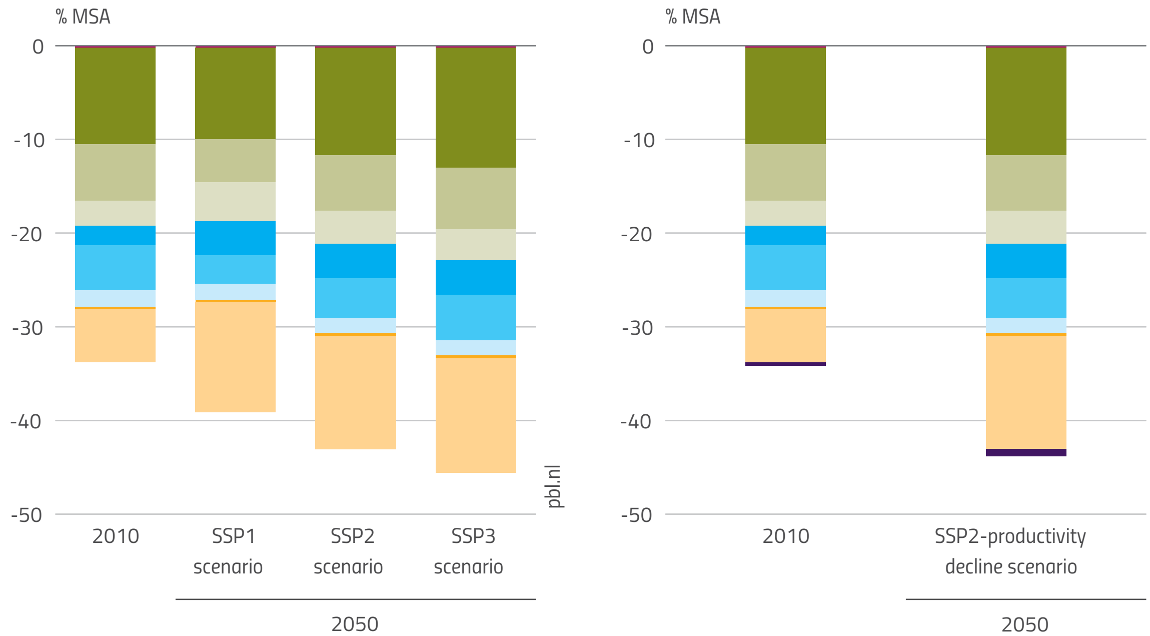


Figure 6.9: Global biodiversity loss relative to the natural situation in 2010 and in 2050 under the SSP1, SSP2, and SSP3 scenarios (left), and for 2010 and 2050 under the SSP2 productivity decline scenario (right).
Source: PBL/IMAGE

Key

- Urbanisation
- Crops
- Biofuels
- Pasture
- Forestry
- Infrastructure
- Encroachment
- Fragmentation
- Nitrogen deposition
- Climate change
- Productivity decline

The SSP2 productivity decline scenario shows an additional biodiversity loss of about 1 per cent point by 2050 (Figure 6.9). The largest share originates from the loss in the productivity in croplands that leads to additional cropland expansion in order to compensate for the loss. A smaller part comes from former land use, now abandoned, and informal, extensive land use, such as extensive grazing and fodder and wood collection. One per cent point may be perceived as relatively small but in absolute terms it is a considerable amount. As a reference, 1 per cent point in MSA loss is equivalent to complete biodiversity loss in a pristine area about 2.4 times the size of continental France.

Soil, Vegetation, and Carbon

The total historical anthropogenic loss of soil organic carbon (SOC), mostly from conversion of natural ecosystems to agriculture, has resulted in an estimated loss of 176 Gt of SOC, equivalent to 8 per cent of the total SOC pool of the total SOC pool of about 2,200 Gt under natural conditions.[19,20] This is in line with the estimates in the literature.[21,22,23] It is estimated that much of these losses have occurred in Europe, the Indian subcontinent, the Sahel, the south-eastern part of South America, and in large parts of China (Figure 6.10 middle).

Under the SSP2 productivity decline scenario, cumulative emissions from SOC are estimated at around 27 Gt C over the 2010–2050 period (Figure 6.11). Of this, 16 Gt C originates from the future conversion of natural land into agricultural land, and 11 Gt C from continued decline in land cover and productivity, other than from land conversion. The largest part of these future losses is expected in the southern hemisphere regions, especially Sub-Saharan Africa (Figure 6.10 bottom). Medium and low productive soils, often with low carbon content, may lose a relatively high share of their (already small) total carbon pool in a short timeframe when they are converted to cropland.

The continued drainage of peat soils and subsequent peat fires are estimated to contribute cumulatively about 9 Gt C (±2) emissions between 2010 and 2050. This amount is based on projections of emissions in Southeast Asia[24] and the extrapolation of current emissions from Europe, including European Russia.[25] Cumulative carbon emissions from vegetation loss are estimated at around 45 Gt C by 2050; this is biomass loss due to agricultural expansion, forest degradation, and forest management (Figure 6.11). This is the net balance of, in particular, afforestation in the Northern regions and continued deforestation in the southern regions.[26]

The above anthropogenic land-based emissions add up to around 80 Gt C by 2050, equivalent to about eight years of annual carbon emissions from fossil fuels of 9.9 Gt C/y[27] (Figure 6.11). These estimates do not include the feedbacks of climate change (temperature and precipitation) on SOC stocks nor the impacts from CO2 fertilization on carbon stocks in vegetation.

Figure 6.10: Current SOC content (top); historical loss of SOC as fraction of SOC in a natural state (middle); future loss of SOC as fraction of the current state under the SSP2 productivity decline scenario (bottom).

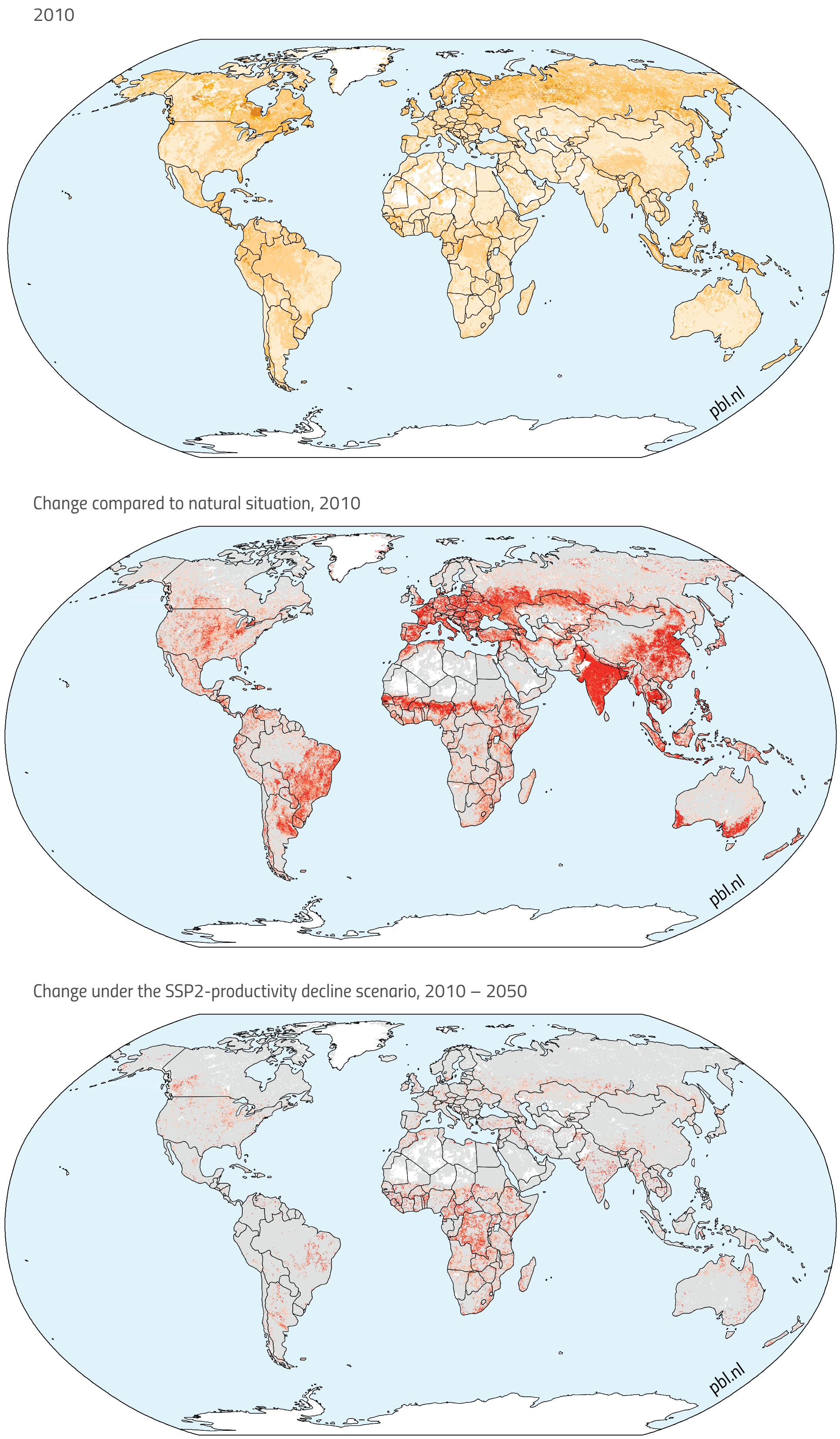
Source: Stoorvogel et al. 2017; Schut et al. 2015; PBL

Key

- Low (1.5% or less)
- Moderate (1.5-3.0%)
- High (3.0-5.0%)
- Humose (5.0-12.0%)
- Organo-mineral (12.0-35%)
- Organic (More than 35%)

- 50 and more
- 30 - 50
- 20 - 30
- 10 - 20
- 2 - 10
- 2% loss - 2% growth
- More than 2% growth

- No data



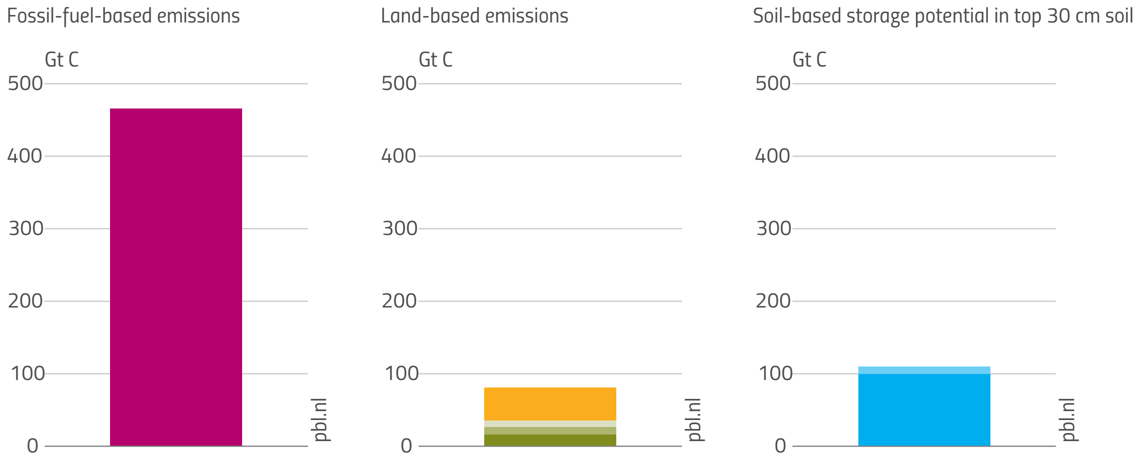


Figure 6.11: Cumulative carbon emissions from fossil fuels from the energy and industry sector (left); cumulative land-based emissions from vegetation (land-use change) and soils (middle); carbon sequestration potential in the top soil (< 30 cm) in agriculture and natural land (right).
Source: PBL

Key

- Total
- Vegetation

Soil organic carbon

- Peatland (drainage, burning)
- Productivity decline
- Land-use change
- Natural area
- Agricultural area

Since the greatest part of the historical loss in SOC originates from the top 30 cm soil in agricultural land, the greatest restoration potential is in current agricultural land. This global potential is considerable but requires the development of agricultural systems that combine high yields with close-to-natural SOC levels (Figure 6.11).

Future land-based carbon emissions are relatively small compared to the emissions from fossil fuels (Figure 6.11). Nevertheless, reducing future land-based emissions and utilizing the carbon sequestration potential in agricultural land would be significant from a climate change mitigation perspective. Scenarios with a likely probability of keeping global temperature increase below 1.5°C to 2°C require future cumulative CO_2 emissions to be limited to 170–320 Gt C.[28,29,30]

Climate Change

The impact of climate change on agriculture is likely to decrease yields and the availability of suitable agricultural land in some regions, while increasing yields in others for moderate levels of warming. This will likely lead to both altered trade patterns and the expansion of agricultural areas, but the uncertainty range of the climate change impacts on agricultural land-use is very large.[31] The impact differs widely between regions: while some temperate regions are likely to benefit from higher temperature and longer growing periods, regions like Sub-Saharan Africa and India are expected to see yield declines due to increased water limitation and – even more importantly – higher temperatures.[32]

Drylands are especially vulnerable. Figure 6.12 shows a global map of current aridity and future change under the SSP2 scenario. Higher productivity due to CO_2 fertilization may compensate for some of the adverse effects, but it is still unclear to what extent these benefits can be realized in practice. Globally, yields on existing cropland could decrease by 10-15 per cent while the area suitable for cropland may increase about 10 per cent, in particular in the northern hemisphere. This would result in a few per cent decline in global production by 2050 compared to a situation without climate change, but the picture is significantly more diverse at the regional scale and moderated through trade.

In addition to the impacts on the suitability of land for food production, climate change will also affect water availability and thus may create wider effects such as conflicts, especially in drylands where strong population increases are expected and water scarcity is already a contentious issue.[33,34,35,36] Finally, warming can also accelerate the decomposition of soil organic matter, putting pressure on the condition of land in already warm regions and further adding to carbon emissions[37] as well as the migration of pests and diseases.

Figure 6.12: The aridity index in 2010 and the change under the SSP2 scenario

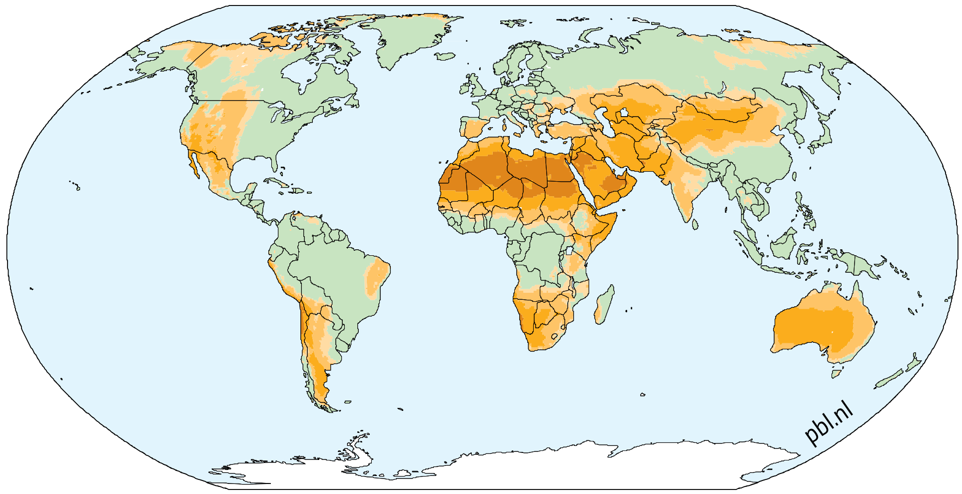
Source: PBL/IMAGE

Key

Aridity index

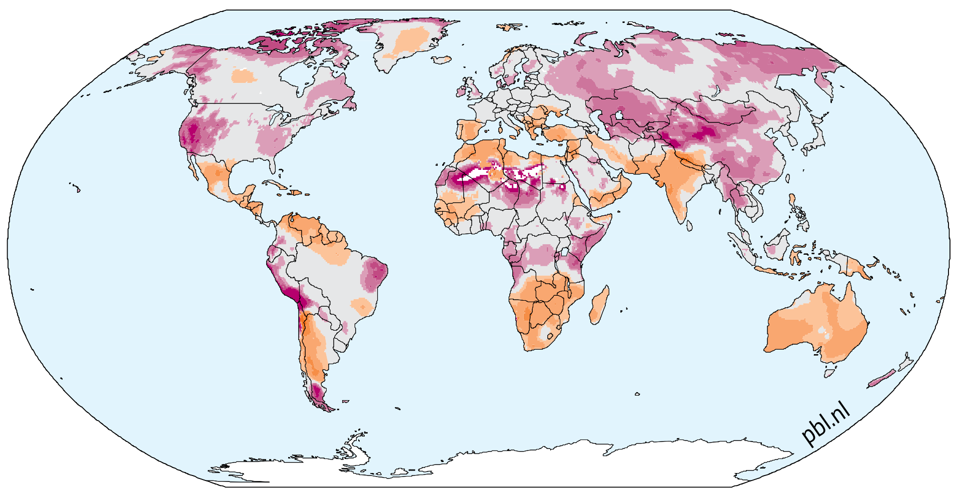
- Hyper arid (< 0.03)
- Arid (0.03 - 0.2)
- Semi-arid (0.2 - 0.5)
- Dry sub-humid (0.5 -0.65)
- Humid (> 0.65)

Aridity index, 2010



- More arid
- No change
- More Humid

Change in aridity under the SSP2 scenario, 2010 – 2050



Urbanization

Expansion of urban areas and infrastructure, while small compared to land conversion for agriculture, increasingly displaces fertile agricultural land. The world is becoming increasingly urbanized, which directly and indirectly affects land-use. Human settlements have historically developed in the most fertile areas, and on accessible lands. Their growing size is beginning to significantly displace fertile agricultural land. In one region of China, more than 70 per cent of the increase in urban land took place on previously cultivated land.[38]

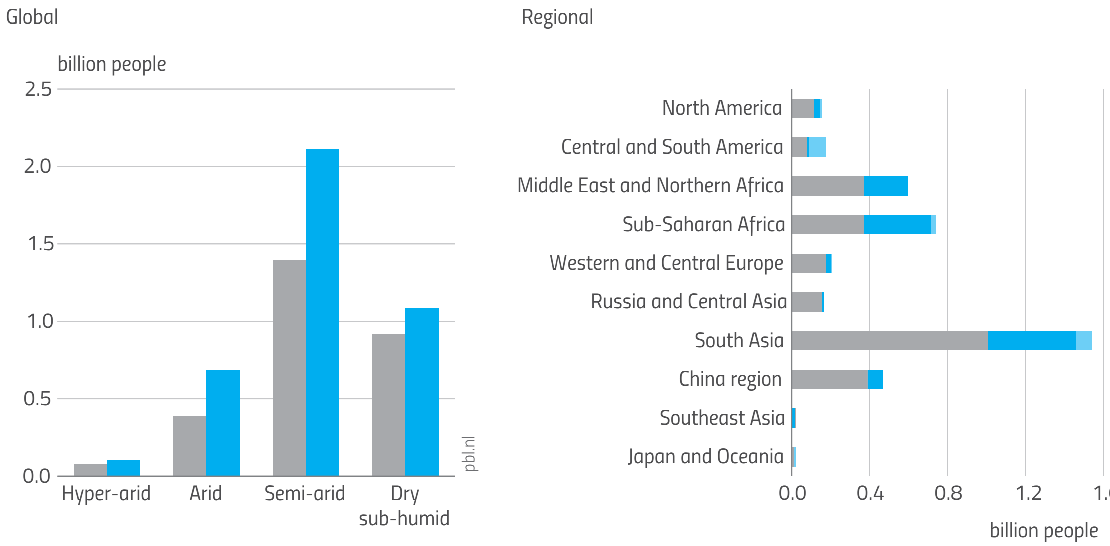
Urban expansion is mainly taking place in peri-urban areas, slowly fragmenting and occupying agricultural and natural landscapes. Agriculture is often then displaced to other, sometimes less productive locations. Urban populations are increasingly disconnected from rural areas and the ways in which food and other land-based goods are produced. The extent of built-up area is projected to increase by 0.4 million km^2 in the SSP2 scenario. Much of this increase occurs on highly productive agricultural areas (see Chapter 11), thereby triggering displacement of agriculture to less productive regions, and requiring more area to produce the same output. This finding is generally consistent with other literature though some project the largest expansion of urban area in other regions, such as China.[39]

Figure 6.13: Population in dry lands by dryland category (left) and by region (right) in 2010 and 2050 under the SSP2 scenario.
Source: PBL/IMAGE

Key

Global
2010
2050

Regional
Population in 2010
Population growth in existing drylands, 2010-2050
Population in new drylands 2050



Drylands

Population in drylands is projected to increase by 43 per cent by 2050 under the SSP2 scenario, a much larger increase than the global population growth rate of around 33 per cent. Overall, population in drylands is projected to increase from 2.7 billion in 2010 to 4.0 billion in 2050 (Figure 6.13).

In the drylands, water is generally the limiting factor for plant growth. With the population increases in the SSP2 scenario, water scarcity is bound to become an even more pressing issue in many of these regions. The largest increases in populations are projected to take place in the semi-arid and arid drylands. Regionally, South Asia is projected to see the largest increase in number of people in drylands, at over 500 million, and Sub-Saharan Africa is estimated to see a doubling of the number of people living in the drylands. Though smaller in absolute terms, such a doubling is also expected in Central and South America. Whereas in Sub-Saharan Africa the increase is mainly driven by population growth, in Central and South America the main cause is the expansion of drylands due to climatic changes. Therefore, while many regions do become somewhat dryer and some become wetter, the overall challenges in drylands will be aggravated by increased demands from larger populations more than by climate change. The effects of climate change however, such as increasingly erratic weather, especially droughts, will affect many more people in drylands in the future.

Regional Perspectives

Examining changes in land-use and ecosystem functions from a regional perspective, Sub-Saharan Africa, South Asia, and the Middle East and North Africa will face the greatest challenges. These regions are characterized by a combination of the following factors: high levels of population growth (especially in the drylands), low per capita GDP, high levels of undernourishment, strong increases in water stress, limited protein intake, lower self-sufficiency rates, expansion in agricultural area, rapid reductions in the remaining potentially available cropland, continued low crop yields, ongoing productivity loss, and high biodiversity losses. At the same time, the economic and institutional means to cope with these changes are currently limited, and although development may improve this in the future, in the meantime this may lead to unmanageable problems and risk of conflict and mass migration, inside and outside of the region.

Southeast Asia faces many similar challenges, but to a lesser degree. It is characterized by a relatively strong increase in water demand, low self-sufficiency, continued agricultural expansion, further declines in potentially available cropland, and high biodiversity losses. The remaining regions show relatively fewer yet still a diverse group of challenges while having better economic and institutional means to cope with these changes.

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CONCLUSION

This scenario analysis demonstrates, that in many regions, significant changes in land-use, demand, and condition can be expected in the coming decades, mainly as a result of the combination of increased population and wealth, leading to an increasing demand for food, shifts towards more meat and land-intensive foods, increased demand for fiber and energy, urbanization, accelerating climate change, and continued local declines in land cover, productivity, and soil organic carbon.

These drivers will influence high and low river discharges, water scarcity, aridity, crop yields, agricultural land expansion, land as carbon source and sink, and biodiversity. Sub-Saharan Africa, the Middle East and North Africa, South Asia and, to a lesser extent, Southeast Asia face an alarming combination of environmental and socio-economic challenges that will increase the pressures on land-based goods and services in the future. As a consequence, the multi-dimensional impacts on human security (see Chapter 5) may lead to unmanageable problems and risks.

Response pathways (see Part Three) need to help alleviate land pressures and achieve a more equitable balance between environmental and socio-economic trade-offs. It is the sum total of our individual decisions – as heads of households, consumers, producers, business owners, and policymakers – that is leading to a global failure in achieving food, water, and energy security for all while mitigating climate change and halting biodiversity loss. Like our response to climate change, a business-as-usual approach is insufficient to address the magnitude of this challenge. Such responses need to address population growth, consumption levels, diets, yield gaps for all commodities, the efficient use of space, water, materials, and energy, deforestation, food waste and post-harvest losses, climate change, and the conversion of natural areas. Land governance at the local, national and international scale coupled with enlightened land use planning and land management systems will be essential to navigate such a transition.

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Part Two

CHAPTER 7

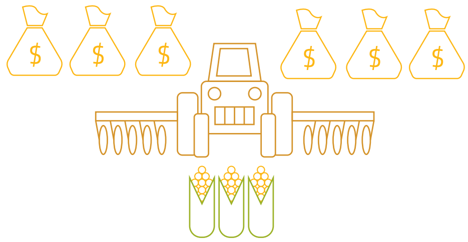
FOOD SECURITY AND AGRICULTURE

Agriculture and livestock cover over one-third of the world's land surface, dwarfing all other land uses. Intensification, driven by a lucrative but largely inefficient food system, has boosted production. However, it has also disturbed cultural landscapes, sustained over thousands of years, and accelerated land and soil degradation, water shortages, and pollution. Agricultural expansion is hastening the loss of species and natural habitats. In spite of production increases, we are now experiencing widespread food insecurity in what should be a world of plenty.

Proven and cost-effective alternatives to minimize these impacts already exist. Overall, agriculture needs to be more effectively integrated with other land use sectors. Multifunctional approaches to food production are needed, recognizing that land provides many other vital services. Key elements include increasing productivity and nutritional values from a given area of land, reducing offsite or downstream impacts on the environment, and promoting more local production, less land-intensive diets, and a reduction in food waste.

Figure 7.1:
Competing pressures on agricultural land

1. Poor management practices

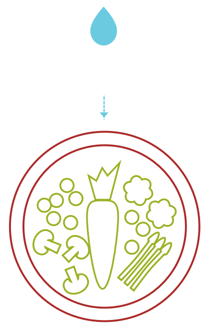


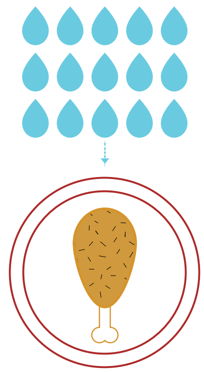
Over the past decades, agricultural management practices in developed countries have prioritized output over sustainability and resilience.

2. Food demand & waste

A plant-based diet requires ~1m³ water per day.

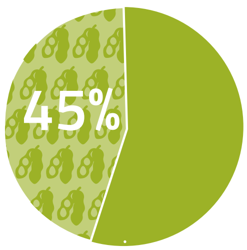
A meat-based diet requires ~15m³ water per day.



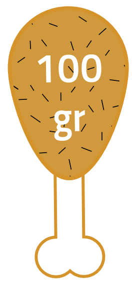


3. Changes in diet

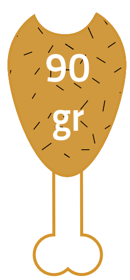
Livestock production, requires 45% of the world's grain, which covers 25% of the global land surface



but represents only 17% of human energy intake.

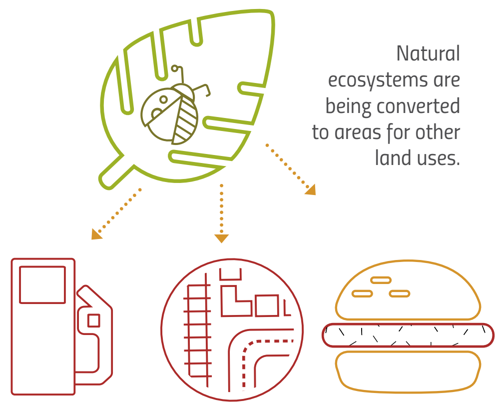


Reducing the average meat consumption from 100 gr to 90 gr per person per day, would make a significant impact on both human health and mitigation of climate change.



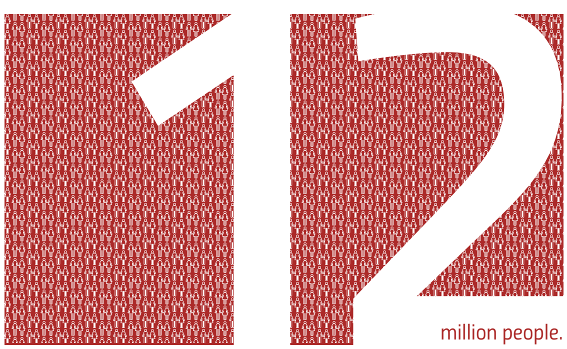
4. Competing land uses

Natural ecosystems are being converted to areas for other land uses.

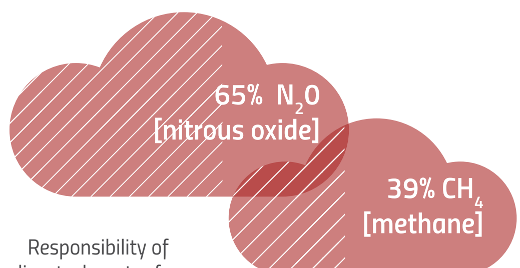


5. Land grabbing

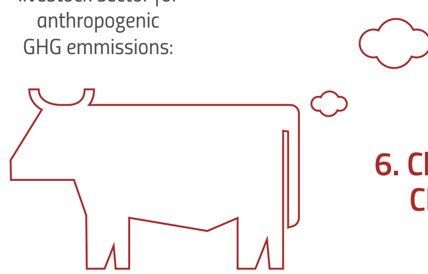
has led to household income losses for



million people.



Responsibility of livestock sector for anthropogenic GHG emmissions:



6. Climate Change

INTRODUCTION

Agriculture is the single biggest land use covering more than one-third of the world's land surface, not including Greenland and Antarctica. Much of the best land is already under cultivation and much of what is left is too high, steep, shallow, dry, or cold for food production.[1] The amount and quality of land available for food production is under pressure from the decisions and demands made by consumers, producers, and governments. The most significant pressures on land resources used for food production include:

1. **Poor management** practices resulting in suboptimal yields, due mainly to resource use inefficiencies associated with irrigation, fertilizers, livestock, crop selection, etc.
2. **Food demand** and waste which is increasing rapidly with population growth, increased incomes, and globalization.[2]
3. **Changes in diet** further drives agricultural expansion as consumers increasingly demand food that is land-intensive, particularly processed foods and meat.[3]
4. **Competing land uses** reduce the area available for food production,[4] including for biodiversity and ecosystem services, urbanization,[5] infrastructure, tourism, and energy as well as biofuels[6] and other non-food crops.
5. **Land grabbing** and virtual natural resource trading undermine food and nutritional security as well as smallholder tenure and resource rights in poor and vulnerable communities.
6. **Climate change**, which is expected to reduce crop yields in many countries resulting in greater food insecurity.[7]

These and other pressures are squeezing a finite resource that is rapidly reaching its limits. Land scarcity is already of serious concern[8] and there is a growing consensus that our remaining forests and grasslands need to be left intact for their biodiversity, carbon stores, and other essential ecosystem services. Some speak about a food, energy, and environment "trilemma," where food and energy compete for land causing further damage to the environment.[9] Maximizing the productivity of land without undermining its associated ecosystem services, often referred to as sustainable intensification, is one of the greatest challenges of the 21st century.

Sustainable Development Goal 2 aims to "*End hunger, achieve food security and improved nutrition and promote sustainable agriculture*" and by way of SDG target 2.4, "*ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality*."

In 1996, the World Food Summit agreed that: "*Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*."[10] This also implies that food supply is sustainable in the long run, and that agriculture does not undermine the provision of ecosystem services or overstep the ecological boundaries.

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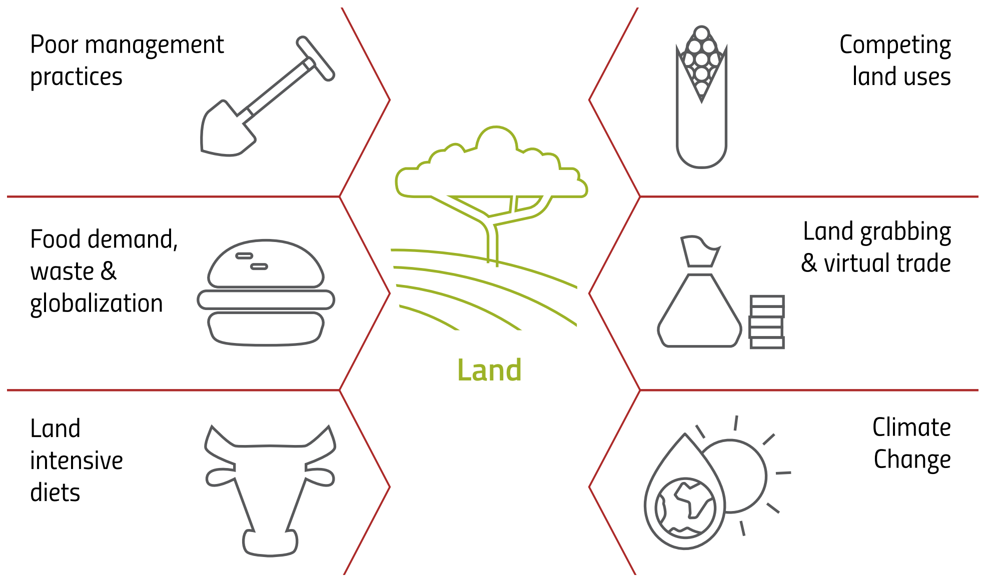
Figure 7.2: Competing pressures on land resources



1. Poor management practices

Over the past few decades, agricultural management practices in developed countries have prioritized short-term productivity over long-term sustainability and resilience. The "green revolution" in the 1970s promoted high-yielding varieties of crops, such as rice, which relied on increased inputs of mainly chemical fertilizers and pesticides. The result has been a much-needed boost in food production but also an accumulation of long-term problems with soil and human health, increases in crop pests and diseases, offsite pollution, and the loss of genetic diversity. At the same time, agriculture in parts of the world that have not adopted modern practices remains inefficient and can also inhibit the long-term sustainability of the food production system.

Swidden or slash and burn agriculture relies on the clearance and burning of forests or grasslands to open up space for crops. After a few years of cultivation, soil productivity declines and weed pressure increases, forcing farmers to clear new areas. Swidden can be sustainable if a small fraction of the landscape (less than about 5 per cent) is cleared and abandoned in any given year, but the cycles become more frequent when the population of farmers increases and space becomes scarce. This can lead to more or less permanent land degradation with forest often changing into low productivity shrubland or grassland.[11] Similarly, the stocking of animals beyond the carrying capacity of the land results in overgrazing and declines in the health of rangelands.[12]

While it is hard to generalize, it seems that overall farming has become more productive but less sustainable in the last few decades,[13] and is now exceeding planetary boundaries for stressors such as nitrogen levels in the ecosystem.[14] Poor management practices are generally not driven by ignorance or irresponsibility but by larger political, economic, and demographic pressures that give farmers little choice.

2. Food demand and waste

Concerns about food security are growing as the global demand for food will likely surpass supply in just a few years. The world currently has more than sufficient agricultural land to feed its population yet economic and distribution challenges still leave large numbers of people hungry and malnourished. If these challenges remain in the near future, demand will likely overtake our ability to increase net production.[15] Some suggest that the world can feed 10 billion people on the current area of agricultural land.[16] Others argue that even if annual increases in major crop yields follow recent trends, food production will still fall short of the 70 per cent increase estimated to be required to feed 9 billion by 2050.[17,18,19] Furthermore, due to increased consumption of animal protein, demand for both meat and crop-based livestock feed (mostly cereals and soy) is expected to rise by almost 50 per cent by 2050.[20]

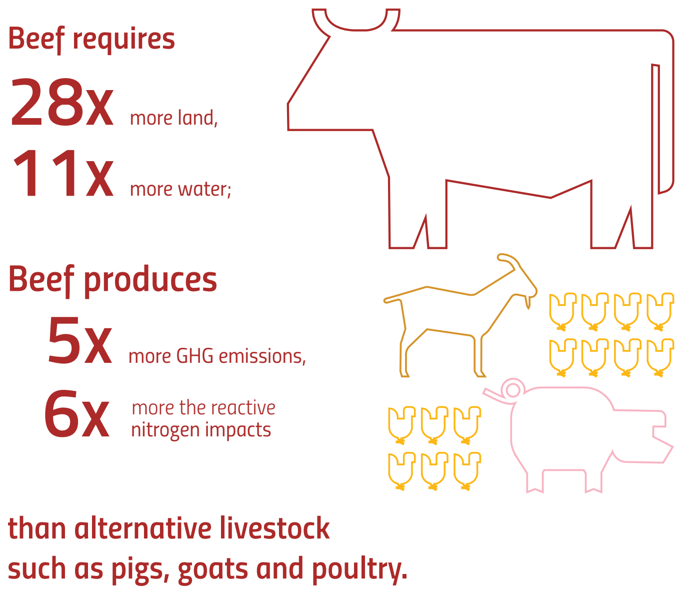


Figure 7.3: The case of beef

One reason that the world faces such grave pressures on land resources is the startling inefficiencies in the way that we produce and consume food. It is estimated that one-third of all food produced is wasted: this is equivalent to 1.3 Gt of edible food every year, grown on 1.4 billion hectares of land (an area larger than China). Annual food waste is also the waste of 250 km^3 of water and USD 750 billion (equivalent to the GDP of Switzerland), and has a cumulative carbon footprint of 3.3 Gt of CO_2 equivalent per year, making food waste the third largest emitter after the United States and China.[21]

Eliminating food waste would reduce the projected need to increase the efficiency of food production by 60 per cent to meet expected demands by 2050.[22] Other studies have estimated even greater losses with up to half of all food produced being wasted.[23] Hotspots of food waste include the industrialized parts of Asia for cereals, fruit, and vegetables, Europe for fruit and vegetables, and Latin America for fruit; high income regions also waste more than two-thirds of meat produced.[24]

The drivers of food waste vary: in poor countries, this is primarily due to lack of capacity to store and transport food early in the process, while in wealthy nations, it is caused mainly by retail marketing decisions, consumer profligacy, and the inefficiencies of mass production towards the end of the food supply chain. In 2005, it was estimated that 25-50 per cent of the total economic value of food was lost during the process of transport and storage because of reduced quality.[25]

Lack of refrigerated transportation, poor roads, and inclement weather combine to generate high levels of food waste in many tropical countries, and poor storage is identified as a major contributing factor to spoilage in many former Soviet countries, such as Ukraine.[26] In China, around 8 per cent of grain is lost during storage, 2.6 per cent in processing and 3 per cent in distribution; a combined annual total of 35 million tons.[27] In many developed countries, consumer and retail food waste is exacerbated by the rejection of misshapen or blemished but perfectly edible fruit and vegetables, short sell-by dates, and bulk offers that encourage over-purchasing. In the United States, about 70 million tons of edible food is wasted every year.[28] With almost 1 billion people now categorized as obese, the excess consumption of food is now considered by some as a form of food waste.[29]

3. Changes in diet

Land scarcity and food insecurity are made worse due to the growing demand for meat and other land-intensive foods, such as processed foods using soy and palm oil, which are an inefficient and unhealthy way of addressing human nutritional needs. Global meat consumption has virtually doubled since the 1960s,[30] and its production requires about five times more land per unit of nutritional value than its plant-based equivalent.[31] The production of animal products has dominated agricultural land use change, expansion, and intensification over the last half century.[32] Similar disproportions exist with regard to water use: average water use for maize, wheat, and husked rice is 900, 1,300, and 3,000 m^3 per ton respectively; while that for chicken, pork, and beef is 3,900, 4,900, and 15,500 m^3 per ton.[33]

The resource use inefficiency and environmental footprint of livestock production is of less concern if animals live entirely or mainly by grazing on natural vegetation in areas unsuitable for crop production. In many instances, livestock help maintain semi-natural habitat and provide valuable protein.[34] The costs, in terms of lost biodiversity and ecosystem services, rise dramatically if forest or woodland is cleared to create pasture as has been the case for much of the new grazing lands in Latin America.[35] If livestock is kept indoors or in enclosures, relying on feed grown elsewhere, the land required increases even more. While industrial livestock production can be an economically efficient way of producing large quantities of animal products, it is a very inefficient way of converting solar energy to nutrient-dense food for humans.

Box 7.1: The case of beef

Out of all the livestock produced, beef is by far the most costly in terms of its inefficiency and impacts on land use and pollution, requiring an order of magnitude more resources than other types of livestock. On average, beef requires 28 times more land and 11 times more irrigation water; it produces five times the greenhouse gas emissions and six times the reactive nitrogen impacts than alternative livestock such as pigs and poultry.[42] There is little dispute that reducing beef consumption would have an immediate and positive impact on both food security and greenhouse gas emissions.[43]

Inefficient beef production also drives land use change. In Queensland, Australia, woodland clearance mainly for cattle pasture averaged 300,000-700,000 ha per year through the 1990s[44] until a ban on further clearance in 2006. The ban reduced woodland losses dramatically but was subsequently relaxed in 2013 after opposition from farming groups. Along with the loss of natural vegetation, the resumption of clearing continues to dramatically reduce ecosystem services in the region. For instance, surface runoff has increased 40-100 per cent due to deforestation. According to the latest analysis of satellite data (2015-16) undertaken by the Australian National Inventory System, conversion of primary, mature forest to other land uses has been reduced by 90 per cent from levels of 1990 and now sits at about 56,000 hectares. The level of clearing of primary forest has been relatively constant in recent years (regardless of regulatory changes).The majority of clearing of forests - about 85 per cent in 2015 relates to re-clearing (secondary forest) on previously cleared land. The regrowth of secondary forest is currently outstripping the re-clearing activity – in 2015, in net terms, there was a net increase of 225,000 hectares of secondary forest on lands previously cleared for grazing. While over 40 per cent of Queensland's cropland is devoted to producing cattle feed, additional imported feed is still required.[45]

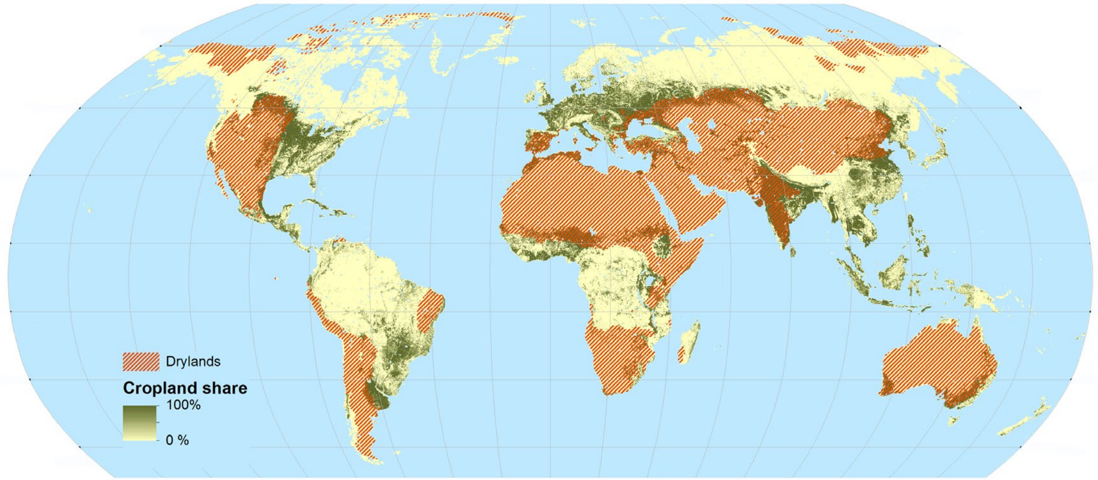
When the amount of land used for grazing and feed crops is combined, livestock production accounts for around 70 per cent of agricultural land[36] and is perhaps the single largest driver of biodiversity loss and reduced ecosystem services. Using crops historically consumed only by humans to feed livestock, such as cereals and legumes, directly increases consumer prices, undermines local food security, and indirectly drives further land use change.[37]

The global market for animal products is booming. Between 1967 and 2007, pork production rose by 294 per cent, eggs by 353 per cent and poultry meat by 711 per cent; while, over the same period, the relative costs of these products declined.[38] Projections for sub-Saharan Africa suggest a tripling of milk consumption by 2050, particularly in East Africa, and that the consumption of meat from poultry and pork, and eggs, could increase by six times in West Africa and four times in Southern and East Africa.[39] Along with changing diets associated with higher incomes, cheap feed crops (particularly soybeans) have been a huge factor contributing to increased meat production. Today, most pigs and poultry are kept indoors and rely solely on protein-rich feed and pharmaceuticals to enhance growth,[40] raising sustainability, environmental, and animal welfare concerns. Currently, 36 per cent of calories produced by the world's crops are diverted for animal feed, with only 12 per cent of those feed calories ultimately contributing to the human diet as meat and other animal products. This means that almost a third of the total food value of global crop production is lost by "processing" it through inefficient livestock systems.[41]

Livestock production is also a major cause of climate change, producing an estimated 7.1 Gt CO_2-eq per annum, or approximately 14.5 per cent of anthropogenic greenhouse gas emissions. Feed production and processing, along with enteric fermentation from ruminants (releasing methane), are the two main sources of emissions; beef and cow milk production contribute 41 and 20 per cent of the sector's emissions respectively.[46] Modeling the impacts of projected increases in livestock production found that by 2050 greenhouse gas emissions from meat, milk, and egg production could increase by 39 per cent.[47] Average global meat consumption is currently 100 grams per person per day; even reducing this to 90 grams per person per day would make a significant impact on both human health and GHG emissions.[48]

Over the past five decades, human diets have moved toward a greater consumption of processed foods that are low in essential nutrients and contain a high percentage of refined sugars, oils, salt, and fats.[49] Common factors driving this are more processed foods, access to cheaper foods, and aggressive marketing of some of the unhealthiest foodstuffs.[50] Major food outlets base their profits on selling large amounts of high-fat, high-protein foods which, if consumed regularly, lead to obesity,[51] a problem now impacting virtually every country in

Figure 7.4: Global cropland (green shaded area) occupies about 14 per cent of the ice-free land of the Earth[63]



the world.[52] Based on recent average annual dietary changes and the contribution of palm and soybean oil to vegetable oil consumption and yields, this will result in converting an additional ~0.5 to 1.3 million hectares of land to oil palm plantations, and ~5.0 to 9.3 million hectares to soybean plantations by 2050.[53] Much of this expansion will occur at the expense of tropical rainforests, unless strict land-use regulations and market initiatives are implemented to avoid deforestation.[54]

There are significant costs associated with the expansion of oil-palm plantations into tropical rainforests in Indonesia. This sometimes entails the draining of peatlands, which can then catch fire. The resulting health risks from air pollution are severe, especially for children and older people. According to the World Bank, the disruption to economic activity in 2015 alone cost the Indonesian economy an estimated USD 16 billion — more than the annual country-wide value added by palm oil.[55] Peat drainage has a huge carbon footprint: the lowering of the water level in the peat meadow system of the Netherlands is comparable to average emissions from 2 million cars.[56]

4. Competing land uses

The demand for food (including more meat and processed foods), urban and infrastructure development, and biofuels will have a growing impact on overall land availability. The world's ice-free land area is estimated at 13.2 billion ha with 12 per cent (1.6 billion ha) currently used for the cultivation of agricultural crops, 28 per cent (3.7 billion ha) under forest cover, and 35 per cent (4.6 billion ha) composed of grasslands and woodland ecosystems, much of which is used for grazing and equivalent to at least twice the cropland area.[57]

The global area of cultivated land has increased by around 12 per cent in the last few decades,[58] or 159 million ha since 1961, much of which has been converted from natural ecosystems.[59] Croplands occupy about 14 per cent of the total ice-free land area while pastures occupy about 26 per cent.[60] Approximately 44 per cent of the world's agricultural land is located in drylands, mainly in Africa and Asia, and supplies about 60 per cent of the world's food production.[61] Most of the new agricultural land has come from the destruction of natural forests; from 2010 to 2015, tropical forest area declined by 5.5 million hectares a year.[62]

Future projections suggest that satisfying global food demand means more land will need to be converted.[64] Future cropland expansion will not be evenly spread. One estimate found that by 2050, 55 per cent of the projected expansion will occur in Africa and the Middle East, 30 per cent in Latin America, and just 4 per cent in Europe.[65] Competing land uses frequently involve trade-offs between production needs (i.e., provisioning services) needs and those of biodiversity, native forest dwellers, and the supporting and regulating services that natural habitats provide.

Food production is a critical driver, particularly of tropical forest loss,[66] where forests were the primary source of new agricultural land throughout the 1980s and 1990s,[67] and continue to be converted to new pasture[68] and farmland today. An analysis of the 11 most critical deforestation fronts found agriculture to be the dominant, and usually the largest, driver of land use change.[69] Furthermore, the type of agriculture is changing from small-scale, peasant farming to large-scale, ranching and monoculture plantations.[70] Soybean[71] and oil palm[72]

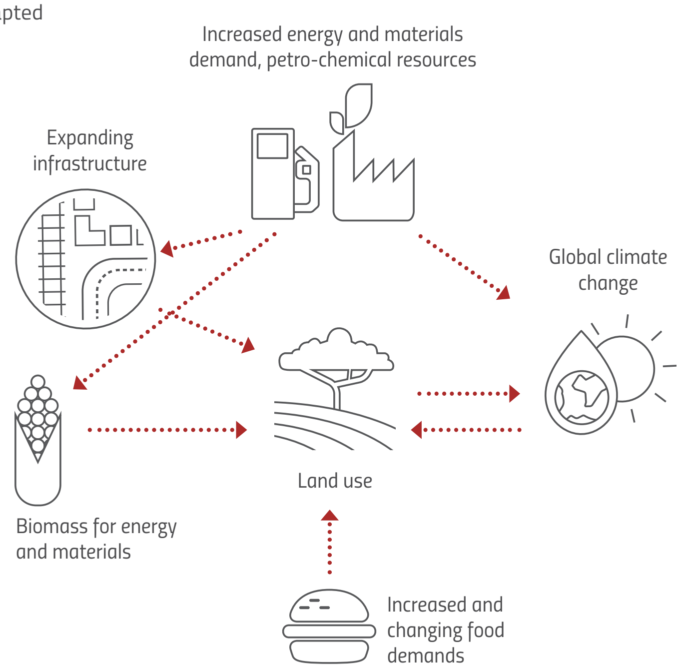
Box 7.2: The rapid expansion of soybean cultivation

Soy or soya (*Glycine max*) is an annual legume grown for its edible bean. Over recent decades, soybean has undergone the fastest expansion of any global crop, resulting in the conversion of forests and other important natural ecosystems. Soy is highly attractive to the food industry as it produces more protein per hectare than any other major crop[95] and has become a key part of the global food supply, particularly as livestock feed. In fact, three-quarters of the global harvest is used for feed, primarily for poultry and pigs, especially in China.[96] Soybean is also becoming an increasingly important source of biofuels.[97]

In the last 50 years, the area of soybean planted has grown tenfold, to over 1 million km^2: the total combined area of France, Germany, Belgium, and the Netherlands. Around 328 million tons are expected to be produced in 2016/17,[98] with the bulk of the production coming from Brazil, the United States, Argentina, China, India, and Paraguay.[99] Millions of hectares of forest, grassland, and savanna have been converted, either directly or indirectly, as a result of this global boom.[100] The fastest growth has been in South America, where the area of land devoted to soybean increased from 17 million hectares in 1990 to 46 million in 2010, mainly at the expense of natural ecosystems. Conversion is not always direct; land cleared initially for cattle pasture is then planted with soybean.[101] Land use change also results in significant social disruption. Soybean production has been implicated in the eviction and displacement of indigenous communities in Argentina[102] and Paraguay.[103] The boom is far from over: it is estimated that soybean production will continue to grow, almost doubling by 2050,[104] not counting the potential for further expansion due to biofuel demand.

have dramatically increased in terms of area planted and biofuels are beginning to escalate competition for scarce land.[73] Urban population growth is more closely correlated with deforestation than that of rural population growth, pointing to the critical role that urban demands for food and fiber have in land use change for agriculture.[74]

Figure 7.5: The new competition for land, interactions and feedbacks: Adapted from[134]



Deforestation in South America is driven primarily by commercial agriculture[75] and large-scale ranching,[76] predominantly cattle;[77] this trend is fueled by low feed prices[78] with many farms planting exotic African grasses.[79] The expansion of plantation agriculture is also important, particularly for animal feed[80] and biofuels,[81] such as soybean,[82] oil palm,[83] and other crops[84] with its production often linked to subsidized resettlements.[85] Indirect land use change is also occurring,[86] for example, when soybeans replace pasture[87] forcing cattle ranchers to move into new areas of forest.[88] In Africa, peasant agriculture and tree cutting for fuelwood and charcoal production remain the dominant agents of change, such as in the Congo Basin[89] where an estimated 90 per cent of wood harvested is for fuel.[90] In southern Africa, 80 per cent of farming is small-scale[91] including resettlement in rural areas in post-conflict Angola[92] and increased tobacco production in Malawi.[93] The growth in plantation and biofuel crops for the export market is also occurring, particularly in Mozambique.[94]

In Asia, plantation agriculture, often preceded by logging, is the most important driver of land use change, although there are large regional differences. Conversion for oil palm is the biggest cause of deforestation across Indonesia,[105] with areas still expanding,[106] and rubber plantations also increasing.[107] The conversion of primary and secondary forest for food and non-food crops, including sugar, rice, rubber,[108] and biofuels[109]

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is increasingly prevalent in the Mekong Basin. Political changes in Myanmar are rapidly fueling land use change,[110] with over 2 million hectares of forest allocated for conversion to agriculture.[111] Conversely, while plantations are emerging in Papua New Guinea,[112] small-scale agriculture remains the largest driver of land use change.

The expansion of agricultural land in many developing countries has only led to marginal increases in livestock production. Livestock systems in these situations are often low-input and relatively inefficient; productivity is often further reduced by land and soil degradation.[113]

The challenges associated with fossil fuels, including both their finite nature and pivotal role in climate change, has stimulated the search for alternative energy sources. Natural forests and timber plantations supply biomass that can be processed for use in domestic stoves, combined heat and power stations, and as a feedstock for liquid fuels,[114] with one global estimate of potential from logging and processing waste being 2.4 billion m^3 per year.[115] Crops, such as soybean and palm oil, are increasingly being processed into fuels, reducing their availability as foodstuffs. Crop calories used for biofuel production increased from 1 to 4 per cent between 2000 and 2010.[116] In Argentina, soybean biodiesel production reached 2.7 million tons in 2016, 50 per cent more than the previous year. Argentina is expecting to resume soybean exports to Europe following a court ruling that ended anti-dumping duties,[117] and soybean oil is projected to supply about 10 per cent of the European Union's biofuel production by 2020.[118]

Advocates of plant-based energy alternatives argue that if food system efficiencies could be further increased, then substantial biofuel production would be possible without impacting food security.[119] This is based on the assumption that biofuel crops will be predominantly grown on degraded land, land not suitable for agriculture, and land made available by intensifying livestock production and thus "freeing up" land.[120] However, in practice today, most biofuel crops are grown on fertile soils, usually with serious negative social and environmental impacts, which threaten to lock in some of the best agricultural land for energy production.[121] Other concerns focus on the amount of natural forest cleared for biofuels,[122] which includes indirect land use change;[123] loss of biodiversity;[124] the long-term effects of tree plantations on soils and hydrology;[125] the impacts of intensifying crop production by using agrochemicals;[126] the social consequences of a rapid increase in biofuels[127] and potential for increased inequality;[128] and the effect on the overall carbon balance.

Although a highly efficient biofuel energy system could in theory help reduce carbon dioxide emissions, clearing natural vegetation can result in a carbon pulse that could take decades to recapture. For example, it would take an estimated 420 years of biofuel production to replace the carbon lost from clearing peatland forests,[129] thus compounding the impacts on biodiversity and climate.[130] A major switch to biofuels could easily have unintended climate consequences through land use change and agricultural intensification.[131] Biofuel expansion in productive tropical ecosystems will always lead to net carbon emissions for decades or centuries while increased biofuel production on degraded or abandoned agricultural land could provide an almost immediate net reduction in carbon emissions.[132] Guidance on sustainable production practices is starting to emerge,[133] yet the question of how much land can be used sustainably for biofuels remains contentious and the potential negative impacts are increasingly recognized.

5. Land grabbing and virtual land trading

As land becomes in shorter supply, poor small-scale farmers generally lose out as more powerful players gain control over a larger proportion of what remains. "Land grabs" are a growing phenomenon in Central and South America, Africa, and southeast Asia. The term refers to the acquisition, by outside interests, of the rights to harvest timber or establish large-scale commercial farms, plantations, or livestock operations often on lands where tenure has historically been communal or customary.[135] The exact size and number of global land grabs is not known, since many transactions are conducted without public notice and against the will of local people.[136] Land grabs increase tensions and the potential for conflict within communities and between affected groups and the governments that facilitate the process.[137]

Concern is mounting about the impacts of these large-scale acquisitions on food security, hydrology, land use change,[138] including deforestation,[139] and losses in rural employment opportunities.[140] Although land grabs still represent a small proportion of total agricultural land, they tend to control the most productive land usually with the most developed infrastructure and transportation links.[141] A more detailed discussion of land grabs and tenure security is contained in Chapter 5.

When a government undertakes major resettlement programmes or displaces communities for development projects, the results can be the same as a land grab. On the grasslands of Inner Mongolia and Tibet, governments have actively resettled pastoralists and rural populations to towns or other rural areas to free up land for development projects, often citing overgrazing as a reason and with mixed results in terms of their welfare.[142] The Three Gorges dam project in China, completed in 2012, flooded 600 km^2 of land and displaced an estimated 1.3 million people who were relocated to other rural areas and urban centers within the same region as well as to other provinces of China.[143]

About one-fifth of global cropland area, and its associated water use, produces agricultural commodities that are consumed abroad. Export demand is one of the leading drivers of cropland expansion.[144] The physical separation of production and consumption has implications for both the exporting and importing countries. Associated environmental burdens of food production are shifted disproportionately to export producing regions, undermining their long-term food security while importing nations in turn become progressively dependent on foreign land resources, such as soil and water, for their food security.

"Virtual land" is a term used to characterize the underlying aspects of international trade in food products that compensate for lack of productive land in the importing country, i.e., the land area and input resources needed to grow the imported foods.[145] Trading in virtual land gives the economically powerful the ability to exploit other countries' land resources to produce their food and biofuel imports; a phenomenon that has further fueled land grabbing. As with other aspects of globalization, the growth in this type of trade means that the balance of power can change radically in a relatively short time. In 1986, China's virtual land import was 4.4 million ha but by 2009 it had risen to 28.9 million ha, mainly from North and South America.[146] Similarly, the European Union requires 43 per cent more agricultural land than is available in the EU itself in order to satisfy its food needs.[147]

Agriculture faces major challenges as a result of climate change and at the same time is also a major source of the greenhouse gases that are causing climate change.

6. Climate change

Agriculture faces major challenges as a result of climate change and at the same time is also a major source of the greenhouses gases that are causing climate change.[148] This brings two complicating factors into predictions about food security: 1) long-term shifts in average climate are gradually moving the optimal areas for specific crops to grow, and 2) an increase in extreme weather events is reducing food security through rainfall or temperature changes[149] and increased plant diseases,[150] livestock diseases,[151] and pest attacks.[152]

Most projections suggest that climate change will reduce food security[153] and increase the number of malnourished people in the future.[154] The Intergovernmental Panel on Climate Change (IPCC) finds more negative impacts than positive ones and projects severe risks to food security, particularly in the tropics where average temperatures are likely to increases 3-4.°C. As a result, food prices will rise steeply and weeds will become more problematic, with rising carbon dioxide levels reducing the effectiveness of some herbicides.[155]

Furthermore, the IPCC concludes: "Under scenarios of high levels of warming, leading to local mean temperature increases of 3-4°C or higher, models based on current agricultural systems suggest large negative impacts on agricultural productivity and substantial risks to global food production and security (medium confidence). Such risks will be greatest for tropical countries, given the larger impacts in these regions, which are beyond projected adaptive capacity, and higher poverty rates compared to temperate regions."

Climate change will likely have varying effects on irrigated yields, with those in South Asia experiencing particularly large declines. One projection suggests that the availability of calories in 2050 could decline relative to 2000 throughout the developing world, increasing child malnutrition by 20 per cent.[156] However, predictions about agriculture and climate are difficult: impacts on food systems will be complex, geographically and temporally variable, and heavily influenced by socio-economic conditions. Most studies focus on availability, whereas related issues of stability of supply, distribution, and access may all be affected by a changing climate.[157] Low-income producers and consumers are likely to suffer the most because of a lack of resources to invest in adaptation and diversification measures to endure price rises.[158]

Box 7.3: Land management impacts on marine communities

The Great Barrier Reef, offshore Queensland Australia, is the world's largest coral reef a UNESCO World Heritage site, and a tourist attraction of huge economic value. Research estimated that the Australia-wide value-added economic contribution generated in the Reef catchment in 2012 was USD 4.4 billion, with just below 69,000 full-time equivalent workers. Some 90 per cent of direct economic activity came from tourism.[184] Yet the reef's living corals have declined almost 50 per cent in the last two decades. Pollution from agriculture is a key factor, including excess nitrogen and phosphorus reaching inshore parts of the reef,[185] suspended sediment from erosion in cattle-growing areas, and herbicides;[186] this along with one of the world's highest deforestation rates due to clearing woodland for cattle pasture, another substantial contributor to sediment pollution.[187] These problems are increasingly found around the world. In the Gulf of Mexico, a "dead zone" resulting from excess agricultural run-off covered 13,080 km^2 in 2014.[188] Around 30 dead zone hotspots have been identified, primarily in Europe and Asia, with the most significant including the Mississippi, Ganges, Mekong, Po, Pearl River, Volga, Rhine, and Danube.[189]

Greenhouse gases are released at almost every stage in the agricultural cycle. According to the 2014 report of the IPCC, the agriculture, forestry, and other land-use sectors (AFOLU) are responsible for just under a quarter of anthropogenic greenhouse gas emissions, largely from deforestation, livestock emissions, and soil and nutrient management (*robust evidence, high agreement*).[159] AFOLU emissions have doubled in the last fifty years and could increase by another 30 per cent by 2050.[160] Crop and livestock production recently surpassed land use change and deforestation in the level of greenhouse gas emissions, now responsible for 11.2 per cent of the total.[161] Climate change impacts of expanding cropland into natural ecosystems differ markedly around the world. For each unit of land cleared, the tropics lose almost twice as much carbon and produce less than half the annual crop yield compared with temperate regions, making it even more important to increase yields on existing cropland rather than clearing new areas.[162] A recent analysis calculated that the livestock sector is responsible for 39 per cent of anthropogenic methane emissions and 65 per cent of anthropogenic nitrous oxide emissions.[163] AFOLU are also carbon sinks which can increase

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their sequestration capacity through conservation, restoration, and sustainable land management practices that increase organic carbon stocks.[164]

ASPECTS OF THE MODERN FOOD SYSTEM

Until now, the focus of efforts to address an impending land crunch has been predominantly on intensification: producing more food per hectare of land by increasing yields, cropping frequencies, and intensifying livestock production through supplementary feed, breeding programmes, and controlled indoor housing.[165] The "green revolution"[166] promoted improved crop varieties supported by chemical fertilizers and a range of pesticides and herbicides; one unplanned outcome being farm unit consolidation and larger industrial monocultures.

Overall, these changes have increased net productivity, lowered food prices, and helped to reduce childhood malnutrition in poor countries since the 1960s.[167] Gains have been greatest in the most commonly grown crops (e.g., cereals, oilseeds, fruits, and vegetables), with increases of an estimated 47 per cent from 1985-2005 due to higher yielding varieties, less crop failure, and multiple annual cropping. For all 174 significant crops assessed, average global crop production increased 28 per cent.[168] Cropland increased only 2.4 per cent over this same period,[169] implying more output per hectare. More profoundly, agriculture became increasingly centralized with a small group of multinational corporations controlling virtually all aspects of food production: from seed, genetic materials, machinery, and agrichemicals to farm production and the transport, processing, and marketing of food. Food transport distances have increased dramatically as have the inputs and energy used in agriculture.

The boost in production and profits has been matched by a steady build-up of side effects and a growing number of "have-nots" who are neglected and continue to suffer malnutrition. The drawbacks of modern farming have been recognized for half a century, since Rachel Carson wrote about the impact of pesticides in the environment,[170] and Susan George identified the unintended side effects of the "green revolution,"[171] including:

- Pollution from agrochemicals such as nitrate and phosphate fertilizers, herbicides, and pesticides
- Irrigation and salinization leading to land and soil degradation
- Crop diseases, invasive pests and diseases, and loss of genetic diversity impacting food security
- Soil and land degradation over a growing area of the planet
- Food miles and the increasing long distance transport of food
- Human health and nutrition with hunger and obesity as converse challenges
- Crop selection and genetically modified crops

1. Pollution from agrochemicals

Modern methods of food production rely on the ability to add enough nutrients, mainly nitrate, phosphate, and potassium (often referred to as NPK) to the soil to boost plant growth and increase yields. All three come with a range of negative environmental impacts, some of which are still not fully understood.

While fertilizers have been responsible for increasing crop yields, the inefficiency in their application leads to major detriment in the wider environment, causing air and water pollution, ecosystem damage, and risks to human health:[173] fertilizers are estimated to be over-used by 30-60 per cent in some situations.[174] Leaching from agricultural areas results in nitrate and phosphate polluting surface and groundwater supplies; excess nutrients promote rapid algal growth and, when the latter die, the loss of oxygen as plant matter decomposes. This process, known as eutrophication, kills fish and other aquatic life. Algal blooms have long been a serious environmental problem in lakes and rivers, and increasingly in offshore marine waters where they create dead zones, i.e., oxygen-depleted water resulting from over-enrichment by nitrogen and phosphorus. Reported cases of coastal dead zones have doubled in each of the last four decades, with over 500 currently known.[175] Nitrous oxide is an increasingly important greenhouse gas, with emissions largely arising from agriculture.[176] Excessive air and water-borne nitrogen has been linked to respiratory ailments, cardiac disease, and several types of cancer.[177] High nitrate levels in water and vegetables[178] can also be a contributory factor[179] in the increased risk of methemoglobinemia (blue baby syndrome) in both temperate and tropical[180] agricultural regions.

Global fertilizer use is still accelerating rapidly and is likely to exceed 200 million tons a year by 2018, some 25 per cent higher than in 2008.[181] Reactive nitrogen added to the biosphere through human activity now exceeds that made available through natural processes.[182] While still relatively low in Africa, nitrogen fertilizer use is generally increasing everywhere with east and southeast Asia together accounting for 60 per cent of total use.[183]

The narrow genetic base in monocultures creates ideal conditions for unwanted species to exploit, exposing agriculture to attacks from a host of invertebrate and fungal pests and diseases, which most farmers control by applying pesticides. Pesticide use is expanding fast, valued at USD 65.3 billion in 2015 and predicted to continue growing annually at about 6 per cent until 2020.

Did you know *that British farmers growing wheat typically treat each crop over its growing cycle with four fungicides, three herbicides, one insecticide, and one chemical to control molluscs. They buy seed that has been precoated with chemicals against insects. They spray the land with weedkiller before planting, and again after. They apply chemical growth regulators that change the balance of plant hormones to control the height and strength of the grain's stem. They spray against aphids and mildew. And then they often spray again just before harvesting with the herbicide glyphosate to desiccate the crop, which saves them the energy costs of mechanical drying.*[172]

Evidence is building that the adverse environmental impacts of pesticides have been underestimated, particularly in the tropics.[190] There is particular concern about a decline in global insect populations (i.e. not just pest species), including catastrophic and economically important impacts on honey bees and wild pollinators.[191] Two recent reports synthesized over a thousand peer-reviewed studies and both concluded that neonicotinoid and other systemic insecticides have serious negative impacts on pollinators and other terrestrial and aquatic invertebrates, amphibians, and birds as well as cause significant damage to ecosystem functioning and services.[192,193] Significant declines in biodiversity[194] are being linked with the increased use of insecticides,[195] fungicides,[196] and herbicides,[197] often acting in combination along with other aspects of modern farming. Species are not even necessarily safe in protected areas because many pesticides drift far from the point of application.[198] These findings help to explain why biodiversity continues to decline in farmed landscapes, even in Europe where habitat loss and poaching pressure have been reduced, and where there has been investment in schemes intended to increase wildlife in production landscapes.[199] Many effects are still largely unstudied, including the impact of pesticide mixtures on human health,[200] but are likely to have high costs in terms of their impacts on both human health and ecosystem services.[201] For instance, the total economic value of pollination worldwide is estimated at USD 165 billion annually;[202] in parts of China, farmers now pollinate plants by hand due to the loss of insect pollinators.[203]

Modern farming methods also rely heavily on herbicides to control weeds. Genetic engineering is increasingly being applied to make crops more tolerant of herbicides. These herbicide-resistant genetically-modified (GM) crops now use 56 per cent of total glyphosate use,[204] and increased herbicide tolerance means that farmers are likely

Box 7.4: Estimates of economic losses due to land degradation[229]

There are wide variations in the estimated global costs of land degradation.[230] Valuation methods vary extensively, from simplistic approaches using land use and land cover data as a proxy for ecosystem services to methods integrating a range of spatial variables which are validated against primary data to derive ecosystem services models and value functions.

Globally, the estimated annual costs of land degradation range between USD 18 billion[231] and 20 trillion.[232] According to the Economics of Land Degradation (ELD) Initiative, the loss of ecosystem services due to land degradation cost between USD 6.3 and 10.6 trillion annually, representing 10-17 per cent of the world's GDP.[233] These costs are distributed unevenly, with negative impacts mostly affecting local communities and the rural poor. The annual global cost of land degradation due to land use change and reduced cropland and rangeland productivity has been estimated at roughly USD 300 billion; most of the costs are borne by those benefiting from ecosystem services, i.e. the farmers.[234]

The ELD Initiative estimated future value of ecosystem services[235] under various different possible futures. [236] Both a future dominated by neoliberal free market economics and one with high levels of protectionism led to dramatic losses of value of ecosystem services, of USD 36.4 and 51.6 trillion per year, respectively. Under conditions of continuing economic growth, but with assumptions about the need for government intervention and effective land policy, there was a relatively small increase in the value of ecosystem services of USD 3.2 trillion per year. Finally, under transformative future policies that overcome limits to conventional GDP growth and focuses on environmental and social wellbeing and sustainability the value increased by USD 39.2 trillion per year. These findings suggest the need to promote adequate policy measures to sustain the socio-economic value of land.[237]

National studies mirror global findings in estimating high costs of degradation. For example in Tanzania and Malawi the annual costs of degradation account for, respectively, USD 2.5 and 0.3 billion, and represent roughly 15 and 10 per cent of their GDP, and in Central Asia the annual costs of degradation across Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan are estimated at USD 6 billion.[238]

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to increase the application rate.[205] Herbicides, such as glyphosate and atrazine remain under constant review in terms of their health and environmental effects, with a ban on glyphosate being discussed within the European Union. In developing countries, low literacy, poverty, and the prevailing conditions of pesticide use continue to translate into major risks to farmers, workers, and their families, consumers, and the environment. Since 2006, UN agencies have identified the need for stakeholder action to reduce risks associated with the use of Highly Hazardous Pesticides, including phase outs.[206] Policy makers often assume that current or increased levels of pesticide use are essential to deliver food security. The latest report from the UN Special Rapporteur on the right to food challenges this assumption and highlights the need for a global treaty to govern the use of pesticides.[207]

Harmful side-effects of pesticide use also carry major and often unrecognized economic cost. For example, UN Environment estimates that between 2005 and 2020, the accumulated cost of illness and injury linked to pesticides in small-scale farming in sub-Saharan Africa could reach USD 90 billion if no action is taken to control hazardous pesticides and poor practices.[208]

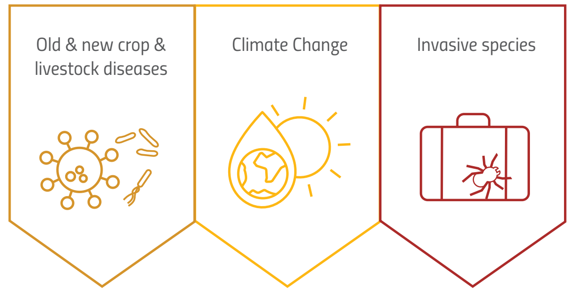
2. Irrigation and salinization

Salinization involves the accumulation of water-soluble salts in the soil, negatively impacting the health and productivity of the land. Salt-affected soils occur in most countries, although they are more common in the drylands. Salinization inhibits germination and eventually undermines the ability of the soil to support plant growth.

Agricultural losses due to salinization are not well documented but at least 20 per cent of irrigated lands are believed to be salt-affected with some estimates putting the figure much higher;[209] researchers suggest that half of all arable land will be affected by 2050.[210] An estimated 2.7 million ha of the world's rice fields are currently affected by salinization.[213]

Figure 7.6: The triple effect of diversity loss, emerging crop and livestock diseases and climate change

Collapse in crop & livestock diversity



Beyond its direct impact on agricultural production and food security, salinization also affects groundwater aquifers. When water movement into aquifers is greater than outflows, the water table rises transporting salts to surface soil[214] which undermines future irrigation capacity and compromises domestic drinking water supplies.[215] Salinity is difficult to reverse and often leads to long-term land degradation. As irrigated areas are among the most productive lands, the so-called bread baskets, salinization is undermining global food and water security (see also Chapter 8).

3. Crop diseases, invasive pests and diseases, and loss of genetic diversity

Crop diseases have been a problem for farmers throughout history. Today, additional problems are created by the increased movement of crops around the world, spreading non-native pests and diseases and creating further challenges to increasing food production. At the same time, climate change is adding new stresses to many species and the significant reduction in genetic diversity within crops is reducing their ability to adapt to emerging pressures.

The development of high-yielding crop varieties and the increasing intensification of livestock husbandry based on selected genetic stocks have drastically reduced diversity.

The development of high-yielding crop varieties and the increasing intensification of livestock husbandry based on selected genetic stocks have drastically reduced diversity. It is estimated that about 75 per cent of crop genetic diversity has been lost in the last century due to the abandonment of traditional landraces in favor of uniform crop varieties.[216] While the latter are often more productive, their narrower genetic variation makes adaptation more difficult. A survey found that 97 per cent of the crop varieties, listed in old United States Department of Agriculture catalogues, are now extinct.[217] Similarly in Germany, about 90 per cent of historical crop diversity has been lost, and in southern Italy about 75 per cent of crop varieties have disappeared.[218] Furthermore, many crop wild relatives, important genetic resources for breeding, are also declining or under threat,[219] with some 70 per cent of important crop wild relative species in need of protection.[220] Such losses reduce opportunities for breeders to help crops adapt to a changing climate, to the emergence of new diseases, and to the spread of invasive species that limit production.

Despite the increasing use of pesticides, pests and disease continue to take a heavy toll on crops worldwide. An average of 35 per cent of crop yields are lost to pre-harvest pests[221] while some argue that these losses would be doubled without pesticides.[222] Emerging infectious diseases from fungi are also acknowledged to pose increasing risks to food security[223] as human activities are now intensifying fungal dispersal.[224] Globalization and the long distance transport of foodstuffs have increased the spread of invasive species. Without natural predators, non-native species can sometimes thrive and inflict heavy damages on crops and livestock. In the United States alone, crop and forest losses from invasive insects and pathogens have been estimated at almost USD 40 billion per year.[225] A recent review of 1,300 insect pests and pathogens in 124 countries assessed future risks and found sub-Saharan Africa the most vulnerable to attack, mainly due to the lack of resources to control such events, while the United States and China stood to lose the most in economic terms.[226]

Meanwhile climate change will further exacerbate all these problems, for example, helping pathogens spread to new areas, increasing the number of generations per season, and altering plant defense mechanisms.[227]

4. Land degradation and soil loss

The UNCCD defines land degradation as the reduction or loss of biological or economic productivity in rainfed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as:

- soil erosion caused by wind and/or water;
- deterioration of the physical, chemical, and biological or economic properties of soil; and
- long-term loss of natural vegetation.[228]

It can refer to a temporary or permanent loss of productive capacity, a loss or change in vegetative cover, a loss of soil nutrients or biodiversity, or increased vulnerability to environmental and disaster risks. As discussed in Chapter 4, the extent of areas

Table 7.1: People living on degraded agricultural land (DAL): Adapted from[247]

	share of rural population on DAL in 2000	change from 2000 to 2010 of rural population on DAL	share of rural population on remote DAL	change from 2000 to 2010 of rural population on remote DAL
Developed Countries	**17.9%**	**-2.8%**	**0.8%**	**-1.8%**
Developing Countries	**32.4%**	**+13.3%**	**5.5%**	**+13.8%**
East Asia & Pacific	50.8%	+8.4%	9.0%	+6.8%
Europe & Central Asia	38.5%	+1.0%	3.6%	+4.4%
Latin America & Caribbean	13.0%	+18.4%	1.9%	+17.1%
Middle East & North Africa	22.3%	+14.3%	2.8%	+5.9%
South Asia	26.2%	+17.8%	2.5%	+18.9%
Sub-Saharan Africa	20.6%	+37.8%	5.8%	+39.3%
World	**34.0%**	**12.4%**	**5.0%**	**+13.6%**

Today, consumers in wealthy countries expect to be able to buy fruit, like tomatoes and strawberries, year-round with the apparent paradox of goods flown hundreds of miles often being cheaper than those grown locally.

experiencing persistent declines in land productivity is increasing and thus impacting food production and security. Although global estimates of the costs of land degradation show great variation, they are all high.

Land degradation is driven primarily by socio-economic forces that put people in vulnerable and insecure positions, obliging them to over exploit the land,[239] such as shortening the periods in which they leave fields fallow or eliminating fallows altogether. The privatization of land can confine pastoralists[240] to smaller areas where they have to keep more animals on degrading pastures[241] and must buy fodder or graze their herds in areas that put them into conflict with other land users.[242] These impacts can be observed in Africa, the high Andes,[243] and in Mongolia where demographic changes have led to the concentration of pastoralists near towns and consequent overgrazing in central and western parts of the country.[244] Similar changes are increasing land degradation in northern Vietnam.[245]

Land degradation generally means that less food is produced on the land which has a direct impact on the health and well-being of the resident and nearby communities. The increase in rural populations on degrading agricultural land is seen as a major obstacle to poverty reduction strategies.[246]

5. Food miles

Waste and inefficiencies in our food system increase further when transport is taken into account. Food has been transported since trade routes opened, but in the past long-distance transport was confined to a few high-value foods that could be kept for long periods, such as spices that crossed into Europe along the famous routes through Central Asia.[248] For most people, food was predominantly local and seasonal: fruits and vegetables when they ripened, livestock slaughtered on feast days, and grains and root vegetables carefully stored with surplus processed through bottling or fermentation.[249] With the advent of refrigerated container ships and more recently cheap air freight, the economics of moving food around the world were transformed. Today, consumers in wealthy countries expect to be able to buy fruit, like tomatoes and strawberries, year-round with the apparent paradox of goods flown hundreds of miles often being cheaper than those grown locally.

The concept of "food miles" was developed to describe and quantify this phenomenon, now central to the commercial foundation of agribusiness. In its simplest form, food miles refers to the distance food travels between the producer and the consumer;[250] in the case of processed food, this figure may be the sum of the transport of multiple ingredients.

Food miles have often been used as a surrogate for understanding the carbon footprint of food but this may be too simplistic: research in the United States found that although food is transported considerable distances (on average 1,640 km for delivery and 6,760 km for the life cycle supply chain), 83 per cent of the average US household's food-related CO_2 equivalent emissions come from the production phase. Transport represents only 11 per cent of food's life-cycle greenhouse gas emissions and final delivery from the producer to retail outlets only 4 per cent.[251] The centralized distribution system of major supermarket chains that dominate retail marketing means that the bulk of transportation is actually in the country of sale, even for imported goods. A study by the UK government found food transport reached 30 billion vehicle kilometers in 2002, 82 per cent of which were in the UK. The study calculated that overall greenhouse gas emissions for tomatoes and strawberries from Spain, poultry from Brazil, and lamb from New Zealand were less than the equivalent produced in the UK, even despite the long-distance transport involved. Overall the carbon balance of foods is likely to be influenced largely by a combination of yield, refrigerated storage, and transportation distance.[252] In the UK, research in 2005 found that food and agricultural products accounted for 28 per cent of goods transported by road, imposing estimated external costs of USD 2.94 billion a year.[253]

So while food transport undoubtedly has major impacts, addressing the question of food miles remains complicated. For those concerned with reducing their footprint, it is not just a matter of not buying imported foods but looking at the entire structure of the food industry in the most developed nations.

6. Human health and nutrition

One in nine people in the world are still chronically undernourished and around the same number are considered seriously obese.

One in nine people in the world are still chronically undernourished and around the same number are considered seriously obese. These dietary inadequacies are causing a global health crisis that is threatening to overwhelm medical services, undermine economies, shorten lives, and reduce overall human well-being.

While the percentage of chronically undernourished people in developing countries has fallen from 34 per cent in the mid-1970s to 15 per cent today, some 788 million people remain chronically undernourished, with the total projected to fall to less than 650 million in the next decade, although sub-Saharan Africa will increase its proportion of the total.[254] Regions such as Latin America have made tremendous progress while other parts of the world are still failing to alleviate widespread hunger and malnutrition within their countries. Undernourishment is highest in south Asia (India, Pakistan, and Bangladesh) while progress is slowest in sub-Saharan Africa where one in four people still go hungry.[255]

There are two main types of malnutrition: protein-energy malnutrition which leads to wasting and stunting, and is what is commonly meant when “world hunger” is described; and micronutrient deficiency[256] which can lead to health issues, such as anemia, growth retardation, and cognitive impairment.

Hunger affects the youngest most severely.[257] In 2013, 15 per cent of the world’s children under five years old were considered to be malnourished but this figure rises to 22 per cent in sub-Saharan Africa and 32.5 per cent in south Asia:[258] of the 6.9 million deaths of children under the age of five in 2011, one-third were attributable to underlying malnutrition, mainly in these two regions. This does not mean that over two million children literally starved to death although many will have done so. Hunger weakens resistance to disease and infection. Chronic diarrhea often coincides with micronutrient deficiencies so that the lack of access to clean water together with a lack of food creates a vicious cycle of malnutrition and infections leading to premature death.[259]

The principal causes of hunger are poverty (by far the most important globally),[260] the impact of inequitable economic systems, and conflict.[261] The key problem is that almost a billion people do not have enough income to buy adequate amounts of nutritious food, or any land on which to produce or collect food. Rapidly growing populations are also straining food production systems although as mentioned earlier there is still ample food produced globally to feed everyone adequately.

At the same time, the number of people who are overweight is increasing dramatically. In 1995, being overweight was recognized as being a larger problem than malnutrition even in many developing countries and, following a World Health Organization obesity consultation in 1997, its critical role in escalating medical problems and health costs was first recognized.[262] In 2014, over 1.9 billion adults over 18 years old were overweight (39 per cent of the world’s population) and 600 million (13 per cent) were considered obese, including 41 million children under the age of five either overweight or obese. Most of the world’s population lives in countries where being overweight kills more people than being underweight.[263]

7. Crop selection and genetically modified crops

Crop selection has been a feature of agriculture since prehistoric times. Indeed, the concept of identifying desirable crop traits and enhancing these through selective breeding is one of the most fundamental stepping stones in the evolution of civilization.[264] More recently, sophisticated selection techniques have resulted in high-yielding varieties, which are reliant on heavier applications of agrochemicals, leading to productivity increases in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important crops but also accompanied by a host of detrimental impacts on human and environmental health. The trade-offs between food production and land degradation are the subject of long, politically charged debates and many policies and laws.[265]

Genetically modified organisms (GMOs) are those whose genetic material has been modified by a variety of engineering techniques performed in the laboratory. One specific type of GMO is a transgenic organism which has been altered by the addition of genetic material from an unrelated organism. The use of GMOs, and particularly transgenic organisms, remains highly contentious; countries and regions have responded in different ways. The European Union insists on all food products containing GMOs to be labeled while in the US,[266] this is not the case as the corporate food industry strenuously opposes labeling. Some critics highlight safety concerns relating to the potential for unintended consequences from genetic alterations while others object on ethical or religious grounds. Some express disquiet about how genetic modification has been used; for example, soybeans and several other crops have been modified to increase their resistance to herbicides, encouraging heavier applications on crops and thus leading to more environmental pollution.

By making crops resistant to pests and immune to the effects of herbicides, the promise of genetic modification is to increase crop productivity and feed the world's growing population while using less pesticide. However, extensive studies, including research by the GMO industry itself, reveal that genetic modification in the United States and Canada has not accelerated increases in crop yields (when measured against Western Europe) or led to an overall reduction in the use of chemical pesticides.[267] A recent report found that "there was little evidence" that the introduction of genetically modified crops in the United States had led to yield gains beyond those seen through the use of conventional crops.[268]

Box 7.5: Traditional breeding for drought tolerance – Years ahead of GM efforts

Genetic engineering lags behind conventional breeding in efforts to create drought-resistant maize. The need for more resilient crops is especially acute in Africa, where drought can reduce maize (corn) yields by up to 25 per cent. The Drought Tolerant Maize for Africa project, which launched in 2006 with USD 33 million, has developed 153 new varieties to improve yields in 13 countries. In field trials, these varieties match or exceed the yields from commercial seeds under good rainfall conditions, and yield up to 30 per cent more under drought conditions. The higher yields from drought-tolerant maize could help to reduce the number of people living in poverty in the 13 countries by up to 9 per cent.[269] In Zimbabwe alone, that effect would reach more than half a million people. Since its launch in 2010, the project has developed 21 conventionally bred varieties in field tests which yielded up to 1 ton per hectare more in nitrogen-poor soils than did commercially available varieties. The project's researchers say that they are at least 10 years from developing a comparable GM variety.[270]

CONCLUSION: TRANSFORMING OUR FOOD SYSTEMS

Something is very wrong with the way we produce, market, and consume our food. A billion people do not have enough to eat while another billion suffer the consequences of being overweight.

Our current agriculture practices use enormous amounts of scarce water and energy supplies, and contribute to the very climate change that threatens the entire food system.

At least one-third of our food is wasted and every year, irreplaceable agricultural land is degraded and lost through mismanagement. Our dwindling natural ecosystems are being destroyed for agriculture, with a food industry still acting as if land resources were infinite. The pollution from agriculture is reaching critical levels in many places yet most research focuses on ways of using more agrochemicals rather than on ways of using less. Our current agriculture practices use enormous amounts of scarce water and energy supplies, and contribute to the very climate change that threatens the entire food system.

Most farmers are deeply committed to the long-term health and productivity of their land. The fact that many are caught in an unsustainable management spiral is a cause of deep distress. Farmers are trapped between the demands of a food system that is squeezing them financially, a public demanding cheap food, and multiple competing land uses. It is no wonder that farmers are among the highest groups at suicide risk in many countries.[271] A fundamental transformation of our entire food system is well overdue. Such a transition towards net positive food systems depends on the development and implementation of a proactive agenda.[272]

A ten point plan for land management and human security based on rights, rewards, and responsibilities

In the future, there will be more people to feed. Food security is under threat and there is no single solution to this challenge; instead the world will need to make a coordinated effort to address shortages, degradation, inequalities, and waste. Ten key steps will be essential; these are listed below and then outlined in more detail. Some of these are already well underway and need to be further supported by national policies and consumer decisions; others require a more fundamental rethinking of the way we approach the entire food system, from production and distribution to consumption. So far, the response has been narrowly focused on intensification, which has boosted food production but has also produced a wide range of side effects including pollution, salinization and land degradation, pests and diseases, invasive species, and the loss of genetic variability and evolutionary potential.

These ten steps would move us closer towards a multifunctional approach to food production which emphasizes human health, ecosystem services, resource efficiency, and above all sustainability for future generations.

1. Close the gap between actual and potential yield in all environments
2. Use land, water, nutrients, and pesticides more efficiently
3. Reduce offsite impacts of food and non-food production
4. Stop expanding the agricultural frontier
5. Shift to more plant-based and whole food diets
6. Raise awareness about health, sustainability, and responsibility
7. Reward sustainable land management practices
8. Reduce food waste and post-harvest losses
9. Improve land tenure security, access to nutritional food, and gender equity
10. Implement integrated landscape management approaches

1. Close the gap between actual and potential yield in all environments

Having sufficient food to feed the world's population until the end of the 21st century is often based on the assumption that it is possible to keep increasing crop yields. However, many experts remain deeply skeptical, and believe that many of the predictions for yield increases are overly optimistic.[273]

Even if yields were brought up to only 75 per cent of their potential, global production would increase by 1.1 billion tons.

The yield gap is the difference between actual crop yields and potential yields at any location given current agricultural practices and technologies. It is much easier to increase output for crops with large yield gaps than it is to boost production on already high-yielding farms. Yet much of the agricultural research and extension still focuses on the latter. Shifting attention to closing the yield gaps, without excessive environmental and resource costs, would provide more immediate and cost-effective gains in food production in much of the developing world. Bringing yields to within 95 per cent of their potential for 16 important food and feed crops would result in an additional 2.3 billion tons or a 58 per cent increase. Even if yields were brought up to only 75 per cent of their potential, global production would increase by 1.1 billion tons.[274]

Global yield variability in crops is determined primarily by nutrient levels, water availability, and climate. Large production increases, of 45 to 70 per cent for most crops, are possible mainly through increased access to nutrients, and in some cases to water coupled with reduced nutrient imbalances and inefficiencies. Research suggests that there are large opportunities to reduce nutrient overuse while still allowing for an approximately 30 per cent increase in the production of major cereals (e.g., maize, wheat, and rice).[275]

The responsibility for closing yield gaps rests less with scientists and researchers, and more with extension workers, governments, farming organizations, the food industry, and civil society as well as their capacity to share expertise, make resources available, and provide market infrastructure; and with farmers and producers themselves.

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2. Use land, water, nutrients, and pesticides more efficiently

Food insecurity can be reduced simply by eliminating much of the loss and waste in the system: e.g., through capacity building among food producers, commitments to better stewardship, and the introduction of improved technologies. These efforts of course need to be supported by policy incentives and a reduction in perverse subsidies that encourage wasteful water and agrochemical use.

Many farmers currently use pesticides very inefficiently[277] without understanding their side effects[278] and thus becoming "locked in" to an increasing cycle of use[279] of what may sometimes include banned products.[280] Furthermore, much of the equipment used to apply pesticides remains relatively crude, resulting in both drift of very small droplets and wastage through release of large droplets.[281] Improved technologies and smart application procedures can dramatically reduce pesticide volumes[282] and thus offsite impacts and toxic loads. Improved technical options exist but uptake often remains low;[283] legal loopholes in many countries foster misuse.[284] Improving efficiency will also require more investment in research. In many countries public funding for research has been reduced on the basis that pesticide companies should pay but understandably have little incentive to invest in systems that would reduce their sales.

A suite of well-known management techniques exists to conserve water, such as conservation agriculture, the use of manures and compost, vegetative strips to control run-off, agroforestry, water harvesting, gulley rehabilitation, and terracing.

Similar options exist to reduce fertilizer inputs and water use, most notably through integrated national or regional plans.[285] Soil and crop nutrient testing, improved timing of application (identifying suitable weather conditions), slow-release and controlled release fertilizers, use of urease and nitrification inhibitors to decrease nitrogen losses, and placement rather than broadcast application, can all reduce fertilizer waste.[286] A suite of well-known management techniques exists to conserve water, such as conservation agriculture, the use of manures and compost, vegetative strips to control run-off, agroforestry, water harvesting, gulley rehabilitation, and terracing.[287]

The concept of "sustainable intensification" is gaining traction, defined as any effort to "intensify" food production that is matched by a concerted focus on making it "sustainable," i.e., minimizing pressures on the land and the environment. Integrated Pest Management approaches are now being used on millions of farms: research demonstrates that higher yields can be achieved with reductions in pesticide use,[288] more intra-specific crop diversity to manage pests,[289] and suggests that efficient agriculture does not require the adoption of large-scale monocultures.[290] Small-scale, labor-intensive, low-input farming systems frequently lead to higher yields than conventional systems.[291] Extension approaches such as Farmer Field Schools, promoting education, co-learning, and experiential learning can help to reduce the wasteful and unnecessary use of pesticides.[292] Yet there is much less investment in research into low-input systems, and this approach continues to remain undervalued.

Box 7.6: Closing the yield gap in Brazil

In the case of Brazil, a country rich in terrestrial carbon and biodiversity, agricultural production is forecast to increase significantly over the next 40 years. A recent study produced the first estimate of the carrying capacity of Brazil's 115 million hectares of cultivated pasturelands, where researchers investigated if the more sustainable use of these existing production lands could meet the expected increase in demand for meat, crops, wood, and biofuels. They found that current productivity is at 32-34 per cent of its potential and that sustainable intensification to bring productivity to 49-52 per cent would provide an adequate supply of these goods until at least 2040, without further land or ecosystem degradation and with significant carbon sequestration benefits.[276]

3. Reduce offsite impacts of food and non-food production

The side effects of the current food system threaten to undermine the very processes it seeks to maintain by emitting greenhouse gases and degrading the biological and economic potential of the land. Efforts to alleviate the offsite impacts of food production need to focus on management practices that ensure the more efficient delivery of agrochemicals to reduce leakage into the wider landscape as well as the development and application of safer and effective alternatives. Efforts to close the yield gap (Step 1) will only produce a net benefit if offsite impacts are reduced at the same time, i.e., sustainable intensification.

An analysis of 85 projects in 24 countries calculated that half of all pesticides used are unnecessary.[293] Farmers often rely heavily on advice from agrochemical companies or their agents.[294] In 2014, the US Environmental Protection Agency concluded

Box 7.7: Precision agriculture

Agriculture has been one of the last industries to embrace an information-driven, real-time business approach. Precision agriculture uses sophisticated monitoring technology to assess variables such as soil and weather conditions, coupled with modeling tools, to help growers adjust farm operations in response to intra-field variability.[296] The incorporation of objective real-time advice across the crop cycle helps growers optimize choices on what, when, and where to plant, and what to apply to the plant and soil. It helps to increase production efficiency while reducing on-site degradation of soil and offsite environmental impacts. Precision agriculture relies on an ability to capture, interpret, and assess the economic and environmental benefits of particular management actions.[297]

that applications of neonicotinoid seed dressings to soybean provide "limited to no benefit" yet they were widely used at a cost to farmers of USD 176 million per year.[295] Major efforts at reducing agrochemical use and leakage could be made using current technology, including a detailed matching of crop needs and conditions as in precision agriculture. Clear, unbiased advice and support to farmers is a critical step in this process.

In the short term, efforts at reducing offsite pollution should focus on where the greatest gains can be made, or where the impacts are most severe. China, India, and the United States collectively account for 65 per cent of excess nitrogen and phosphorus usage globally; focusing efforts on improved fertilizer efficiency to a small set of crops and countries could potentially reduce global nitrogen and phosphorus pollution with further efficiency gains achieved by modifying the timing, placement, and type of fertilizer used.[298]

One critical offsite impact is greenhouse gas emissions from agriculture. In some cases, these may be hard to reduce without major changes to production systems, such as reducing emissions from ruminant animals. In other food production systems, minor changes in practices can make a big difference, such as using different crop varieties or species, planting at different times of the year, and making use of accurate climate forecasting.[299] Species selection along with water, soil, and stubble management can reduce emissions from rice production.[300] Regenerative forms of agriculture, which make use of natural processes to help build soils, retain water, sequester carbon, and increase biodiversity, are receiving increasing attention.

Table 7.2: Elements of precision agriculture

Categories	Advice Offered	Description
Crops	Variety selection	Seed variety selection
	Best planting times	Right time and conditions for planting
	Variable seeding rate	Seeding based on intra-field variability
Fertilizer use	Variable fertilizer rate	Nutrient application based on intra-field variability
	Field maps	Field maps to assist precision application
	Variable application rate	Chemical application based on intra field variability
	Sustainability advice	Steps towards sustainable resource optimization
Pest and disease management	Disease diagnostics	Predictive or diagnostic assessment
	Scale of pest problems	Predictive and diagnostic models
	Protocol advice	Scalability for image-based diagnostics; model driven algorithms
Crop health	NDVI/EVI indices	Satellite/drone imagery using Normalized Difference Vegetation Index and Enhanced Vegetation Index to assess field conditions
	Weather/field alerts	Predictive models based on weather-driven agronomic planning
	Monitoring soil nutrients	Algorithm-driven field nutrient mapping
	Biomass mapping	Field monitoring of organic matter

Box 7.8: Organic agriculture and integrated production systems

Various types of agriculture can have a place in feeding the world depending on the availability of land, the degree of self-reliance of agricultural systems in terms of critical inputs to value chains, such as nutrients and other resources, the scale of food production, and the desired and feasible trade in agricultural goods.[301] Organically grown food, beverages, supplements, cosmetics, and other goods are a rapidly growing market in the developed countries and among the emerging middle classes in the developing world. The perceived human health (nutritional) and environmental benefits are the primary drivers of this market growth. Over a quarter of the world's organic agricultural land and more than 1.9 million, or 86 per cent, of the world's organic producers, are in developing countries and emerging markets, notably India (650,000), Uganda (189,610), and Mexico (169,703).[302] Organic agriculture is defined and verified by global and national standards.

Organic agriculture addresses many of the drivers of land degradation and their offsite impacts by eliminating chemical fertilizers and most pesticides, helping to build soil organic matter, and applying water conservation methods. There are already over 43 million hectares of organic production worldwide, with a further 35 million hectares of natural or semi-natural areas used for the collection of "wild" organically certified products, such as honey and herbs.[303] In most cases at large-scales, organic systems produce lower yields than conventional systems, however they generally protect associated ecosystem services, and demand has risen steadily: in 2013, global sales were worth USD 72 billion and are predicted to double by 2018.[304] There is strong evidence that organic agriculture supports more biodiversity.[305] Organic farming focuses on increasing soil organic matter, maintaining on-farm biodiversity, and using less energy,[306] however, in some cases organic farming may cause nutrient mining of the soil and in the long run may diminish soil organic matter.[307] A recent meta-analysis shows that under some circumstances organic agriculture comes close to matching the yields of conventional agriculture while in other cases it does not.[308,309] Productivity in organic agriculture is being further boosted by introducing greater crop diversity under integrated pest management and thus substituting companion plants for pesticides.[310] The role of organic agriculture is currently undervalued in addressing food security issues and offers significant opportunities for further development.

4. Stop expanding the agricultural frontier

Further agricultural expansion into natural ecosystems, primarily through deforestation and other land use changes, such as converting pasture to crops, carries unacceptably high costs, in terms of biodiversity and ecosystem services lost, and often for very modest returns in terms of the food produced.[311] Where expansion is absolutely necessary, this should occur in areas already degraded and where there is little to be lost or recovered,[312] or abandoned land where ecosystem services can be regained by converting to farmland. Even here, the selection of sites needs to be carried out with care. For instance, many *Imperata* grasslands in Asia developed as a result of unsustainable swidden practices and appear to be degraded but nevertheless continue to support subsistence agriculture.[313] Planning and managing land use change requires strong leadership and institutions but can also be influenced by business and consumers; for example, several certification schemes stipulate that the products they cover, such as palm oil and soybean, do not come from plantations established on newly-cleared forests (see Step 6).

5. Shift to more plant-based and whole food diets

Changing diets, especially in the richer countries, could have major positive impacts on both personal health and the condition of the land. Virtually every scenario of future food availability shows that reducing meat consumption, especially beef, is the quickest and most effective way to increase food security and reduce carbon emissions and offsite impacts.[314] Even a slight reduction, to the level recommended by health officials,[315] would incur major savings in land and its resources. For example, reallocating the land currently used for cattle feed in the United States to producing poultry feed would meet the caloric and protein demands of an additional 120-140 million people.[316]

Dietary reforms need to address the time bomb of chronic obesity and its impacts on well-being, lifespan, health services, and economies.[317] Bad diets, many of them implicitly promoted by major retailers,[318] have already undermined the health of a billion people. Public health campaigns have been struggling to convince a generation hooked on fast foods and a high-protein, high-fat diet. Health

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education based on positive encouragement, rather than "fat shaming,"[319] more exercise,[320] additional taxes on unhealthy foods (in the region of at least 20 per cent),[321] and where necessary legislative controls, are all needed. The emergence of sugar taxes, a soda tax in Mexico,[322] and similar initiatives show that many governments increasingly recognize the scale of the problem.

One way to highlight the stark differences is to evaluate agricultural productivity in terms of people fed per hectare rather than by tons per hectare. Based on the current mix of crop uses, food production exclusively for direct human consumption could potentially increase available calories by up to 70 per cent, enough to feed four billion people, and even slight changes in crop allocations for animal feed and biofuels would significantly increase global food availability.[323] A switch to less processed foods and less meat will ultimately lead to more sustainable practices in food production.

6. Raise awareness about health, sustainability, and responsibility

Experience shows that many people are prepared to make healthy and ethical choices about food when they are given accurate and timely information. Both mandatory and voluntary schemes have a role to play. Government-led, obligatory labeling schemes that provide information about nutritional information, calorific value, dietary advice, and health risks are able to persuade many consumers, as has been shown for example by controls on cigarette advertising.

At the same time, the growth of voluntary product certification schemes supports consumers prepared to choose and invest in products that minimize environmental degradation and their carbon footprint. The rapid growth of fair trade and environmental certification schemes over the last two decades provides the basis for more sustainable production, because standards of good management and systems are in place to ensure that scheme participants keep to their commitments. Table 7.3 outlines some of the more prominent schemes.

7. Reward sustainable land management practices

Farming is the biggest use of land on the planet and farmland is in short supply. In the future, farmland will need to be managed much more consciously for the delivery of a full suite of ecosystem services not just food, fiber, and fuel.[335] Agriculture needs to shift from being a source of climate change to a sink for carbon. Many of the steps towards lower greenhouse gas emissions are the same as those already identified: less nitrogen-based fertilizers, lower fossil fuel energy use, better management of waste, increased soil organic matter, ecological restoration, and improvements in irrigation.[336] Agricultural soils need to be conserved, both for the sake of productivity and to avoid downstream impacts. Pollinators, which are facing extreme threats in some areas, require dedicated conservation approaches.[337] In some cases, this more holistic form of management has been in place for decades or centuries; in others it will require a fundamental shift in attitudes.

It will also mean a shift in the way that farmers do business. If farms are expected to provide multiple benefits, they need to be paid for these; greater diversification may mean, for example, that a greater proportion of agricultural income comes from innovative funding sources, such as Payment for Ecosystem Service (PES) schemes.

Engineering a shift towards rewards for land managers based on multiple functions and services will require actions at every level: subsidies and incentives at the local, national, and sometimes global scale; equitable stakeholder platforms linking business, local authorities, extension agents and NGOs with ecosystem providers, such as land managers, individual farmers, or cooperatives; valuation systems to ensure fair prices and financial mechanisms for collection and disbursement of financial and other forms of compensation. While there is a growing body of experience, much more still remains to be learned.

8. Reduce food waste and post-harvest losses

Given that one-third of food produced never reaches the consumers' stomachs, reducing waste would appear at first sight to be an easy win in terms of food and nutritional security. But in practice this will not be easy as a culture of waste has been woven into the fabric of our food systems through purchasing and trade policies, food regulations, and the economics of distribution and retail. It will entail changing the rules on sell-by dates and consumer attitudes towards misshapen fruit and vegetables, a major pubic re-education campaign about our culture of waste and what constitutes desirable or acceptable food, and ultimately changes in the structure of a food industry that is based on the large-scale and constant movement of food products.

Box 7.9: Payment for Ecosystem Services (PES)

It is theoretically possible to collect user fees from people and companies benefiting from ecosystem services to help pay for potential benefits foregone by the people managing the ecosystems producing these services. PES schemes (also called Payment for Environmental Services) can be an important way of supporting farmers and land managers providing these services;[338] for example, by protecting forest to maintain water quality or by reducing stocking levels in hilly country to encourage vegetation growth to reduce flooding. About 80 per cent of Quito's 1.5 million population receive drinking water from two protected areas: Antisana (120,000 ha) and Cayambe-Coca Ecological Reserve (403,103 ha). The government is working with a local NGO and farming communities to protect the watersheds, including stricter enforcement of protection to the upper watersheds and measures to improve or protect hydrological functions and waterholes, prevent erosion, and stabilize banks and slopes.[339] PES schemes suitable for farmers currently focus on carbon sequestration, forest conservation, watershed protection, and disaster risk reduction; payments can be either in cash or in kind, such as equipment, beehives, etc.[340] The value of ecosystem services from agriculture are huge; the challenge lies in finding politically and socially acceptable ways of ensuring that the farmers stewarding these values get adequate compensation.[341]

However, it is very easy to make a start. Many technical, policy, and lifestyle options exist for cutting waste, including facilitating food redistribution and donations, using evaporative coolers in places where refrigeration is unavailable, introducing hermetically sealed plastic storage

Figure 7.7: Food losses along the food chain: Redrawn from[345]

	PRODUCTION	POST PRODUCTION	PROCESSING	DISTRIBUTION	CONSUMPTION
VALUE CHAIN STAGES	Preharvest Harvest Breeding	Handling Storage Transport	Canning Packaging Transformation	Retail Transport	Preparation Table
CAUSES OF LOSS	Damage/spillage Left behind in fields Pests/diseases Weather Wrong imputs	Degradation Pests Premature animal death Spillage	Degradation Discard Spillage	Degradation Discard Excess supply Spillage Spoilage	Discard Excess preparation Spoilage

Table 7.3: Voluntary certification schemes

Voluntary certification scheme	Remit and background
Bonsucro Better Sugarcane Initiative	Fostering the sustainability of the sugarcane sector, Bonsucro has almost 200 members from 27 countries.[324]
Climate, Community and Biodiversity Alliance	A multi-organizational initiative promoting land management activities that credibly mitigate climate change including REDD+ projects.[325]
Fair Trade International	Sets global standards for trade that gives farmers a decent livelihood with many individual standards for producer and trader groups and for individual products.[326]
Forest Stewardship Council	One of several forest certification schemes which imposes controls on the clearing of natural woodlands.[327]
Global Roundtable for Sustainable Beef	Promotes responsible beef production throughout the supply chain.[328]
Initiative for Responsible Mining Assurance	Developing a certification scheme for mining operations.[329]
International Federation of Organic Agriculture Movements	International body setting overall standards for organic agriculture with national standards that need to meet those of IFOAM.[330]
ProTerra	A Dutch-based group certifying all aspects of the food chain.[331]
Roundtable on Responsible Soy	Reducing environmental impacts of soybean: there are currently 181 RTRS members and 1.3 million tons of certified soybean were sold in 2014.[332]
Roundtable on Sustainable Palm Oil	Reducing the environmental and social impacts of oil palm production, RSPO has over 2,000 members and over 3 million hectares certified.[333]
Sustainable Agriculture Network	A coalition of non-profit organizations promoting environmental and social sustainability of agriculture through development of best practice standards, certification, and training.[334]

bags or plastic crates for crops, using smaller metal silos, reducing confusion about food date labels, conducting consumer awareness campaigns, and reducing portion sizes at restaurants and cafeterias. Waste reduction targets need to be set by governments; if the current rate of food loss and waste could be cut in half by the year 2050, for instance, it would produce roughly 22 per cent of the gap between the food produced today and projected demand by the middle of the century.[342]

In developing countries, food waste and losses occur mainly at early stages of the food value chain and can be traced back to financial, managerial, and technical constraints in harvesting techniques as well as distribution, storage, and cooling facilities. Cooperation among farmers could reduce the risk of overproduction by allowing surplus crops from one farm to solve a shortage of crops on another.[343] Poor storage facilities and lack of infrastructure cause post-harvest food losses in the tropics; overcoming this challenge will require improved infrastructure for roads, energy, and markets, and ultimately storage and cold chain facilities.[344] The lack of processing facilities also results in food losses due to the seasonality of production and the cost of investing in processing facilities that will not be used year-round.

9. Improve land tenure security and gender equity

Most of the steps above apply equally to the whole food system and indeed the planet. But in the context of food security, it is the poorest that suffer the most, including rural dwellers without access to land and urban dwellers too poor to buy sufficient food to feed their families. The recognition that we have a massive problem of obesity must not obscure the fact that almost as many people are underweight due to lack of sufficient nutrition and, under current projections, this number is likely to increase in the future. A food system that explicitly fails to address the needs of the poor, landless, and powerless will fail to provide food security,[346] and recent trends have tended to increase their vulnerability.

A critical element of success is the recognition of women's rights to secure land tenure, separate from male members of the family. Such rights need to be set out in law in countries where this has not happened, and publicized, explained, and implemented in places where legal changes have not made much difference to everyday practices. Gender issues extend beyond just ownership and influence the type of agriculture practiced. In countries where agricultural labor is mainly left to women, greater equity in working conditions must also be encouraged, both to increase overall well-being and to ensure maximum efficiency.

Food justice is thus about far more than just the volume of food produced. Strategies that aim to develop resilient food systems need to look beyond traditional farming issues to consider, for example, issues of gender equity and social justice that shape access to land and natural resources; adopting integrated agro-ecological approaches to produce more food with reduced environmental impacts; supporting more regionally organized food systems; and embedding access to healthy and culturally-relevant foods within production policies.[347]

Land redistribution from wealthy owners of large farms to land-poor farmers, tenants, or farm workers can foster economic growth, poverty reduction, and gender equity if managed well and supported by strong policies and capacity development. For example, community-based land reform in Malawi led to improvements in landholdings, land tenure security, crop production, and productivity as well as increased incomes and food security.[348]

Land reforms aimed at distributing land to the poor need to steer a delicate course that redistributes land without causing political tension or undermining the position of existing smallholders. This must, for example, include elements to enhance the purchasing power of the poor, remove incentives for land consolidation, and provide sufficient subsidies and extension services.[349]

10. Implement integrated landscape management approaches

To some extent, Step 10 is the summation of the previous nine. Increasing pressure on the agricultural land base, widespread land degradation and desertification, rising pollution, climate change, and growing human populations means that the world needs to move away from a narrow focus on food production and see farmland as part of a multifunctional landscape that supplies food but is also responsible for a wide range of supporting, regulating, and cultural services.

Managing the increasing competition for and trade in land-based goods and services as well as different stakeholder interests requires land use planning to ensure efficient land allocation that promotes sustainable land use options and helps balance competing uses. Land use planning is not a simple land valuation, which can be very attractive for urban developers and detrimental for agriculture; neither is it a land capability classification. Comprehensive land use planning covers all potential uses of land including areas suitable for agriculture, forestry, urban expansion, wildlife, grazing lands, and recreational areas. By modifying spatial landscape structure and allocating land use activities to optimal places in the landscape, it is possible to enhance the production of multiple services and the resilience of the land system.[350] In this way the designed systems would better accommodate local interests and ecosystem service demand, be sustainable from both local and landscape perspectives, and implemented within the local socio-economic and land governance context.[351] Another major aspect of these systemic changes includes the psychological and social aspects of changing practices that have sometimes been accepted for centuries, requiring collaborative approaches with a wide range of stakeholders,[352] including industry.[353]

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Part Two

CHAPTER 8

WATER RESOURCES

Rising water demand creates shortages, depletes groundwater sources, and results in high salt levels in soils. At the same time, wetlands are rapidly disappearing due to drainage, conversion, and the disruption of natural flows. These trends have serious health and environmental impacts: reducing ecosystem services and biodiversity, and resulting in high carbon emissions, soil subsidence, loss of productive land, and water insecurity. The current business model for agriculture, energy, and industry, including water pricing and trading, creates perverse incentives to waste water. Rapid unplanned urbanization and climate change make things worse.

An integrated approach to land and water resource management is essential: this entails reducing demand and increasing use efficiency, protecting and restoring wetlands and watersheds in our working landscapes, providing incentives for sustainable use, and designing more sustainable cities. We have the technical know-how to sustainably manage global water supplies, but we need coordinated action and the political will to incentivize equitable water sharing and improve management practices at progressively larger scales.

INTRODUCTION

Throughout history, the success and failure of human communities have been closely linked to the effectiveness of water management. The first great civilizations developed on the banks of major rivers – like the Nile in Egypt,[1] Tigris and Euphrates of Mesopotamia, Indus in India and Pakistan, and Hwang Ho in China – drawing on seasonal plenty to supply irrigation systems and create agricultural surpluses. Irrigation systems also helped farmers move into arid areas, or survive changing weather patterns.[2] The eventual breakdown of these civilizations was triggered in part by the failure of their water systems,[3] through mismanagement leading to problems such as desiccation, water-logging, and salinization.[4]

Today the world faces growing problems relating to land-water interactions and water security, which have reached crisis levels in many countries and regions. Key issues include over-use and waste; fluctuations in abundance, with an increasing frequency of both droughts and floods; poor water quality with impacts on environmental and human health; and the knock-on effects of land degradation. The world is becoming increasingly urban, with half of the population already living in cities and likely to increase to 66 per cent by 2050,[5] putting urban water supply and sanitation systems under even more pressure. While extreme water scarcity and floods are in many cases human-induced, the impacts of climate change add a potent new factor that aggravates an already precarious situation.

Water goods and services from wetlands contribute significantly to the global economy. A recent analysis of over 300 ecosystem service valuations estimated an average contribution of USD 25,682 per hectare, per year for inland waters and USD 4,267 per hectare, per year for lakes and rivers,[6] often regarded as "free goods" in conventional economic analysis. Inland and coastal wetlands continue to be degraded or lost at an alarming rate;[7] they are key to the global water cycle and in regulating local water availability and quality. The total value of wetland services is estimated at USD 70 billion per year for Asia.[8] While some countries recognize the nature of the risks and benefits and make strategic investments in their water management systems, others have done little in terms of addressing water stress through either policy or innovation.

Despite massive demographic and environmental changes, water problems are rooted more in management approaches, business models, outdated policies and practices rather than in physical limitations. The technical basis for sustainable water management is well understood, suggesting that solutions need to be aimed primarily at changing behavior and encouraging a multi-functional systems approach to water management.[9] Getting water management right is absolutely critical for the future well-being of people and the environment.

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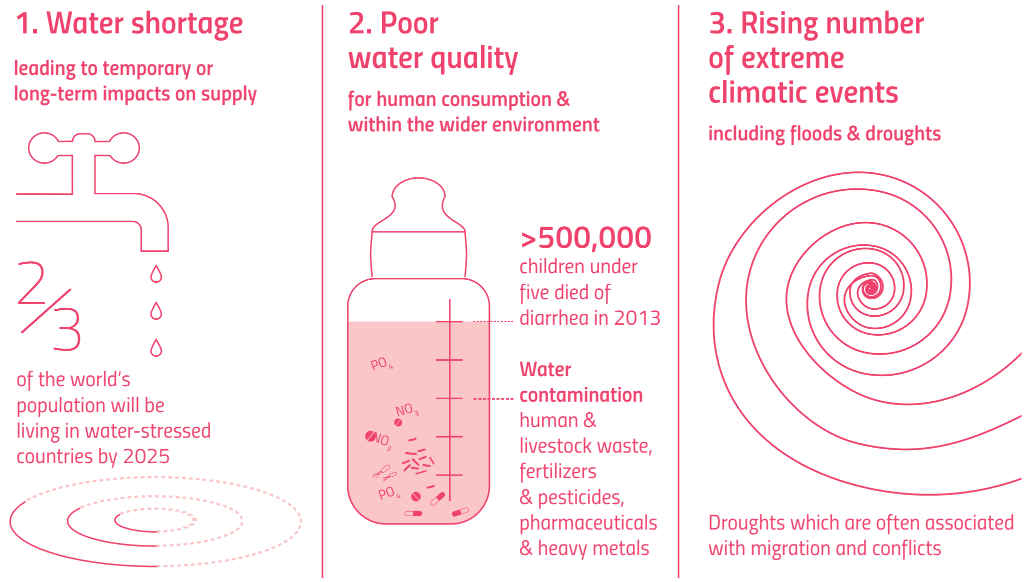


SEVEN ASPECTS OF WATER INSECURITY

Despite years of effort during the "Water for Life" UN Decade for Action (2005-2015), the World Economic Forum's *Global Risk Report 2016* identified potential water crises among the top ten risks facing the world and ranked them as the number three global risk in terms of potential impact.[10] Yet water is still often sidelined in discussions about the role of land and natural resources in economic development.

Sustainable Development Goal 6, "*Clean Water and Sanitation: ensure availability and sustainable management of water and sanitation for all*," will hopefully bring greater attention to these issues.[13] A healthy water cycle is perhaps the most critical component of sustainable and equitable land management policies and practices.

Water security is defined as the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.[14]

The World Water Congress 2015 noted: "*In spite of its relevance in terms of security, water is often not regarded as a key determinant for development, absent from many political agendas.*"[11] The *World Water Development Report 2012* recognized that *"water-related hazards account for 90% of all natural hazards, and their frequency and intensity is generally rising."* Furthermore, the corresponding report in 2015 emphasized the links between water and poverty, environment, and governance: with poor water management impacting negatively on all three issues.[12]

Here we discuss seven distinct aspects of water insecurity:

1. **Water shortages** leading to temporary or long-term impacts on supply
2. **Poor water quality** for human consumption and within the wider environment
3. **Rising number of extreme climatic events** including floods and droughts
4. **Disruption of natural flows** in a growing number of rivers and inland water bodies
5. **Land degradation** as a result of altered hydrology and poor irrigation management
6. **Climate change impacts** due to greenhouse gas emissions from water systems and wetlands
7. **Loss of biodiversity** and water-related ecosystem services

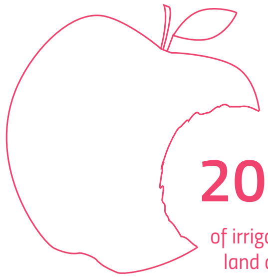
4. Disruption of natural flows

in a growing number of rivers and inland bodies

of the planet's remaining free flowing rivers will be reduced due to hydropower

5. Land degradation

as a result of altered hydrology and poor irrigation management

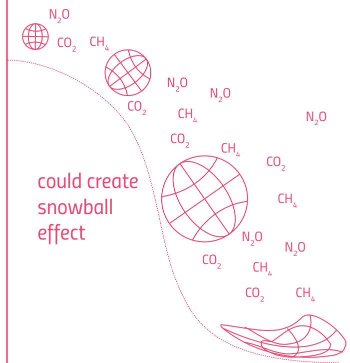


20%

of irrigated land area suffered from crop yield reductions due to salinity

6. Climate change impacts

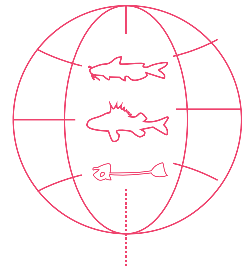
due to release of greenhouse gases from water systems & wetlands



could create snowball effect

7. Loss of biodiversity

& water related ecosystem services



One in three freshwater fish species is threatened with extinction

1. Water shortages

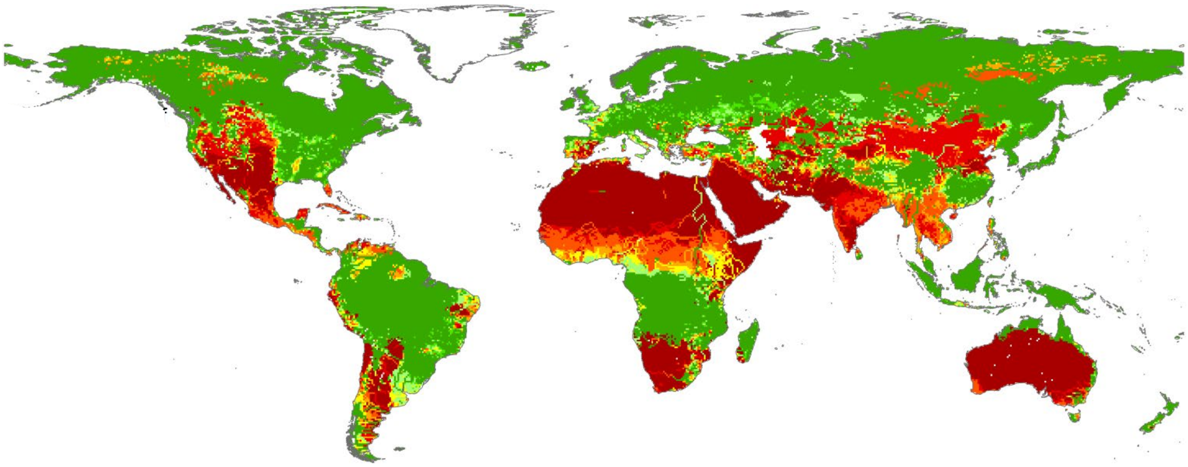
Over 1.7 billion people already live in river basins where water use is greater than the rate of natural replenishment; if this trend continues, two-thirds of the world's population will be living in water-stressed countries by 2025.[15] Other estimates are even more pessimistic with up to 4 billion people, over half the population of the planet, already facing severe water stress for at least one month of the year and half a billion suffering permanent water stress;[16] 71 per cent of the world's irrigated area and 47 per cent of major cities experience at least periodic water shortages.[17]

Shortages are driven not only by a growing population but also by the disproportionate increase in the levels of use and waste as well as the loss of the water retention and supply capacity of wetlands. As humans become more disconnected from water resources, they generally become more careless in their use. At the same time, the lack of pricing regimes in many industrial, energy, and agricultural production systems effectively treats water as a free or very cheap input, further encouraging waste. In the last century, the world population tripled while water consumption increased six-fold,[18] largely due to agricultural use.[19] Various projections indicate that water demand will soon exceed reliable water supplies at a global scale.[20,21,22] Our understanding of the severity and location of water stress is improving; increasingly sophisticated models can identify hotspots by river system and catchment as well as critical areas of shortage.[23,24,25]

Water shortages are a function of both availability and use: some very dry regions do not appear as hotspots due to low population density or efficient management practices whereas heavily populated or industrialized regions can suffer water scarcity even if they have more rainfall. Some of the world's most dramatic drying events, such as the notorious loss of the Aral Sea lying between Kazakhstan and Uzbekistan,[27] and the drying of Lake Chad between Chad, Niger, and Nigeria,[28] are almost entirely due to the diversion of upstream water flows. Current hotspots of scarcity include much of India and China, large areas of the central and western United States, southern Africa, the Mediterranean region, Central Asia and the western rim of South America. Some areas that have yet to face shortages, such as large parts of Africa, are projected to face major problems due to population growth and urbanization.[29] Hotspots of scarcity or floods can be related to the seasonal loss of water retention capacity in the catchment due to the degradation of wetlands, in particular high mountain wetlands or peatlands in southeast Asia and Russia which results in extreme water shortages in dry years and the potential for increased fire risk.[30]

Water insecurity can contribute to social instability and political insecurity, causing tensions within[31] and between countries. Several river basins are particularly at risk, including the Ganges–Brahmaputra, Han, Incomati, Kunene, Kura-Araks, Lake Chad, La Plata, Lempa, Limpopo, Mekong, Ob (Ertis), Okavango, Orange, Salween, Senegal,

Figure 8.1: Hotspots of water shortage:
Used with permission[26]



Key

Annual average of monthly blue water scarcity

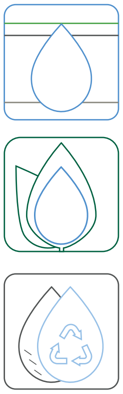
- 0 - 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 3.0
- 3.0 - 5.0
- › 5.0
- No data

Tumen, and Zambezi.[32] While some believe tensions could eventually create open conflict, so-called "water wars,"[33,34] others question the extent to which tensions could grow into conflict between states.[35] The debate continues as some point to rainfall variability as being a more important factor in promoting conflict, or even to water abundance as a cause, while others focus on the role of dams in interrupting water flows between countries. Nations are well aware of the tensions and over 680 water treaties have been signed since 1820 to explore negotiated approaches to disputes about freshwater resources, and the number of treaties is increasing.[36] Most analysts agree that the chances of tensions spilling into conflict are greater at local than at global scale,[37] in fact, the reality of localized, often violent, conflict due in part to environmental degradation is already well recognized.[38]

One outcome of water stress, in countries running short of surface water sources, is the increased use of groundwater sources. Some of these are being exploited faster than they are replenished; while this may be due partly to the reduction in recharge to the groundwater system resulting from climatic variation, the so-called "mining" of non-renewable water sources is not considered a sustainable option. While some groundwater reservoirs remain very large with reserves predicted to last many decades into the future, water security is being threatened by the rapid depletion of others,[39] particularly in drylands,[40] including the North China Plain, parts of Australia, the Northwest Sahara Aquifer System, the Guarani Aquifer in South America, the High Plains and Central Valley aquifers of the United States, and aquifers beneath north-western India and the Middle East.[41] Globally, 1.7 billion people live in areas where groundwater resources and/or groundwater-dependent ecosystems are under threat.[42] Groundwater accounts for up to a third of global water withdrawals, supplying 2 billion people and over 40 per cent of the irrigation water.[43] The countries with the largest areas using groundwater irrigation systems are India (39 million ha), China (19 million ha), and the USA (17 million ha).[44] Knowledge about the extent of reserves remains very limited in some areas,[45] and the lack of regulation has frequently led to unregulated use.

Agriculture is by far the most important driver of water shortages around the world; irrigation accounts for 70 per cent of global water withdrawals, and even more in some places facing critical water stress.[46] Most new land brought into production in the last fifty years is being irrigated,[47] and some estimates suggest that water demand in agriculture could double by 2050 due to growing demands for food.[48] Intensive or mono-cropping agriculture generally uses more water; other uses are divided between the demand from the industrial and energy sectors (20 per cent) and municipalities (10 per cent). The typical contributing factors to excessive water use in agriculture are leaky irrigation systems, wasteful field application, and the cultivation of crops with high water needs. Among the world's most water-intensive crops are cotton (7,000-29,000 liters per kg); rice (3,000-5,000 liters per kg); sugar cane (1,500-3,000 liters per kg), soya (2,000 liters per kg), and wheat (900 liters per kg).[49] Due to the sheer amount grown, rice accounts for 21 per cent of total water used by crops and wheat 12 per cent.[50]

Box 8.1: Blue, green, and grey water



The term "blue water" refers to water in rivers, lakes, and underground reservoirs commonly used for the irrigation of crops through construction of infrastructure such as dams, irrigation channels, and wells. "Green water" is the water that falls as rain, enters the soil root zone, and returns to the atmosphere as vapor from evaporation or transpiration by plants. After irrigation with blue water, the consumptive portion used by a crop returns to the atmosphere as the green water portion of the hydrological cycle. Green water is free, in that it requires no significant built infrastructure for its delivery, but will vary in availability within and between years. Blue water, by its nature, has more storage capacity and thus less short-term fluctuation, particularly in the case of lakes and groundwater, but overuse of blue water can deplete the resource in the long term. With proper treatment, "grey water" or domestic wastewater can be recycled and put to good use. These uses include water for household functions and the irrigation of both food and non-food crops, which can take advantage of the nutrients in the grey water, such as phosphorus and nitrogen.

Livestock production is even less water efficient, particularly if animals are grain-fed and raised within confined spaces. Beef production uses the most water; measurements in the United States found that beef requires 11 times the average amount of water used in other forms of livestock production.[51] A significant water footprint is also created by draining wetlands for agriculture, including the intensive use of peatlands for grazing of livestock (e.g., in the Netherlands and the Tibetan Plateau) and for palm oil and wood pulp. Besides the water loss, the drainage often results in land degradation and ultimately the loss of the peat layer (from oxidation) impacting biological productivity.[52]

Assessing the extent of water use is further complicated because water use in one country may be supporting lifestyles in another when agricultural products are exported. The *water footprint* concept identifies the real extent of water use per country in relation to the consumption of their population. The internal water footprint of a country is the volume of domestic water used, while the external water footprint is the volume of water used in other countries to produce goods and services imported and consumed by that country. The sum gives the total national water footprint. Four major factors influence the national water footprint: volume of consumption (related to the gross national income); consumption patterns (e.g., high versus low meat consumption); climate (plant growth conditions); and agricultural practices (water use efficiency).[53] Inefficiencies in agriculture are probably the most important single factor affecting water security and therefore need to be considered as a high priority for the reform of policies and practices.

2. Poor water quality

Equally challenging is the issue of water quality, both in terms of access to potable drinking water and the wider impacts of pollution on the environment. Almost 3 billion people face problems accessing safe drinking water. The UN's Millennium Development Goal to *reduce by half, by 2015, the proportion of people without sustainable access to safe drinking water*[54] was achieved by 2010, when measured by access to safe drinking water.[55] This was supported by a vigorous campaign by the UN and formation of the Global Water Operators Partnership Agreement to build regional platforms for cooperation and utility partnerships to deliver safe water to the poorest.[56] While the goal was reached overall, showing that major improvements are possible on a global scale, this was not the case in almost half the low- or middle-income countries for which data are available. Even where piped water was introduced, there is no clear data about how much is safe.[57] Lack of access to potable drinking water remains a major health hazard; in 2014, it was estimated that 1.8 billion people still used unsafe supplies, with 1.1 billion more using sources with at least moderate risk.[58,59] In Africa, over 300 million people lack access to clean drinking water,[60] including 17 per cent of city dwellers south of the Sahara.[61]

Unsafe drinking water carries a huge toll in terms of illness and death. Diarrhea is caused primarily by drinking water and infant formula contaminated with human or animal waste. This can be attributed to a number of underlying factors: shallow, contaminated wells; the illegal or ad-hoc nature of new settlements, which hampers government investment; governments overwhelmed by growing urban populations; inadequate transfer of funds from central to local governments; and limited funding due to debt.[62] Over half a million children under five died of diarrhea in 2013; a fall of over 4 per cent per year since 2000[63] but still a massive and largely preventable death toll.

Water is not only contaminated by human and livestock waste, but also and increasingly so by nitrate and phosphate fertilizers and pesticides,

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Rainfall is becoming increasingly erratic due to climate change, with the increased risks of flooding and droughts often affecting the same places at different times.

pharmaceuticals, heavy metals and other industrial pollutants. Since the 1960s, the use of synthetic nitrogen fertilizers has grown nine-fold, with further increases of 40-50 per cent expected over the next half century, while phosphate use has tripled.[64] Increasing fertilizer use, livestock production, and fossil fuel burning is leading to higher levels of reactive nitrogen in the environment, raising nitrate levels above safe thresholds for human and ecosystem health,[65] including in drinking water[66] and through the eutrophication of fresh and coastal waters.[67] Total global leaching and run-off of nitrogen is estimated at 32.6 million tons per year, the large majority from poor agricultural practices.[68] Excess phosphate exacerbates the impacts of nitrate pollution.[69] Other forms of agricultural run-off, including pesticides, herbicides, and fungicides which enter freshwater and marine ecosystems, have harmful impacts on biodiversity,[70] including sometimes at concentrations that current legislation in many countries deem safe.[71] So while there have been welcome improvements in drinking water quality in terms of gross contamination, there is still a long way to go, and conversely other aspects of quality, such as contamination with agricultural chemicals, appear to be worsening.

3. Rising number of extreme climatic events

Rainfall is becoming increasingly erratic due to climate change, with the increased risks of flooding and droughts often affecting the same places at different times.[72] There is already increased precipitation in the higher latitudes of the Northern Hemisphere, decreased rainfall in parts of China, Australia, and the Pacific Islands, and more variability in equatorial regions[73] impacting the frequency and severity of floods and droughts.[74] In 2000, 30 per cent of global urban land was situated in high risk flood areas and will likely grow to 40 per cent by 2030.[75] The intensity and frequency of extreme rainfall events are also likely to increase the magnitude and frequency of landslides.[76] Flooding, like the effects of shortages and poor water quality disproportionately impact the poorest and most vulnerable in many societies.[77]

Erratic bursts of high rainfall create increased hazards for communities living near rivers and wetlands. Since 1900, 90 per cent of disasters from natural hazards have been related to water.[78] Flooding accounted for 47 per cent of weather-related disasters from 1995-2005, with over 3,000 flood disasters affecting 2.3 billion people and killing 157,000; impacts were highest by far in Asia.[79] Water-related disasters are the most frequent

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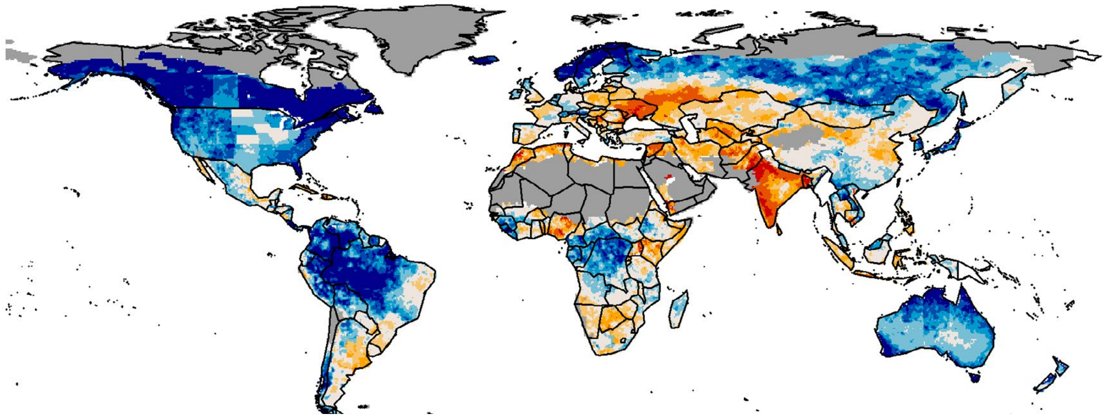
of all so-called natural disasters.[80] Floods also carry high economic costs: for example, the 2006 Danube flood in Europe cost over USD 630 million in damage to infrastructure and crops.[81]

When poorly managed, drought becomes a humanitarian catastrophe, threatening security at all levels.

Lack of rainfall is also a serious problem. Over 50 million people around the world were affected by droughts in 2015.[82] The frequency and intensity of droughts are both likely to increase due to climate change as will their impacts as we continue to use more water. Drought can cause enormous damage to the environment, economy, and social stability. From 1950-2000, there were 296 large-scale drought events (i.e., those greater than 500,000 km^2 and longer than 3 months) reported across the world,[83] and the frequency, intensity, length, and extent of droughts are all steadily increasing,[84] particularly in the tropics and sub-tropics. For example, in Somalia droughts were the primary causes of an estimated 258,000 human deaths from 2011-2013.[85] Between 1900 and 2013, global economic losses totaling USD 135 billion were recorded from drought disasters.[86] When poorly managed, drought becomes a humanitarian catastrophe, threatening security at all levels. Droughts are often associated with migration and conflicts, particularly in areas where political tensions, weak institutions, economic problems, and group rivalries are already present.

Climate change could create an escalating effect in the future.[87] The year 2015 was the driest since record-keeping began over a century ago and one of the hottest, producing drought conditions across much of the globe with over 50 per cent of the people affected in Africa.[88] The 2015 drought was aggravated by one of the strongest ever-recorded El Nino events.[89] In Africa, the Middle East, and the Mediterranean, the severity of drought impacts are exacerbated by higher demands for water.[90] Droughts cause human hardship and ecological stress; when they occur in poorly-adapted communities and ecosystems, as recently occurred in parts of the Amazon, they can also result in major, long-term changes in the ecology.[91] Droughts related to the El Niño–Southern Oscillation (ENSO) are increasingly linked to major fires affecting millions of hectares of peatlands in southeast Asia, causing major smog events. In 2015, Indonesia incurred over USD 16 billion in economic losses[92] with over 106,000 premature deaths[93] as a result of peatland fires and smog. The occurrence of unexpectedly severe droughts in many parts of the world, such as the 2001-2009 "Millennium Drought" in southeast Australia,[94] is forcing a rethink about agricultural strategies and the viability of some long-established traditional societies. Shifting climatic norms along with more frequent and more intense climatic extremes together have major impacts on both water and food security.

Figure 8.2: Global map of drought risk: Used with permission[96]



Key

Lower risk

Higher risk

no data

Types of Drought

Meteorological drought: lack of precipitation/ moisture, made worse by dry winds and high temperatures can create a water crisis if prolonged and can begin and end suddenly.

Agricultural drought: changes in atmospheric moisture to the extent that soil moisture is reduced, affecting crops and animals and evapotranspiration.

Hydrological drought: decline in quantity and quality of surface water and groundwater, due to lack of precipitation and overuse for farming and often a consequence of meteorological drought.

Socio-economic drought: supply of goods and services such as energy, food, and drinking water are reduced or threatened by changes in meteorological, hydrological, and soil conditions.[95]

Proactive Drought Management

The key pillars for enhanced drought preparedness and resilience are:

Drought Monitoring and Early Warning Systems: To assess the adequacy of meteorological weather stations, water resources, hydrological networks, and satellite information, etc.; To establish a comprehensive drought monitoring and early warning system which integrates climate, water, and soil parameters as well as socio-economic indicators at the national and sub-national levels; To produce high resolution gridded precipitation data over the country and produce a map of risk zones using drought early warning systems by computing drought standard indices.

Vulnerability Risk and Impact Assessment: To identify the processes that contribute to vulnerability and community resilience; To develop the risk profile of vulnerable communities and regions prior to the onset of droughts; To capture drought impacts after the incidence of droughts.

Drought Risk Mitigation Measures: To increase water supply through rainwater harvesting, land rehabilitation, groundwater recharge, potential new sources, etc.; To reduce demand through efficient use of water such as the review of water allocation, adopting/reviewing water tariffs, adjusting legal and institutional framework, water pricing, water treatment and use of wastewater/ recycling, etc. but in particular to increase the efficiency of agricultural water use; To increase drought resilience for livestock production through the balancing of livestock in irrigated areas, managing pasture and rangeland supportive capacity, use of indigenous feed and fodder, genotypes of mammals/low water use, etc.

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4. Disruption of natural flows

Rapid hydrological changes in many of the world's major river systems, mainly due to dam construction for hydroelectric power and surface water storage, are causing additional stresses on freshwater ecosystems and surrounding communities. Dam building provides great benefits in terms of power but has major social and environmental side-effects, which are becoming more evident over time[97] and leading to growing resistance from local communities and civil society organizations.[98] Globally, at least 3,700 major dams, each with a capacity of at least one megawatt, are either planned or under construction. These will in theory increase global hydropower by 73 per cent, to about 1,700 GW, but will reduce the planet's remaining free flowing rivers by over a fifth.[99]

The operation of dams can result in extreme drought conditions downstream. For example, in the Upper Niger Basin it is estimated that the combined impact of water diversions for planned hydropower and irrigation schemes could reduce fish catches in the delta by 31 per cent and reduce pastures by 28 per cent, with disastrous consequences for communities depending on these resources. Unless there are sufficiently large and correctly timed flood releases from dams, these measures would create conditions similar to the last major drought in 1984, when three-quarters of the delta dried out and people fled *en masse*.[100]

Blocking the free flow of rivers has a number of damaging effects, given the loss of both longitudinal and lateral connectivity of freshwater ecosystems. Dams negatively impact fish and other aquatic species, downstream sedimentation and water availability, livelihoods, and transportation. Water storage in reservoirs can also alter downstream water temperatures.[101] Dam construction itself causes direct ecosystem loss, and encourages settlement which triggers further land conversion and loss of ecosystems.[102] Deforestation, whether or not it is associated with dam construction, creates a negative feedback, increasing siltation and changing hydrology, reducing the output and lifetime of the hydroelectric power system.[103] Dams are also associated with high methane emissions, contributing significantly to climate change.[104] Reduced flooding in downstream floodplains can also reduce groundwater recharge and contribute to decreases in regional rainfall. But the attraction of such major power sources means that the wider trade-offs are often given insufficient attention.

Box 8.2: Changing hydrology in the Amazon[105]

A massive increase in dam construction for hydroelectric power is changing the flow and integrity of rivers throughout the Amazon:[106] impacting ecology, migratory catfish and river dolphins; blocking critical annual water pulses; trapping fish larvae and young;[107] disrupting river transport and food supply; and dramatically reducing downstream and coastal sedimentation.[108] There are already 154 large dams in operation, mainly in Brazil, generating 18,000 MW,[109] along with tens of thousands of small dams to collect water for cattle.[110] An estimated 277 more large dams are in the initial planning stages,[111] including in protected areas and indigenous lands,[112] with an installed capacity of around 95,000 MW.[113] If these all go ahead, there will only be three free-flowing tributaries remaining in the Amazon Basin,[114] permanently affecting ecology, economics, and climate.[115] One study concluded that due to projected forest losses, hydroelectric power generation could be reduced by up to 75 per cent of maximum output by 2050.[116] Basin scale planning and incorporating social and environmental criteria into decision making are both needed to ensure that energy production does not undermine other ecosystem services.[117]

5. Land degradation

Although water scarcity is a global problem, the conversion of natural forests and grasslands to agricultural land has increased water in soils at a local scale.

Poorly managed irrigation systems directly damage the land, reducing yields, raising water tables, and increasing salinity and alkalinity (e.g., sodic soils). Although water scarcity is a global problem, the conversion of natural forests and grasslands to agricultural land has increased water in soils at a local scale. Even when crops are not irrigated, the conversion from natural vegetation can impact water availability and quality. Over the past 300 years, rainfed cropland has increased by 460 per cent and pastureland by 560 per cent, decreasing evapotranspiration and increasing recharge (two orders of magnitude) and stream flows (one order of magnitude).[118]

At the same time, increased water quantity in agricultural systems has further degraded water quality by mobilizing salts and increasing salinization, due to shallow water tables and the leaching of fertilizer into aquifers and surface waters.[119] Irrigation with mineralized groundwater also increases soil salinity and decreases crop productivity. As early as 1993, the World Bank estimated that 20 per cent of irrigated land area suffered from crop yield reductions due to salinity,[120] and some estimate that up to half of the irrigated land is now affected by abnormal salt levels.[121] For example, salinity now affects 70-80 per cent of the Murray-Darling Basin, half the Aral Sea Basin, a third of the Nile Delta,[122] 28 per cent of the United States, and a quarter of Pakistan and Uzbekistan.[123]

The drainage of peatlands is linked to various forms of land degradation.[124] In parts of Central Asia and China it has led to the desertification of former peatland dominated landscapes, major soil erosion from overgrazing, and subsequent loss of productivity. Peatland drainage inevitably causes soil compaction and peat carbon oxidation, resulting in soil subsidence posing significant risks in lowland regions. As the base of the peat layer often lies at or below sea or river level, soil subsidence over time will result in enhanced flood risks. In many countries, this has been mitigated by the construction of dikes and pumping systems, however, given the inevitable continuation of subsidence of drained peat soils, entire landscapes may eventually lie below sea level. For example, half of the Netherlands lies below sea level as a result of centuries of peatland drainage, causing significant risks in terms of water security and salt water intrusion as well as high costs in terms of maintenance of infrastructure (projected at 25 billion Euro between 2010 and 2050 for the remaining 200,000 ha of Dutch peatlands).[125] Whereas the Netherlands has long since reached a point of no return, in southeast Asia the drainage of lowland peatlands started only in the 1970s. In the tropics, peatland drainage results in high CO_2 emissions,[126] causing subsidence of 3 to 6 cm per year.[127] However, the high levels and seasonal pattern of precipitation may exclude options for mitigation by dike and pumping systems. Continued drainage can lead to devastating consequences, including massive flooding risks and the loss of productive land.[128]

Land degradation directly impacts water security by reducing overall water quality: from high salt levels in groundwater to the increased flow of suspended solids and agrochemicals into both surface and groundwater. The loss of vegetation and subsequent soil erosion around reservoirs can lead to rapid siltation and a dramatic shortening of the lifespan of impoundments and hydroelectric power plants.[129] Erosion can lead to dramatically degraded landscapes of gullies and wind-blown sand deposits. It can also reduce agricultural productivity in more subtle ways. Bare, degraded, and eroding soil has less water retention capacity, either for storing water throughout the year or for absorbing sudden excesses and minimizing flooding after heavy rains.[130]

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6. Climate change impacts

Wetland management has a significant effect on the climate. In general, wetlands tend to be sinks for carbon and nitrogen but can be sources of other greenhouse gases such as methane;[131] the balance determines whether a wetland is a net source or sink of greenhouse gases.[132] While caution needs to be exercised in estimating the extent to which wetlands contribute to climate change mitigation through sequestration,[133] it is clear that their ability to store carbon provides a substantial global carbon store. Coastal wetlands are particularly important in taking up carbon dioxide and sequestering it in sediments, thus building large stores of carbon. Globally wetlands hold a disproportionate amount of Earth's total soil carbon, approximately 30 per cent of the total despite occupying only 5-8 per cent of its land surface.[134] Conversely, draining or burning peat increases carbon and smoke emissions,[135] as does draining or disturbing other wetland types. Wetland destruction ultimately leads to carbon release,[136] and the poor management of wetlands can also result in large carbon losses[137] although uncertainties remain about the total quantity of the overall carbon stocks contained in wetlands.[138]

While peatlands only cover about 3 per cent of the land surface, they contain the planet's largest store of carbon believed to be equivalent to that contained in all other terrestrial biomes,[139] particularly in boreal tundra. Intact peatlands contain up to 1,300 tons of carbon per ha[140] and 550 Gt of carbon are estimated to be stored in peatlands globally.[141] Peat "hotspots" include tropical forests in southeast Asia and tundra in Russia, Canada, Alaska, and Scandinavia. Drainage for plantation establishment, such as oil palm, creates a sharp rise in emissions.[142] It is estimated that 0.5-0.8 Gt of carbon per year is already being lost as a result of peatland conversion, mainly in the tropics.[143] For example, emissions from drained peat in southeast Asia equaled 355-874 Mt per year in the early years of the 20th century, with a further 1,400 Mt of emissions per year from 1997 to 2006 due to peat fires, mainly in Indonesia.[144] While carbon losses from the boreal tundra are currently much lower, they have the potential to exceed those from the tropics as warming thaws ice and dries peat. Some sites in Alaska have already switched from being sinks to sources of carbon,[145] and there are fears of a sudden pulse of carbon being released from the Arctic.[146]

Experience in Canada found that CO_2 losses from cut peat areas could be slowed through restoration and revegetation.[147] Successful peatland restoration has taken place in Ireland following past industrial cutting,[148] and similar positive results are reported from southeast Asia, Russia, Argentina, and the Himalayas.[149] Efforts to restore coastal wetlands (e.g., salt marshes, mangroves, sea grass beds) are increasing as a means to recover their natural ability to sequester carbon. Large-scale mangrove restoration is, for instance, currently underway in countries such as Kenya, Tanzania, Sri Lanka, and India.[150]

7. Loss of biodiversity and water-related ecosystem services

Wetland loss is continuing at a more rapid rate than for other ecosystems along with a disproportionate loss in ecosystem services.

Despite efforts to conserve and wisely use wetlands,[151] between 64 and 71 per cent have been lost since 1900,[152] and many others have been degraded by pollution, flow disruptions, over-harvesting, and invasive species.[153] Wetland loss is continuing at a more rapid rate than for other ecosystems along with a disproportionate loss in ecosystem services.[154] Between 1970 and 2008, the extent of natural wetlands declined globally on average by about 30 per cent.[155]

These losses have subsequent effects on freshwater biodiversity as well as the health and productivity of the surrounding lands and their communities. Open freshwater bodies occupy less than 1 per cent of the Earth's surface but contain as much as 12 per cent of all known species, including a third of all vertebrate species.[157] Freshwater biodiversity is declining[158] and one in three freshwater fish species[159] and 30 per cent of amphibians[160] are threatened with extinction. For example, catfish make up 39 per cent of known Amazon fish species, which rely on the integrity of critical spawning areas in the upper catchment,[161] but their survival is under threat from proposals to dam major rivers[162] and overexploitation.[163] Beyond species survival, fisheries are an important source of food and income, with per capita consumption of fish averaging 94 kg per year for riverside communities.[164] An analysis of 145 major watersheds found that those with the highest biological value were generally the most degraded.[165] Other freshwater groups are also threatened. Many mollusks are range-restricted and thus vulnerable; out of over 1,200 spring glass snail species (*Hydrobiidae*), 182 are listed as threatened on the IUCN Red List.[166]

Box 8.3: The Ramsar Convention

The Ramsar Convention on Wetlands, signed in Ramsar, Iran in 1971, is an international agreement aimed towards the "*conservation and wise use of wetlands and their resources.*" Parties to the Convention are obligated to designate at least one suitable wetland (typically more are listed) within their territory as a *Wetland of International Importance*. While all Ramsar sites are committed to sustainable management, some are also official protected areas while others remain open to multiple uses. The Ramsar Convention provides technical guidance on the management and evaluation of wetlands, working closely with the IUCN and with other international organizations to promote the sustainable management of global wetlands.

The Convention also promotes the wise use of wetlands as a fundamental element of its mission, and defines wise use as "the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development." Wise use is the conservation and sustainable use of wetlands and all the services they provide, for the benefit of people and nature. Practical aspects include adoption of national wetland policies; ensuring wetland inventory, monitoring, research, training, education, and public awareness; and developing integrated management plans at wetland sites.[156]

When freshwaters and their biodiversity are degraded or destroyed, their ecosystem services are also lost. These services are usually worth more to society than the productive uses that replace them[167] since the benefits are often distributed among many people, whereas the benefits of conversion and production tend to be concentrated in the hands of a few. Ecosystem services are often not really noticed until they disappear, and their restoration, if possible, is almost always expensive compared to protecting the functioning ecosystem in the first place. Table 8.1 summarizes some of the key water-related ecosystem services.

Table 8.1: Typology of ecosystem services from wetlands[168]

Services	Ecosystem service	Example
Supporting	Primary production	Photosynthesis in aquatic plants and wetland vegetation.
	Nutrient cycling	Highest total economic value of all wetland ecosystem services[169] although this value is generally not realized at present.
	Biodiversity conservation	The Amazon has around 6,000-8,000 fish species,[170] and the Mekong 850 fish species.[171]
	Nursery function	Breeding grounds for aquatic species important for both commercial and subsistence purposes.
	Soil formation	Sediments in the Mekong support over 50 per cent of Viet Nam's staple food production.[172]
	Marine productivity	Sediments carried by rivers also maintain offshore ecosystems. Every year, 500-1,000 million tons of mud from the Amazon and Orinoco Rivers[173] create huge mud banks[174] that support mangroves,[175] and maintain highly productive fisheries.[176]
	Recharging aquifers	Standing wetlands are a key resource for aquifer recharge, which is often the least cost option for stabilizing and ensuring supply.[177]
Provisioning	Capture of fish and other species	African freshwater fish catch exceeds 2.5 Mt per year;[178] the Niger Delta producing 40-80,000 t/year.[179] The Mekong yields 2 Mt per year;[180] supplying 80% of animal protein in Cambodia.[181] Yet fisheries are at risk: 4 out of 11 species caught commercially in the North American Great Lakes are now extinct.[182]
	Collection of plants	Many freshwater species are collected for food and feed.[183]
	Collection of materials	Papyrus, reeds, rushes, etc. are used for roofing, tools, fencing, etc.
	Livestock grazing	Wetlands are often very productive pastures, providing seasonal grazing for pastoralists and ranchers.
	Crop growing	Rich peat soils support productive agriculture.
	Energy source	Hydro-electric power is a critical energy source. Papyrus is compacted into fuel briquettes in Rwanda. Peat-cutting is still an important domestic fuel in parts of Ireland and Scotland.
	Raw materials	Fuelwood and building timber is collected from riparian forests.
	Medicines	Freshwater plant species are often used as medicines.
Regulating	Flooding	Wetlands absorb floodwater providing disaster risk reduction.[184]
	Storm protection	Riparian forests and seasonal wetlands slow flooding and protect downstream communities.[185]
	Carbon sequestration	Wetlands and particularly peatlands are the planet's largest carbon store,[186] containing up to 1,300 tons of carbon per ha. [187]
	Climate stabilization	Evaporation from lakes helps to reduce climatic extremes.
	Water provision	Some forests types, including montane cloud forests[188,189] and some old eucalyptus forests,[190] increase net water flow.
	Water purification	Forested watersheds and wetlands provide cleaner water, reducing the need for water treatment.[191]
Cultural	Recreational	Wetlands can be a tourist attraction: the Okavango Delta in Botswana attracts 120,000 tourists per year.[192]
	Cultural and artistic	Lakes and rivers have inspired artists, musicians, and writers.
	Spiritual	Many wetlands have local sacred values or are important pilgrimage sites, such as sacred high altitude lakes in India.[193]
	Science and education	Freshwaters provide important research and educational centers.

INDIRECT CAUSES OF WATER INSECURITY

The section above addressed some of the direct causes of water insecurity: poorly managed irrigation and livestock production, demand from industry, energy, and urban sectors, pollution, dam construction, changing climate, and population growth. Below we discuss some of the indirect causes:

1. A fragmented approach to water management
2. Policies and business models that drive water-intensive management systems
3. Trading and pricing patterns that act as perverse incentives
4. Demographic changes and rapid urbanization
5. Climate change

1. A fragmented approach to water management

Single sector water use, without an integrated water policy,[194] often leads to serious negative impacts. Spectacular examples include the Aral Sea in Central Asia, which by 2016 had shrunk to one tenth of its size in 1961; this was because most of the water from two tributary rivers was diverted for irrigation.[195] Lake Chad in Africa has decreased over 90 per cent by area in the last forty years due to drought and irrigation.[196] Conversely, the benefits of integrated or "nexus" approaches to water management have been known for a century, with a few prominent examples showing the way.[197]

Still, cooperation at relatively large scales remains rare. Water planning (where it occurs at all) tends to follow a piecemeal or siloed approach, with different sectors (and even different individuals within a single sector) competing rather than collaborating at the expense of the common good.

2. Policies and business models that drive water intensive management systems

An emphasis on monocultures in modern agriculture tends to increase the use of and impacts on water (see Chapter 7). For example, in the last 50 years, the area devoted to soybeans has grown tenfold to over 1 million km^2: the area of France, Germany, Belgium, and the Netherlands combined.[199] Growth has been mainly in South America where production grew by 123 per cent between 1996 and 2004.[200] Projections suggest a further 140 per cent increase to 515 million tons by 2050.[201] Soybean cultivation is primarily rain-fed in South America but irrigated elsewhere.[202] Large-scale conversion to intensive soybean cultivation will likely continue to reduce water availability.[203] Water quality is also impacted by soil erosion and agrochemical residues as a result of heavy pesticide use, as documented in soybean fields in Argentina.[204] Yet soybeans are a multi-billion dollar business selling high-value products like animal feed. Alternative production systems that use water resources more efficiently cannot compete economically with soybeans, especially when water is underpriced.

Other crops also put hydrological systems under stress. Analysis in Thailand found rice (paddy) production had the highest water use; followed by maize, sugar cane, and cassava. The production of a second rice crop puts some watersheds under considerable pressure.[205] The drainage of peatlands for grazing and agricultural crops reduces their water retention capacity, leading to increased water shortages in dry periods and flood peaks in wet periods.[206]

Increasing imports of agricultural products have been advocated as one solution for water scarce countries. This strategy might provide a sustainable solution if crops are grown in water-rich countries. But if they use up scarce water supplies, disadvantage poor communities, degrade land, and increase water stress, they should be considered environmentally and socially unsustainable.

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Box 8.4: Integrated land and water resource management in the North China Plain

Intensive irrigation in northern China had dramatically reduced river flow in the Hai River Basin and seriously depleted aquifers subject to irrigation pumping. The Government of China had identified the need for urgent action aimed at the restoration of water resources and reducing over-exploitation. The International Waters Focal Area of Global Environmental Facility (GEF) supported a major restoration effort highlighting three key processes in integrated water management: (1) formation of national inter-ministry committees; (2) analysis of the status of the river or aquifer basin, different sector water uses, conflicts, and future projections; and (3) development of a strategic programme of policy, legal, and institutional reforms and investments, through multi-stakeholder, participative processes across sectors to balance competing uses, negotiate trade-offs, and form partnerships for action.[198]

The seven year Hai River Basin IWRM project pioneered water and land management reforms to improve water quality in the river and aquifers, and to reduce water use in irrigation. It introduced higher charges for irrigation water; a new water rights/allocation system under Chinese law based on estimates of evapotranspiration (ET) rather than standard withdrawal amounts; the use of satellite technology to support issuing and enforcing water allocations; and other water saving irrigation technologies with the aim of rebalancing food and water security and environmental objectives in the basin. The project included water quality improvement measures, capacity building for the basin water resources commission, and use of ATM cards for individual farmers. Pumping allocations were limited to ensure water savings: once an individual's allocation was exhausted, no more water could be pumped. Satellite data on estimated ET (at a 30 by 30 meter scale) was used with simulation models to identify reduced allocations to farmer-led water user associations that distributed the quotas to over 100,000 farmer households. Extension services also assisted by recommending practices for on-farm green water savings, best management practices (e.g., mulching, cropping patterns, drip technology), and the planting of alternative crops to increase farmer income. After seven years, per capita income increased by 193 per cent, water efficiency increased by 82 per cent, and consumptive use decreased 27 per cent. These water savings helped to stabilize aquifer draw-down and made more water available for ecosystem functioning.

The success of this project encouraged the Government of China to introduce the remote sensing/water rights/water allocation system for all new water allocations. This led to the application of the ET-based allocation system to the entire Tarim Lake basin and a subsequent GEF/World Bank/China-funded project for the entire Hai Basin system. Other project achievements included formal agreements among ministries that never worked together and a knowledge management system established for the revitalized basin commission. Finally, the setting of project targets consistent with GEF policy proved to be important measuring and evaluating progress over time.

3. Trading and pricing patterns that act as perverse incentives

Land grabbing is also water grabbing when, as is increasingly the case, large-scale land acquisitions by foreign investors come with guarantees of water.

Land grabbing or large-scale land acquisitions for agricultural exports are discussed in Chapter 5, but one important related issue is the export value of agricultural products in the form of "virtual water" (the hidden flow of water that grows food that is exported). Land grabbing is also water grabbing[207] when, as is increasingly the case, large-scale land acquisitions by foreign investors come with guarantees of water.

The virtual water trade is growing, and this particular trade balance between countries is shifting over time. China, until recently a net exporter of virtual water related to trade in non-edible animal and plant products used for manufacturing, is now the world's largest virtual water importer for these same products.[208] This can lead to the displacement of small farmers, accelerated land degradation, and the abuse of water resources, along with the creation of downstream or aquifer conflicts, particularly when weak institutions are unable or unwilling to regulate water use. The corporate control of water is an increasingly divisive and politicizing issue.[209] Pricing policies, such as those implemented to reduce food prices to consumers by major food retail companies, squeeze farmer profits and encourage unsustainable use, such as intensive irrigation.

4. Demographic change and urbanization

Growing populations are recognized as often putting water resources under stress.[210] But as important as the total numbers is the issue of demographic movements, either gradual through urbanization and economic migration, or rapid shifts in population as a result of disaster, war, or internal conflict. Urbanization is now a global phenomenon. Almost half the world's city dwellers live in relatively small settlements of less than 500,000 inhabitants while around one in eight live in the 28 mega-cities with over 10 million inhabitants. Until recently most of the world's largest cities were found in the North but today are increasingly concentrated in the South. The fastest growing urban centers are medium-sized cities and cities with less than one million inhabitants located in Asia and Africa.[211]

Africa provides a striking example of urbanization and its impact on water. In 1960, there were only 11 cities in Africa with over half a million inhabitants and just five in sub-Saharan Africa, which was overwhelmingly rural. By 2015, there were 84 such cities south of the Sahara, including megacities like Lagos with over 13 million inhabitants. By 2030 there will probably be over 140.[212] Current estimates indicate that new urban residents in Africa will increase by over 300 million in the period between 2000 and 2030: more than twice rural population growth.[213] Wetlands and watersheds provide both provisioning services (e.g., food, water, raw materials) and regulating services (e.g., flood control, climate stabilization) to urban populations. But throughout Africa, urbanization is encroaching upon both types of services, either directly through urban sprawl draining wetlands for housing or because population density increases pressure on natural resources, releases more pollutants, introduces invasive species, and requires more water for agriculture, industry, and domestic use.

Box 8.5: Water and African cities

Rapid urban and peri-urban expansion in many African cities is putting pressure on surrounding water resources, at the very time when their ecosystem services are needed more than ever. For example, rapid urban sprawl and a booming horticultural industry are threatening Lutembe Bay wetland around Kampala in Uganda. Lutembe Bay, which is a Ramsar site, is almost completely cut off from the rest of Lake Victoria by a papyrus island. Swamps filter silt, sediments, and excess nutrients from surface run-off, sewage, and industrial waste. But the wetland is rapidly being lost to agriculture and horticulture; a horticultural firm illegally infilled some in 2013.[214] Similarly, wetlands around Harare are the water source for half the population of the country, recharging the water table, filtering and purifying water (thus reducing purification costs), preventing siltation and flooding, and providing a valuable carbon sink. The wetlands are also an important bird sanctuary and again a Ramsar site. However, the hydrology is being damaged as a result of land use change, informal agriculture, fertilizer pollution, and the extensive use of commercial boreholes, which have resulted in an average fall in the water table of 15-30 meters over the past 15 years. Building capacity and generating awareness among city planners and government staff of the importance of wetlands protection is a major priority.[215]

5. Climate change

Rapid climate change is exacerbating almost all of the aspects of water insecurity outlined above. Climate change will have multiple impacts on water supply, including the melting of glaciers and ice caps, changes in snow and rainfall, increasingly fluctuating weather patterns and greater climatic extremes. Overall water scarcity is likely to increase.[216] The Intergovernmental Panel on Climate Change concluded (with robust evidence, high agreement) that climate change is likely to reduce renewable surface and groundwater resources in most dry subtropical regions. Conversely, in the higher latitudes water availability is likely to increase. The composition, structure, and function of many wetlands will also change, and many freshwater species will face increased risks of extinction.[217]

AN INTEGRATED APPROACH TO GLOBAL WATER SECURITY

New approaches to managing water resources are urgently needed.[218] Sustainable Development Goal (SDG) 6 on water and sanitation includes an emphasis on improving water quality (target 6.3) and protecting and restoring water-related ecosystems (target 6.6). Improved water management is also a critical component of SDG 2, on food security, and SDG 15 to combat desertification, and halt and reverse land degradation, and halt biodiversity loss. Such a nexus approach focuses on system efficiency, rather than on the productivity of isolated sectors, by reducing trade-offs and generating additional benefits that outweigh the transaction costs associated with stronger integration across sectors. Such gains would accelerate progress towards sustainable development and encourage governments, the private sector, and civil society to enhance water security.[219]

Maximizing water security is neither a simple technical fix nor the responsibility of a single sector.

Maximizing water security is neither a simple technical fix nor the responsibility of a single sector. It requires a range of responses relating to the provision and quality of water for human uses; the management of land resources, in particular soils; the protection and where necessary the restoration of wetlands and watersheds; and the regulation of water flows and long-term availability.[220] Key elements of an integrated approach to water management include:

- **Managing water resources through sustainable land management, especially in agriculture**
- **Protecting and restoring natural ecosystems for water-related goods and services**
- **Working towards sustainable cities**
- **Policy reform at a local, national, and international level**

Water-related ecosystems cannot be managed in isolation since water basins or watersheds connect over vast areas and the global water cycle ultimately functions as a single system. Integrated Water Resources Management (IWRM)[221] promotes the coordinated development and management of water, land, and related resources in order to maximize economic and social welfare in an equitable manner without compromising the functioning and sustainability of our working landscapes.

Managing water resources through sustainable land management

Irrigation carries high water costs, but also high rewards from crop production. In the United States, 7.5 per cent of crop and pasture land is irrigated, producing 40 per cent of agricultural value and accounting for 80-90 per cent of consumptive water use.[222] Maximizing the efficiency of irrigation technologies and their application is clearly a priority focusing on all aspects of irrigation from sourcing and distribution to field application. Even small increases in crop-water productivity in precipitation-limited areas would have important implications for both overall food productivity and water availability.[223] In addition, there are a number of proven, cost-effective land management practices that reduce waste and conserve water in agriculture while providing additional benefits to the environment and long-term productivity (see Table 8.2). The fact that these practices are not used more widely is due to factors such as a lack of capacity or investment, and subsidies, regulations, and other perverse incentives that discourage efficient use. In some countries, cultural and religious customs also play a part, for instance a reluctance to use grey water.

IWRM has been an aspiration for decades but has often failed in practice due to entrenched sectoral interests, political and governance barriers, and the failure to engender a sense of collective responsibility. Water managers traditionally have been focused on managing water in isolation, whereas good water management depends in large part on managing land sustainably.[243] The wider concept of integrated land and water resource management continues to gain currency as is reflected in a growing number of applications around the world.

One of several examples from China, the seven year Hai River Basin IWRM project pioneered water and land management reforms to improve water quality in the river and aquifers, and to reduce water use in irrigation.[245] The project demonstrates some of the essential elements of a national water conservation programme including a central organization with comprehensive water laws; regional and watershed-level land and water use planning; decision-making frameworks based on long-term water supply and demand; adequate research, demonstration, and extension services; a system of demand management; quality control of equipment; promotion of water user associations; and, where needed, land reform and agricultural credit for irrigation.

Table 8.2: Some examples of water saving approaches in agriculture

Technique	Details
Increasing water availability/efficiency	
Improved infrastructure	Poorly constructed irrigation canals and ditches leak water, causing water-logging and productivity loss. Pipes are more efficient but also more expensive.
Improved irrigation systems	Earth canal networks are the least efficient, followed by lined canals, pressure pipes, hose irrigation, sprinkler systems, microjet sprinklers, and drip irrigation: efficiencies ranging from a low of 40% to 80-90%.[224]
Conservation agriculture	Combines minimum tillage with cover crops and rotations to reduce evaporation, run-off, and erosion[225]
Organic agriculture	A production system that relies on ecological processes, biodiversity and cycles adapted to local conditions avoiding the use of synthetic fertilizers, pesticides, GMO, growth hormones and antibiotics;[226,227] some argue that this maximizes the recycling of nutrients and increases in soil organic matter, thus enhancing soil water holding capacity[228]
Eco-agriculture	Emphasizes the restoration of ecosystem services and biodiversity, increasing support for water-related ecosystem services
Agroforestry	Mixing tree and ground crops to conserve water by reducing evaporation and transpiration; in Kenya soil evaporation was reduced by an average of 35%.[229]
Participatory irrigation management	Cooperation between users can increase efficiency, in New Zealand cost savings of 65% were achieved through local control.[230]
Rainwater harvesting	Various options exist, from channels running to open pools to film-covered ridges and underground storage.[231]
Contour ploughing, bunding, and terraces	Traditionally used to reduce soil erosion and increase efficiency of water retention.[232]
Mulching	Reduces water loss and improves yields; its viability is often constrained by lack of mulching material (e.g. because of burning or grazing on stubble after harvest).[233]
Early sowing varieties and high water-use efficiency	Three factors are important: reducing losses; increasing biomass for given water; and partitioning more biomass into harvested product.[234] For example, varieties sown earlier can grow in cooler times of the year when less water evaporates.
Pumps	Can raise groundwater and maintain year-round productivity in countries with a pronounced wet and dry season. Treadle pumps are a simple, cheap system.[235]
Reducing water use	Watering can sometimes be reduced at certain periods without reducing crop yields.[236]
Weather forecast texts	Use of mobile phones to share texts on weather forecasts for planting times has improved water efficiency in countries of the Niger basin.[237]
Radio station alerts of rain or drought	In Senegal, 915 village chiefs and many radio stations have signed up for a service covering up to half the country's population.[238]
Grey water and sewage effluent use	Wastewater separated from industrial effluent can be used for irrigation; waste water from 100,000 people irrigates around 1,000 ha using efficient systems.[239]
Soil and plant moisture sensing devices. computer crop-growth simulation	Use has reduced water losses by 20% in South Africa.[240] Technology, such as precision agriculture, offers enormous opportunities for increasing efficiency but requires investment; less than 10% of US farms use these methods[241]
Reducing the need for water	
Crop choice	Avoiding crops with heavy water requirements in arid or semi-arid regions. Choosing perennial crops that hold soils and stimulate mycorrhiza systems.
Climate-smart agriculture	An amalgamation of many of the techniques and technologies mentioned above with a focus on locally appropriate climate resilient practices.
Farmer support	
Weather index insurance	Banks can provide climate-smart financial services for climate resilient agricultural value chains.[242]

Box 8.6: Rainwater harvesting in Brazil[244]

The north-east of Brazil is a semi-arid region, characterized by severe lack of water and droughts that contribute to underdevelopment of the region. The "One Million Rainwater Harvesting Programme" (P1MC) was launched by civil society groups in the region, targeting rural families without a secure drinking water source close to their home. By December 2007, 228,541 families had been mobilized; 221,514 rainwater harvesting (RWH) systems constructed and 5,848 masons trained under the programme. The objective of P1MC was to construct one million RWH systems for decentralized access to drinking water to one million families. This programme benefited women in particular as it reduced their daily work of fetching water. In 2012, Brazil experienced one of the most severe droughts ever recorded, causing major crop and cattle losses, and reducing several reservoirs to critical level. The drought caught the attention of different decision makers, experts, and international and local media, as well as the population. Brazil has since aimed to move from reactive crisis management to proactive risk-based approaches.

Protecting and restoring natural ecosystems

Protected areas of various sorts already cover around 20.7 per cent of the world's remaining lakes and wetlands.

Ensuring the future delivery of freshwater ecosystem services requires a suite of coordinated strategies, operating at the level of a watershed or catchment, integrated with the management of the surrounding terrestrial ecosystems. While investment in necessary built infrastructure is a critical component of such management,[246] "natural infrastructure"[247] or "green infrastructure"[248] will need to play an increasingly central role[249] in providing long-term water security for human societies via maintenance of natural freshwater ecosystems.[250] For example, forested watersheds and some wetlands can supply cleaner water than other ecosystems.[251] Certain forests, such as mountain cloud forests,[252] increase the net flow out of the catchment. Forests and wetlands also supply important flood control mechanisms by providing space for floods to dissipate safely and by blocking the rate of flow as well as other important ecosystem services.[253]

Recognition of these multiple roles means that natural ecosystems are less often regarded as unproductive and suitable only for human exploitation, but as essential components for maintaining the health and livelihoods of populations. This recognition is the first step in achieving long-term water security.

Protected areas therefore have a central role to play in catchment-scale sustainable management approaches,[254] although specific protection of freshwater ecosystems has often been overlooked in this respect.[255] Protected areas of various sorts already cover around 20.7 per cent of the world's remaining lakes and wetlands[256] helping to shape overall water policies and enable large-scale rehabilitation and restoration. These areas are vitally important in sustaining water services by protecting natural flow regimes, excluding non-native species, and sometimes providing whole basin conservation.[257] Integrating them more consciously and centrally into IWRM approaches is an important component still missing from many national water strategies.

Many good examples of IWRM integration already exist, which show the value of a joined up approach to conservation and sustainable development. Cities like New York[259] and Melbourne[260] have found it cost-effective to protect and restore forests as suppliers of clean water rather than to invest in new purification plants. The cloud forests and high mountain peatlands (paramos) in protected areas around Quito and Tegucigalpa provide a high

Box 8.7: Wastewater use

Judicious use of wastewater to grow crops will help solve water scarcity in the agriculture sector. At a time when we need to produce more food to feed an ever-increasing population, wastewater can be used by farmers either directly through irrigation, and indirectly by recharging aquifers. In Tunisia, wastewater is being widely used in agroforestry projects, supporting both wood production as well as efforts to combat desertification. In central Mexico, municipal wastewater has long been used to irrigate crops. In the past, ecological processes helped reduce health risks. More recently, crop restrictions (some crops can be safely grown with wastewater, while others cannot) and the installation of water treatment facilities have been added to the system. Properly managed, wastewater can be used safely to support crop production – directly through irrigation or indirectly by recharging aquifers – but doing so requires diligent management of health risks through adequate treatment or appropriate use.

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quality water supply for these two important Latin American cities.[261] An increasing number of countries rely on strategically located protected areas as part of their disaster risk reduction policies.[262] The protection and restoration of wetlands can help in reducing carbon losses and thus mitigating climate change, particularly the huge carbon stores in peatlands that are currently under threat.[263]

With political will and stakeholder participation, the establishment and management of protected areas is a relatively straightforward policy or regulatory tool to maintain natural infrastructure, and usually comes with the associated legal or customary protection to ensure a degree of permanence, along with employment, capacity, and management policies.[264] However, the responsibility for conservation within most legal frameworks is usually separate from the responsibility for other services and civil defense, meaning that the cross-linkages are often missed in practice.

Box 8.8: Protecting Natural Forests for Flood Control

Irregular rainfall patterns in Argentina cause both floods and droughts. Under all climate change scenarios, these weather extremes will continue and be more frequent. Currently, about a quarter of the country is repeatedly flooded, particularly in the north-east, which has three major rivers (Paraná, Paraguay, and Uruguay), extensive, low-lying plains, and over half the human population. A flood protection programme provided cost-effective activities for the most important economic and ecological areas and a strategy to address recurrent floods: maintenance of flood defense installations, early flood warning systems, environmental guidelines for flood-prone areas, and flood emergency plans. In addition, extensive areas of natural forest were protected as part of the flood defense system, thus providing a relatively inexpensive alternative to costly infrastructure with high biodiversity conservation benefits.[258]

Box 8.9: Water services from protected areas

Most of the world's population lives downstream of forested watersheds.[265] These offer higher quality water than watersheds under alternative land uses, which tend to have less vegetation cover (hence more soil erosion and sediment) and are likely to be more polluted (e.g., with pesticides and fertilizer or toxic waste).[266] The benefits that forests provide have been recognized for many years by companies that depend on high quality water: for example, the mineral water company Perrier-Vittel pays to restore forests in the catchment where it collects water in France.[267] One-third (33 out of 105) of the world's largest cities source a significant proportion of their drinking water directly from protected areas. At least five other cities in this group obtain water from sources that originate in distant watersheds that include protected areas; and at least eight more obtain water from forests managed in a way that gives priority to their ecological functions in providing water.[268] Many areas originally protected for scenic or wildlife values are now also considered vital for their water-related benefits. Yosemite National Park in California, USA, for example, helps supply high quality water to San Francisco; the cloud forests of La Tigra National Park in Honduras provide more than 40 per cent of the annual water supply to the capital city, Tegucigalpa and about 80 per cent of Quito's 1.5 million population receive drinking water from two protected areas.[26]

Payment for Ecosystem Services (PES) schemes help to provide people living in areas that supply water services with economic incentives to maintain healthy managed or natural ecosystems. One approach is to collect user fees from people and companies benefiting from drinking water to help pay for these catchment benefits provided by protected area management, or by local communities. Such PES schemes are increasingly considered as viable economic models provided there is an identifiable source of compensation (those willing to pay a fee), low transaction costs, good information flows, and a method to transfer benefits equitably among individuals.[270]

Protection alone is no longer enough. The world has already lost so much wetland area and major efforts are needed to restore free flowing rivers, lakes and ponds, groundwater reservoirs, and functioning wetlands. Restoration is therefore another important component of managing freshwaters for their ecosystem services.[271] Restoration does not simply mean putting back areas of water or taking away redundant dams. For example, river restoration embraces "the re-establishment of natural physical processes (e.g., variation of flow and sediment movement), features (e.g., sediment sizes and river shape), and physical habitats of a river system (including submerged, bank and floodplain areas)."[272] Similar principles can be applied in the restoration of coastal areas to halt erosion, involving a "Building with Nature" approach, using permeable dams to reduce wave energy and stimulate sedimentation.[273]

A combination of planned restoration and judicious protection of watersheds can therefore together ensure greater water security for downstream users.

Box 8.10: Water Management in South Africa

South Africa is one of the 30 driest countries in the world. While the average water use per capita per day is 173 liters, South Africans use 62 per cent more water on average.[277] In order to match demand and supply, South Africa has made significant progress in the last decades to increase water use efficiency. Firstly, in 1994 the government published a White Paper on Water and Sanitation Policy, which led to the Water Services Act of 1997. Secondly, the National Water Act (NWA) No. 36 of 1998, promoted an integrated and decentralized water resource management approach, which emphasized the importance of economic efficiency, environmental protection, equity, and the empowerment of people.[278]

South Africa is one of the few countries in the world that enshrines the basic right to sufficient water in its Constitution, stating that "Everyone has the right to have access to (...) sufficient food and water." Building on this foundation, both Acts are complementary and provide a framework for sustainable water resource management while enabling improved and broadened service delivery. The NWA requires water managers and policymakers to have a thorough understanding of the economic values of water and its various uses as well as information systems that integrate hydrological, economic, and social dimensions of water supply and demand within the framework of an integrated water resource management (IWRM) system.[279]

Working towards sustainable cities

Although cities pose particular challenges for water supply and management, they also offer a range of innovative solutions by connecting people, transferring know-how, and supporting clusters of firms doing similar things. Forward-looking local authorities can stimulate rapid improvements. Efficient urban transport systems, renewable energy, and sewage control can all reduce water consumption and waste while information campaigns, coupled with pricing policies, can make consumers more water-aware.

Sustainable cities depend on well-managed ecosystems. Degradation far away can impact city dwellers. People living in the port of Mombasa, in Kenya, rely on water from the Chyulu Hills, a hundred miles away. Despite Chyulu being a protected area, poor management capacity means illegal logging and settlement continue, threatening the security of urban water.[274] It often makes sense for municipal authorities to invest in ecosystem management, but it takes an imaginative set of civil servants to make the connection and procure the necessary funds. Pricing policies that encourage more efficient use of water are one universal way of addressing urban shortages, although the relative effectiveness of this as compared to technical measures and public awareness campaigns remains inconclusive.[275] Steps towards more sustainable urban planning are described in Chapter 11.

Policy reform

Many of the changes identified above can only be achieved if they are supported by strong policies and laws at the national level, set against a background of international agreements and a global recognition of the need to manage water more carefully to avoid crisis. Proactive approaches are required, focusing on maintenance of natural infrastructure for multiple benefits, increasing resilience of hydrological systems in the face of environmental change, and more equitable access to clean and adequate supplies of water. Changing consumer behavior is also a critical part of this process, and attempts to do this can draw on public awareness campaigns, technological changes, regulation, and pricing policies. While all may be useful in different contexts, there is still debate about their relative effectiveness.[276] Policies not only need to be set, but communicated effectively to stakeholders in government, industry, and communities so that there is a thorough understanding of the importance of and the practical means to achieve a safe and sustainable supply of water.

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CONCLUSION

Water security is being undermined, in particular by the combination of unsuitable agricultural models, rapid demographic changes, and the destabilizing effects of climate change. Poor choices from the individual to the national level exacerbate the situation. Countries and communities are suffering from both shortages and excesses. The loss of wetlands, declines in water quality, and dramatic changes to the flow regimes of major hydrological systems are leading to a collapse in freshwater biodiversity and essential ecosystem services.

Improving water security requires an integrated, cross-sectoral approach which capitalizes on the links between the land management practices and the health of hydrological systems. In sum, some of the most critical steps include: more efficient water use in agriculture, industry, energy, and households; regulation and legislation, including pricing and allocation, to encourage efficiency; and increased protection and restoration to improve overall ecosystem functioning in the watershed. The technical know-how to help solve the water crisis is largely known; the next step is to apply these lessons learned at the scale required.

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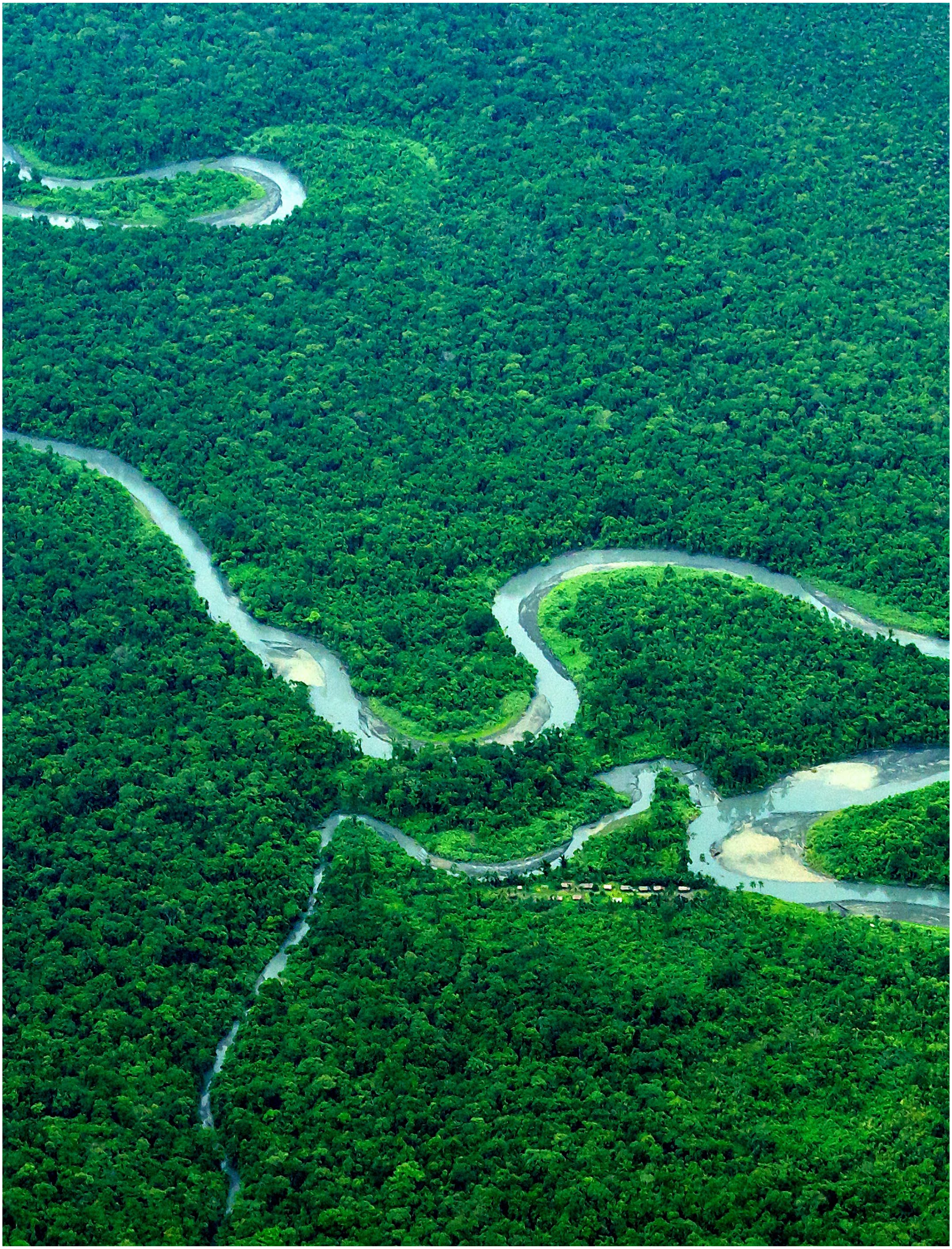

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Part Two

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

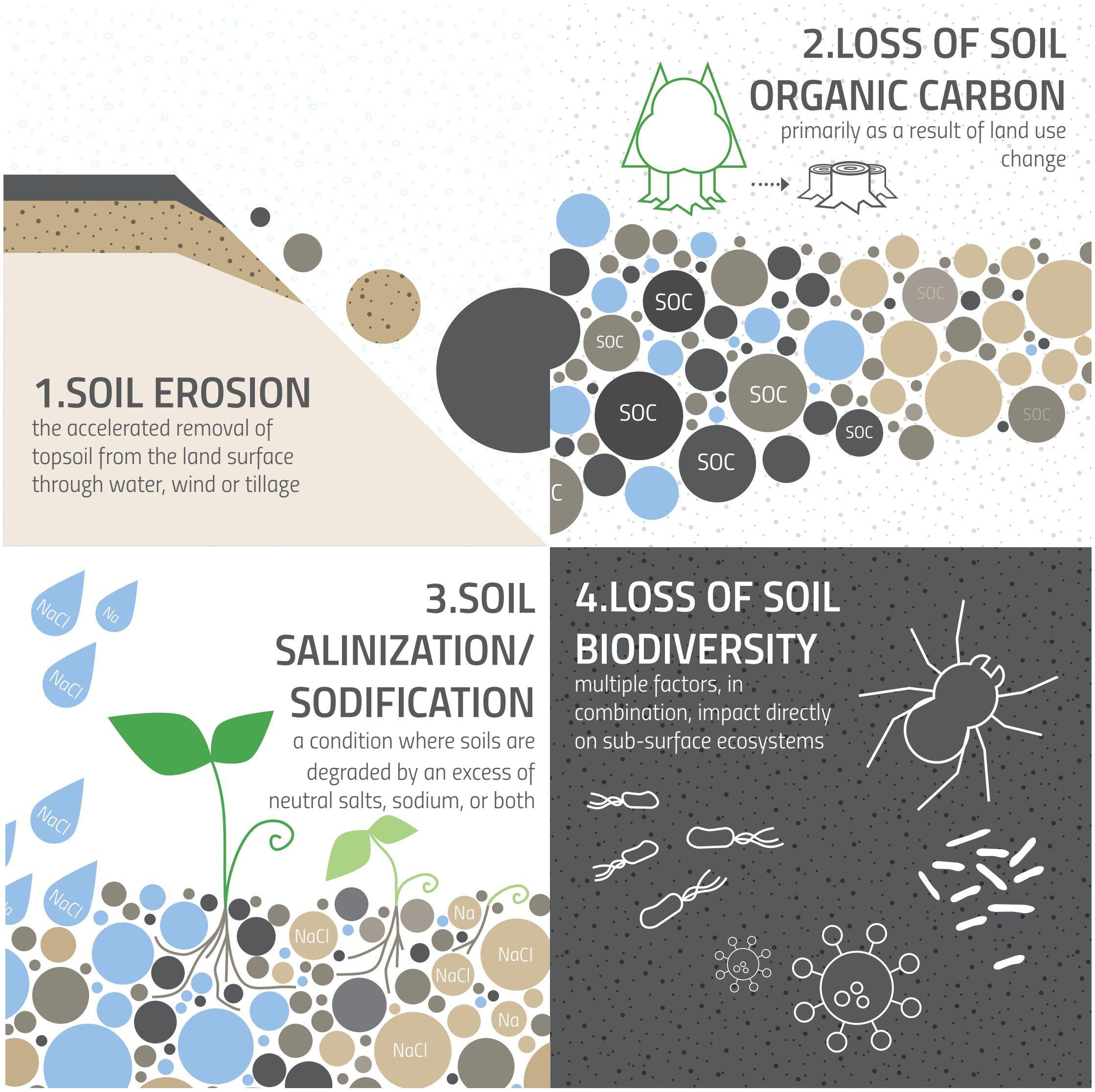
Many of these disconcerting trends are generally well known. In fact, Sustainable Development Goal 15.5 states "*Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species.*"

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]

Table 9.2: Deforestation fronts

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]

Up to 70 per cent of global forests are at risk of further degradation.

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]

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]

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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]

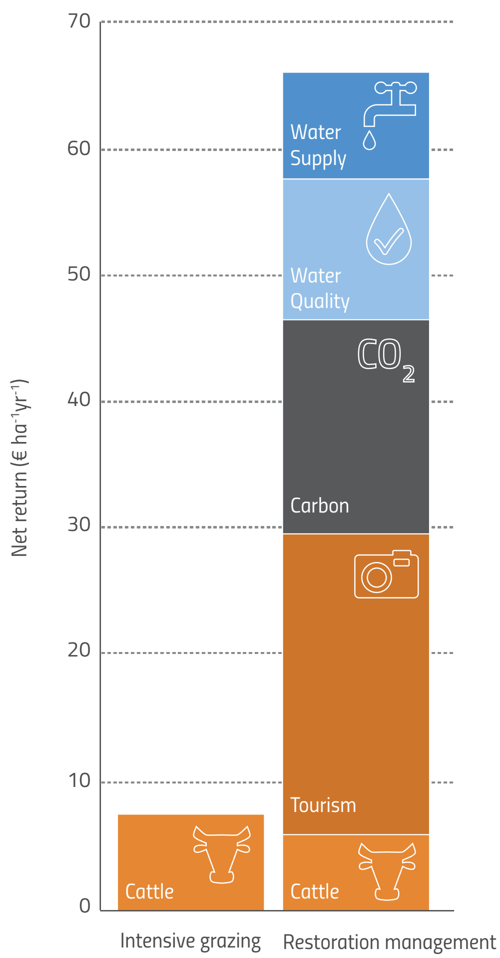
Shinyanga region of Tanzania, are driven by far more than technical expertise, with success being facilitated by a complex mixture of personalities, supportive policies, and issues related to gender politics, traditional knowledge and institutions, and participation.[212] Each case is unique and no single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



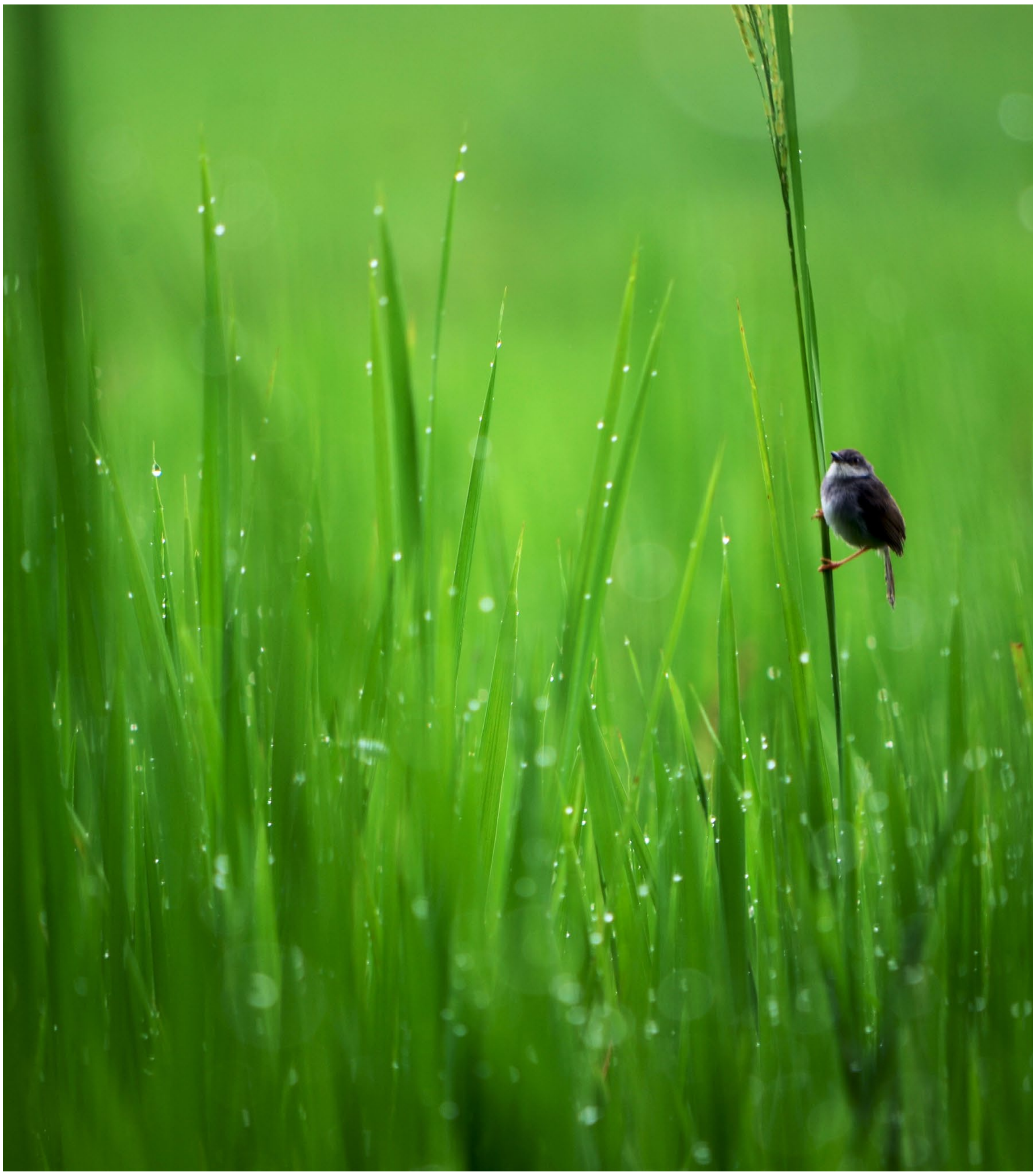
CONCLUSION: LANDSCAPE APPROACHES

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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Part Two

CHAPTER 10

ENERGY AND CLIMATE

Abundant energy drives the world economy. But it comes at a price: our efforts to extract energy from fossil fuels and renewable sources take up large amounts of land. The pollution generated by energy production and consumption, including the burning of biomass, is altering the ecology of the entire planet.

Climate change is the largest and most serious of these impacts, created mainly by fossil fuel burning together with significant greenhouse gas emissions from forest loss and the food system. While land is both a source and victim of climate change, it is also a part of the solution. Sustainable land management practices can contribute to climate mitigation strategies by halting and reversing the loss of greenhouse gases from land-based sources and can provide irreplaceable ecosystem services that help society to adapt to the impacts of climate change.

INTRODUCTION

There has been a massive and unprecedented explosion in energy use since the 19th century; global energy use has grown by more than 20 times in the last 200 years, far outstripping the rate of population growth.[1] In particular, the use of fossil fuels has increased dramatically, nuclear fission has emerged as a globally important energy source, and more recently a range of renewable energy technologies have moved from niche markets into the mainstream. The rapid growth in energy production and consumption has in turn had major impacts on land resources. This includes direct impacts, such as land use change and land degradation, and more subtle influences from the local and downstream pollution of soil, air, and water as well as carbon emissions causing global change.

The most significant impact has been the acceleration of human-induced climate change. In the 19th century, scientists first hypothesized that anthropogenic emissions of greenhouse gases could change the climate, but the idea only became more widely accepted from the 1960s.[2] There has been an increasing consensus on the reality, scale, and rate of climate change in the years since, although a few skeptics still deny any human influence on the climate. The establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988 led to a rapid growth of information, as scientists from around the world were encouraged to pool research efforts and work together to analyze data, build climate models, and carry out assessments.[3]

In 1992 at the Earth Summit in Rio de Janeiro, the signing of the UN Framework Convention on Climate Change (UNFCCC) brought the issue into sharp political focus thus starting a decades-long process of negotiations on how to address climate change.[4] Land and climate have a complex relationship: crop and livestock management practices are both a cause of climate change and a potential solution, in terms of both mitigation and adaptation, while terrestrial ecosystems will themselves be heavily altered as a result. This chapter provides a brief overview of some critical land issues relating to energy and climate change.

Energy

Every energy source has implications for the condition of land resources and many also have side effects in terms of damage to biodiversity, the wider environment, and to human health; while the extent of these impacts differs, no energy source comes without some costs. Environmental and social costs, life cycle analysis, and ratio of energy investments to return are all important factors to consider.

Policy choices are complex and virtually every type of energy supply has at least one civil society group lobbying against it.[5] Although there have been attempts to provide a unified environmental strategy for energy supply,[6] the field remains fractured, complicated, and deeply contentious. However, the move towards renewable energy is gathering pace and will further be spurred on by the Paris Agreement on climate change, which strives for global "decarbonisation."[7]

Sustainable Development Goal 7 aims to "*Ensure access to affordable, reliable, sustainable and modern energy for all*" with associated targets 7.1 to "*ensure universal access to affordable, reliable and modern energy services*" and 7.2 to "*increase substantially the share of renewable energy in the global energy mix*."

Many of these issues are covered elsewhere in this *Outlook*, for example, biofuels are discussed in Chapter 7 and hydropower in Chapter 8. Table 10.1 summarizes some of the major implications of different energy sources operating on or having an impact on land resources.

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Table 10.1: Implications of different energy sources for land, environment, and human health

Source	Issues
Oil	There are serious pollution risks during extraction on land[8] and at sea, and during distribution. The world's biggest accident oil spill so far, in the Gulf of Mexico, released 4.9 million barrels of crude oil,[9] impacting large coastal areas. Regular oil spillage can also damage vegetation such as mangroves.[10] Oil burning is a major contributor to air pollution; nitrogen oxides and particulates, predominantly from transport, are estimated to cause over 50,000 premature deaths a year in the UK.[11] Fossil fuels are also the world's single largest contributor to greenhouse gas emissions.[12] The mining of tar sands (a viscous form of oil) in Canada is a bitterly contested issue,[13] as is drilling in the Arctic and rainforests.[14]
Gas	The role of hydraulic fracturing ("fracking") in the extraction of fossil fuels, including particularly tightly-held natural gas, has created widespread opposition on health and environmental grounds,[15] and cumulative land impacts can be damaging to biodiversity.[16] Gas burning is also a significant source of greenhouse gases; flaring of unused gas during oil production alone creates emissions of around 250 million tons of carbon dioxide a year.[17]
Coal	Pollution occurs during extraction and in particular open cast mines create widespread damage to air, water, and human health.[18] But underground mines actually have a larger land footprint due to the need for timber pit props, etc.[19] There are serious health and safety issues for coal miners, who suffer a range of fatal illnesses through long-term inhalation of coal dust.[20] Coal pits and waste dumps destroy habitat. Coal is a major source of local pollution and smog, which is associated with a range of human illnesses;[21] long-range dry and wet deposition ("acid rain") impacts on freshwater[22] and forests, water pollution[23] and greenhouse gas emissions. Abandoned coal mines result in acid mine drainage lasting decades.[24]
Nuclear	Regarded by some as a favorable option because of its low greenhouse gas emissions,[25] others are highly critical of this perspective.[26] The overall land impact is also low, although uranium mining can have significant biodiversity impacts, cause contamination, and there are serious health issues among miners.[27]. However, there is widespread concern about safety implications, highlighted by major accidents at Harrisburg in the United States, Chernobyl in Ukraine,[28] and Fukushima in Japan, damaged during the 2011 earthquake[29] and still highly unstable today. The highly radioactive waste from nuclear fission also requires unprecedentedly long storage, a problem that the industry has yet to resolve and will be likely left to governments.[30]
Hydropower	There are high costs in terms of changes to river flow, leading to impacts on biodiversity (e.g., migratory fish), downstream nutrient availability, and ecosystem services such as periodic flooding for irrigation.[31] Reservoirs for hydropower flood valleys and low-lying areas, replacing either natural vegetation or agricultural land and communities.[32] Under some circumstances, hydropower impoundments are significant methane sources.[33]
Tidal power	To date only developed in a few places. There is a long-term controversy about the potential impacts of a tidal power scheme in the Severn Estuary in the UK due to likely impacts on bird populations.[34] New lagoon and tidal stream technologies have lower environmental impacts and may offer viable alternatives.
Wind	Wind energy systems have significant land use implications and have been opposed on aesthetic grounds, in terms of impacts on landscape appearance, and also because of potential impacts on bird populations[35] and biodiversity-rich areas.[36] Farming can in theory take place within wind farm installations,[37] and planning strategies exist to avoid areas of conservation importance.[38] Offshore wind farms are less controversial and becoming more popular; they can have negative impacts for seabirds but conversely provide refuges for benthic habitats and marine life.[39]

Source	Issues
Solar	Three main types of solar energy exist: solar water heating systems, concentrating solar power systems, and photovoltaic (PV) cells.[40] The emergence of solar power stations – large banks of photovoltaic cells or concentrating mirrors generating heat – on farmlands and in arid regions has created concerns about the trade-off between energy and both food production and nature conservation.[41] However, solar power stations can, if carefully designed be integrated with agricultural systems,[42] and such "agrivoltaic" systems are increasingly being installed.[43] It is important to note that greenhouse gas emissions from PV manufacturing are themselves significant.
Biofuels	More than 2.4 billion people rely on fuelwood and charcoal for cooking, and when unsustainably harvested, these contribute to forest loss and degradation.[44] Biofuel plantations also have major impacts on land use, through directly clearing natural or semi-natural vegetation to establish biofuel crops, or by displacing food crops. Conversely, sustainable management of grass for biomass harvest could in theory provide an incentive to protect threatened grasslands.[45] Various standards and certification systems exist.[46] Some biofuels can also have serious health impacts: an estimated 420,000 people die prematurely every year in China alone due to indoor air pollution from coal and fuelwood.[47] Fossil fuel use is too large for a simple substitution by biofuels to be viable.[48]
Bioenergy with Carbon Capture and Storage	If bioenergy is combined with carbon dioxide capture and storage (BECCS), this could result in negative GHG emissions: biomass cultivation removes carbon dioxide from the atmosphere, biomass is converted to energy, and the carbon dioxide released from biomass combustion is captured and stored, providing BECCS with a unique advantage in terms of greenhouse gas reduction if feedstock supply could be managed with low greenhouse emissions. BECCS is central to virtually all strategies for a "below 2°C" world, which require substantive negative carbon emissions by the end of the 21st century.[49] However, the technology remains unproven.[50]
Geothermal	An important and long-term source in countries with a large supply, such as Iceland. Lower grade geothermal energy can also be harnessed through heat pump technology.[51]
Energy recovery from waste	A growing energy source, through for example thermal treatments systems[52] and biogas generators.[53] The land and footprint implications of such systems are relatively low.

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Table 10.2: Land intensity in different energy systems

Data Sources

(a) Trainor et al. (2016)

(b) Fthenakis and Kim (2009)

(c) IINAS (2017)

(d) UNEP (2016)

(e) generic estimate

			Land use intensity [m²/MWh]				
Product	Primary energy source		US data (a)	US data (b)	EU data (c)	UNEP (d)	typical (e)
Electricity	Nuclear		0.1	0.1	1.0		0.1
	Natural gas		1.0	0.3	0.1	0.2	0.2
	Coal	Underground	0.6	0.2	0.2		0.2
		Surface ("open-cast")	8.2	0.2	0.4	15.0	5.0
	Renewables	Wind	1.3	1.0	0.7	0.3	1.0
		Geothermal	5.1		2.5	0.3	2.5
		Hydropower (large dams)	16.9	4.1	3.5	3.3	10
		Solar PV	15.0	0.3	8.7	13.0	10
		Solar CSP	19.3		7.8	14.0	15
		Biomass (from crops)	810	13	450		500
Liquid Fuel	Fossil oil		0.6		0.1		0.4
	Biofuels	Corn (maize)	237		220		230
		Sugarcane (from juice)	274		239		250
		Sugarcane (residues)					0.1
		Soybean	296		479		400
		Cellulose, SRC	565		410		500
		Cellulose, residues			0.10		0.1

The greatest impacts in terms of direct land use change come from biofuels and the extraction of fossil fuels, with tar sand and oil shale mining probably having the largest direct fossil fuel footprint in terms of land area per unit of energy produced. Indirect impacts on land come from various forms of pollution, with fossil fuels again the most important in terms of area impacted, both from sulfur and nitrogen oxides, and more pervasively through the release of greenhouse gases. Table 10.2[54] provides a summary of land use intensity related to energy systems.

In general, non-renewable energies imply land footprints of 0.1 - 1 m²/MWh (except open surface coal mining), while land use from non-biomass renewables is in the order of 1 - 10 m²/MWh, and 100 - 1,000 m²/MWh for biomass (except residues and wastes).[55] Nuclear power generally has fewer impacts on the land base, although if things go wrong the effects are much longer lasting.

Hydroelectric power causes dramatic changes to rivers and watersheds, which in turn affects the surrounding land, reduces the availability of irrigation water, affects soil fertility, and often creates other land use changes: large dams flood areas, destroy habitats, and displace communities.

Choices about energy supplies are not simple and planning needs to take into account the whole life cycle of technologies and fuels. It is for example important to differentiate between centralized (non-renewable) technologies that require fuel and other resources to be delivered to the production facility and distributed, and renewable energy technologies that rely on either on-site fuel and/or use the energy locally, significantly reducing the need for transportation and transmission infrastructure.[56]

CLIMATE CHANGE

Sustainable Development Goal 13 states "*Take urgent action to combat climate change and its impacts*" recognizing that climate change will cause fundamental changes in ecosystem functioning that increase risks to overall human security. The IPCC is blunt in its assessment of the evidence for climate change, its causes, and likely future impacts on the environment and human society.

Impacts of climate change

The IPCC outlines likely impacts on a range of issues pertinent to this *Outlook*:

- **Food security:** a projected reduction in food security. Wheat, rice, and maize grown in tropical and temperate regions will on balance be negatively impacted under local temperature increases of 2°C, although some places may benefit (medium confidence). Greater temperature increases would pose large risks to food security globally (high confidence).
- **Water security:** a projected reduction in renewable surface water and groundwater resources in most dry subtropical regions (robust evidence, high agreement)
- **Disasters:** Coastal regions and low-lying areas will be at risk from sea level rise, which will continue for centuries even if the global mean temperature is stabilized (high confidence). Evidence of an increase in extreme precipitation events implies greater risks of flooding at regional scale (medium confidence). Impacts from recent climate-related extremes, including heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some ecosystems and many people to current climate variability (very high confidence).
- **Biodiversity**: A large fraction of species face increased extinction risks during and beyond the 21st century. Most plant and animal species will be unable to shift their geographical range fast enough to keep up with projected rates of climate change in most ecosystems (high confidence). At a large scale, there will likely also be changes to the composition, structure, function, and resilience of many ecosystems.
- **Human health:** Until mid-century, projected impacts on human health will exacerbate existing health problems (very high confidence), leading to increased ill-health in many regions throughout the century, especially in developing countries with low income (high confidence).

Figure 10.1: Impacts of climate change

- **Cities:** In urban areas there will likely be increased risks for people, assets, economies, and ecosystems, including risks from heat stress, storms, and extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, water scarcity, sea level rise, and storm surges (very high confidence). These risks will be worse for those lacking essential infrastructure and services or living in exposed areas.
- **Rural areas:** are expected to experience major impacts on water availability and supply, food security, infrastructure, and agricultural incomes, including shifts in the production areas of food and non-food crops around the world (high confidence).
- **Migration:** increased displacement of people is likely (medium evidence, high agreement). Populations unable to undertake planned migration will be more exposed to extreme weather events, particularly in low income countries.
- **Political and social security:** "Climate change can indirectly increase risks of violent conflicts by amplifying well-documented drivers of these conflicts such as poverty and economic shocks (medium confidence)."[58]

The Earth is heading into a period of climatic instability unprecedented in historical times, where ecosystems will change and extreme weather events become more common, thus undermining overall human security. We are already feeling the impacts; the continuation of current trends could result in changes of a magnitude several times greater than those already experienced.

Land management drives climate change

In addition to land being impacted, land use and management practices are an important contributor to climate change. Land use change, land and water management, and climate determine how much carbon can be stored, sequestered, or released in the form of greenhouse gases. In 2019, the IPCC will publish a special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.[59] Land use change often entails the conversion of pristine, carbon-rich systems to a land use with lower carbon storage potential (e.g., forests to grasslands or cropland to settlement and transportation infrastructure). Land management activities can increase carbon loss through soil disturbance, reduced aggregate stability, increased fire incidence, and loss of vegetative cover.

Box 10.1: Likely impacts of climate change

The Intergovernmental Panel on Climate Change released its latest report in 2014. Below are some key findings.

"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen...

"Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century...

"In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate...[57]

"Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks."

Agriculture, forestry, and other land use (AFOLU) is responsible for just under a quarter of the world's greenhouse gases and the total contribution has remained consistent for some time. The main factors are deforestation and agricultural emissions from livestock, and soil and nutrient management, although biomass burning is also significant.[60] Estimates suggest that under a business-as-usual scenario, the global economic cost of climate change from forest loss could reach USD 1 trillion a year by 2100.[61] While cutting emissions from fossil fuels remains the number one global priority, halting and reversing forest loss and land degradation is thus one of the most urgent tasks in mitigating climate change, fully recognized by researchers,[62] governments,[63] and NGOs.[64]

Storing carbon in terrestrial ecosystems

At the same time, the world's ecosystems also have the potential to mitigate climate change by storing and sequestering greenhouse gases, and to help humanity adapt to changes by maintaining vital ecosystem services and the biodiversity that underpins them.

For climate change mitigation, the challenge and opportunity is how to turn the land from a carbon source into a carbon sink. If land management is to significantly contribute to mitigation, the impacts of different land uses and management practices on carbon sequestration rates, plant productivity, and total storage capacity must be better understood.[65] Sufficient incentives to encourage land uses that prevent emissions and sequester additional carbon are needed. Changes in land management practices could reduce greenhouse gas emissions and also help sequester carbon from the atmosphere (see Table 10.3), but potentials remain unclear.

Soils, including peat, are thought to be the largest carbon reservoir on land, holding more than the atmosphere and vegetation combined,[66] although estimates vary. Carbon is sequestered into soils from atmospheric carbon dioxide, obtained by plants through photosynthesis and contained in crop residues and other organic solids. Sequestration is increased by management systems that add more biomass to the soil, reduce soil disturbance, conserve water, improve soil structure, and enhance soil fauna activity. Conversely, stored soil carbon may be lost through mismanagement as discussed in Chapters 7, 8, and 9. Despite the size of the carbon store, the role of soil carbon has often been downplayed or ignored as a mitigation strategy in many climate change initiatives.[67]

Forests also represent massive carbon stores. Estimates for carbon stored in tropical moist forests range from 170-250 t carbon/hectare (tC/ha),[68] depending partly on the amount of large woody species:[69] around 160 tC/ha in above-ground biomass, 40 tC/ha below ground and 90-200 tC/ha in soil.[70] Tropical moist forests sequester carbon even once they reach old-growth stage, both in the Amazon[71] and Africa.[72] Boreal forests contain the second largest terrestrial stock of carbon, stored mostly in soil and leaf litter, averaging 60-100 tC/ha,[73] and continue to sequester carbon as they mature.[74] The peat under boreal forests is the main reason this ecosystem type stores so much carbon. However, carbon is lost if fire frequency is high,[75] a condition likely to increase under climate change,[76] and if wood harvest volumes increase,[77] the biome could very well switch from a sink to a source of carbon in the future.

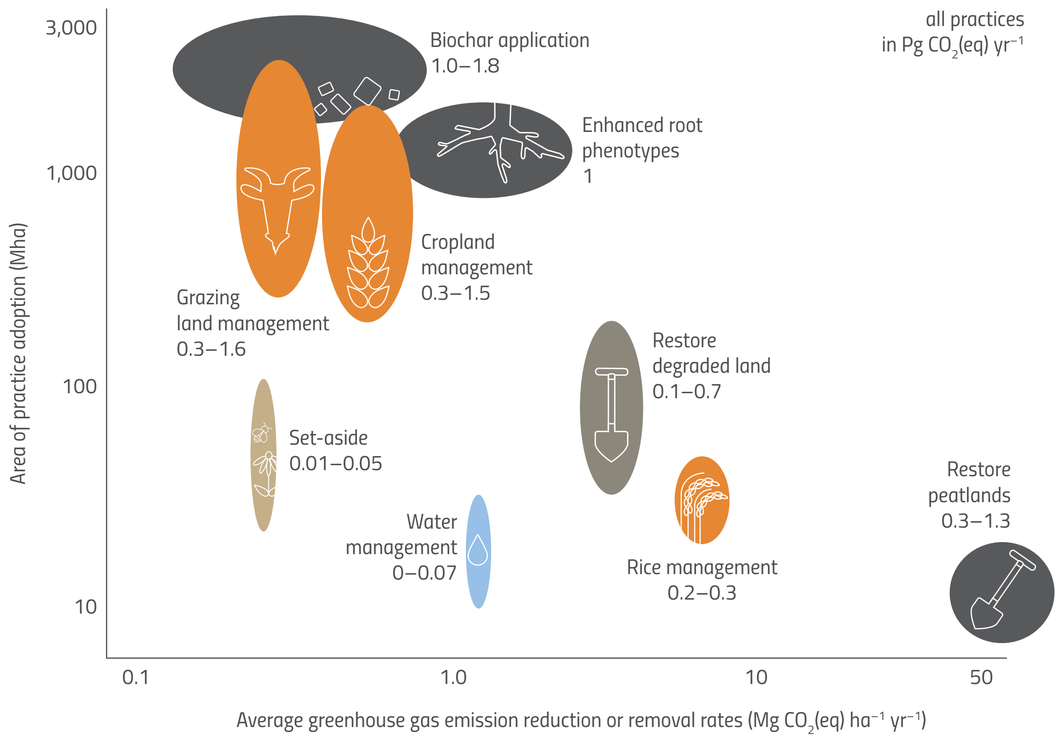
There is a host of crop and livestock management practices that protect and restore the productivity of land resources while at the same time reducing emissions and sequestering carbon (see Figure 10.2). Inland wetlands, particularly peatlands, are very significant carbon stores. While they only cover about 3 per cent of the land surface, peat is believed to contain the planet's largest store of carbon.[79] Intact peatlands contain up to 1,300 t of tC/ha[80] with global estimates of 550 Gt of carbon stored.[81]

Grasslands are also major carbon stores[82] holding in excess of 10 per cent of total terrestrial carbon.[83] Tropical grasslands and savanna have carbon storage ranging from less than 2 tC/ha when trees are absent and up to 30 tC/ha for wooded savannah.[84] Temperate grasslands and steppe are also significant carbon stores.[85]

Table 10.3: Carbon stored by biome[86]

Biome	Gt Carbon
Tropical and subtropical forests	547.8
Tropical and subtropical grasslands, savannas, shrublands	285.3
Deserts and dry shrubland	178.0
Temperate grasslands, savannas, and shrublands	183.7
Temperate forest	314.9
Boreal forest	384.2
Tundra	155.4
Total	**2049.3**

Figure 10.2: Global potential for agricultural-based GHG mitigation practices where 1Pg (Pentagram) equals 1 billion metric tons and Mg (Megagram) equals 1 metric ton: Redrawn from[78]



Maximizing the amount of carbon stored in land-based ecosystems[87]

1. Reduce emissions from land management changes and intensive cultivation which constitute a source of greenhouses gases:

- Spare land with a higher carbon-storage potential from conversion through sustainable intensification of land already in production (mainly cropland)
- Avoid or reduce major land use changes (e.g., deforestation, rapid urbanization and unplanned urban sprawl, biofuel plantations)
- Protect wetlands and grasslands from conversion
- Improve production systems that currently release high amounts of greenhouse gases (e.g., reducing greenhouse gas emissions by drying and wetting of paddy rice fields)

2. Protect high carbon content soils:

- Avoid excessive drainage leading to oxidation and mineralization of organic soils; keep groundwater levels at an optimal height by regulating groundwater levels; protect and restore wetlands
- Avoid agronomic practices and production systems that accelerate soil erosion and the decomposition of soil organic matter; replace with no- or low-tillage systems, permanent soil cover, rotational grazing, etc.
- Avoid clearance of bush or forest related with burning, overgrazing, and overexploitation of vegetation, which reduces above and below ground organic matter

3. Increase carbon sequestration and improve storage capacity

- Restore intensively-used cropland or grazing land to more extensive systems, such as rewetting of organic soils or reversing land-use (e.g., from cropland back to grasslands or restoration of wetlands)
- Increase carbon sequestration and carbon stocks of mineral soils; apply agronomic management practices that improve above and below ground biomass production and residue retention
- Where necessary maintain "cool fires" by prescribed burning and avoid large and intense wild fires

Climate change mitigation through improved land use and management is a long-term investment which involves tradeoffs, in some cases due to the time required and lack of immediate benefits accruing to the local land users. For example, the improved management of mineral soils by planting cover crops and reducing soil disturbance can improve carbon stocks without increasing groundwater levels. This reduces the risk of methane emissions in both organic and mineral soils, and demonstrates why the overall carbon balance needs to be carefully calculated. Some strategies for climate change mitigation, including re-wetting of organic soils and restoration of grasslands, have clear co-benefits for both biodiversity conservation and increasing the resilience of the whole system.

Land management to increase resilience

In addition to carbon sequestration and storage, properly managed natural and semi-natural ecosystems provide a range of important ecosystem services, as described in Chapter 4. This includes their role in preventing or reducing the effects of weather-related disasters, providing a secure and potable water supply, addressing climate-related health issues, and protecting food supplies, including wild foods, fisheries, and crop wild relatives. More fundamentally, by maintaining a healthy, functioning biosphere by protecting nutrient and water cycles and soil formation, well-functioning ecosystems can provide the building blocks to ensure long-term food and water security.

Effective adaptation depends on the ecosystem itself continuing to function, so that those responsible for management of natural areas are increasingly looking at options to increase resilience against climate change and other forms of stress.[88] Ensuring that land-based natural capital is as robust as possible and sustainably managed reduces the release of greenhouses gases and sequesters carbon while improving human and ecosystem resilience to the impacts of climate change.

CONCLUSION

Responses to these challenges sound simple: less polluting energy sources, more efficient, energy-saving solutions, and land use and management practices that prioritize the conservation of carbon in the soil.[89] However, agreeing on what this means in practice has proved challenging, and implementing equitable clean energy strategies and scaling up sustainable land management more challenging still.

Reconciling rapidly increasing food demand with the pressing need to address global climate change by stabilizing or reducing emissions from agriculture is a complex problem requiring novel policy measures that incentivize best practices. Climate mitigation policies should therefore be directed to locations where crops have both high emissions and high intensities. Findings clearly indicate that climate mitigation policies for croplands should prioritize elimination of peatland draining.[90] Dietary shifts also have a high potential to help reduce carbon losses.[91]

Some believe that nuclear power, whatever its hazards, is preferable to our continued reliance on fossil fuels,[92] while others argue for a non-nuclear, renewable energy future.[93] Some analysts believe that oil supply has peaked and that the world faces real energy shortages[94] while others disagree.[95] The extent to which countries should rely on hydropower remains a subject of deep controversy. The momentum to continue with business-as-usual approaches is enormous, and major industry players have the power to create energy futures that profit their own industries. Strategies that address the twin challenges of energy and climate are starting to emerge, but are generally doing so piecemeal and much more slowly than we need.

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Part Two

CHAPTER 11

URBANIZATION

The millennia-old relationship between town and country is being transformed. Rapid urbanization is taking place all over the world, driven largely by rural migration, resulting in urban sprawl and slum developments as well as in the development of high quality infrastructure and overall improvement in the standard of living. If current projections are accurate, 66 per cent of the world's population will be living in cities by 2050. This is having dramatic impacts on the environment and increasing pressure on limited land resources; future urban expansion is likely to result in the loss of some of our more productive croplands.

The footprint of cities extends far beyond their boundaries due to the demand for food and water as well as transport and energy infrastructure. But cities can offer economies of scale with respect to resource use and environmental impacts. The concept of sustainable cities is gaining ground but urban planners are struggling to put these approaches into practice.

Cities are growing at an unprecedented and challenging speed

INTRODUCTION

The distinction between urban and rural lifestyles goes back centuries. The oldest cities in Mesopotamia, China, the Indus valley, Egypt, Peru, and Mesoamerica can trace their roots back over 4,000 years and were at first predominantly ceremonial centers. Gradually cities developed into independent administrations, which distributed food, focused on manufacturing, and controlled trade. Before 1800, urban areas contained less than 2.5 per cent of the world's population and most were relatively small. With the exploitation of fossil fuels and industrialization, truly urbanized societies began to emerge in Europe and North America around 200 years ago. Where land was cheap and population density low, as in North America, urban sprawl was extensive; Boston's radius grew from 2 to 10 miles between 1850 and 1900.[1] By 1900, about 10 per cent of the world's population lived in cities, which gradually began to take on the characteristics we recognize today.[2]

However, the overall rural/urban balance was slower to change. In 1960, only 34 per cent of people lived in urban settlements and two-thirds were still rural.[3] From the second half of the 20th century, change was more rapid. Symbolic of the fundamental shift in the way that we live is the rise of the megacities. In 1990, there were only 10 cities with more than 10 million inhabitants[4] but by 2017 there were 34,[5] containing about 12 per cent of the world's population.[6] Urban agglomerations, encompassing multiple cities, suburban, or peri-urban areas, began to form as contiguous and continuous regions.[7] In 2007, the global balance of urban versus rural living tipped for the first time in history, with more people living in urban than in rural areas.[8] Levels of urbanization have varied across regions. By 2014, urbanization at or above 80 per cent could be found in Latin America, the Caribbean and Northern America while 73 per cent of Europeans, 48 per cent of Asians and 40 per cent of Africans lived in urban areas.[9] Some countries are almost completely urbanized. Singapore is considered 100 per cent urbanized, followed by Qatar at 99.2 per cent, Kuwait 98.3 per cent, Japan 93.5 per cent, and Israel 92.1 per cent.[10]

Future urbanization

In the early 21st century, cities generated over half of global GDP and this economic dominance is helping drive their continued growth.[13] Addis Ababa, for example, has 2.6 million residents representing only 4 per cent of the total population yet it accounts for almost one-fifth of Ethiopia's GDP.[14] In 2014, 28 megacities were home to 453 million people; by 2030, 13 new megacities are expected to emerge in the less developed regions.[15]

Nearly 90 per cent of this increase is likely to be in Asia and Africa where urban populations are projected to rise to 56 and 64 per cent respectively.[16] Current estimates indicate that new urban residents in Africa will rise by over 300 million between 2000 and 2030 – more than twice that in rural populations.[17] While African cities, such as Dar es Salaam and Kinshasa, are among the fastest-growing in the world, only 12 percent live in settlements of 1 to 5 million people and 52 per cent in settlements below 200,000.[18] Changes have been more dramatic in Asia, where countries like China have moved from being overwhelmingly rural societies to increasingly urban within a single generation. Twenty-two of the world's 100 largest cities are now in China.[19] Although numerically relatively small, the fastest rate of urbanization has been in the Caribbean with 62 per cent of the

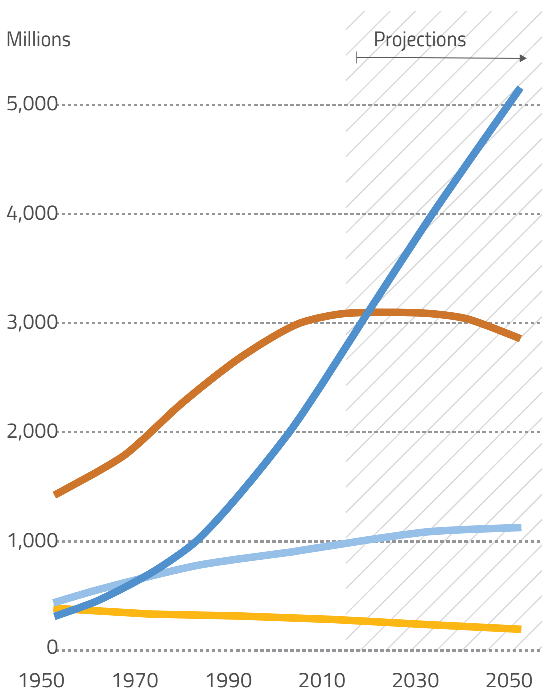

Figure 11.1: Urban and rural population in developed and less developed world regions, 1950–2050: Redrawn from[12]

Less developed regions
Africa, Asia (excluding Japan), Latin America and the Caribbean, Melanesia, Micronesia & Polynesia

- Urban Population
- Rural Population

More developed regions
Europe, Northern America, Australia, New Zealand & Japan.

- Urban Population
- Rural Population


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population residing in urban areas at the start of the millennium, increasing to 70 per cent in 2015, and projected to reach 75 per cent by 2025.[20]

In most parts of the world, the urban land footprint is expanding faster than urban populations.[22] While urban populations are projected to reach around 5 billion in 2030 and 6.3 billion people in 2050,[23] the extent of urban areas is forecast to triple from a 2000 baseline over the same period,[24] increasing by 1.2 million km^2.[25]

Box 11.1: Rapid urbanization in India

High profile projects in India highlight infrastructure developments and land use change associated with rapid urbanization, with over half the population expected to be city-dwelling by 2050:[26]

- **Transport infrastructure:** New Delhi alone is adding 1,400 new cars a day onto the roads. To improve transport systems, the country constructed 20,000 km of new and upgraded roads between 2012 and 2017.
- **Urban agglomerations:** An industrial corridor is being planned between Mumbai and Delhi, which will develop as many as six new cities.
- **Energy infrastructure:** Investments worth USD 250 billion are planned for electric plants and power grids.[27]

While attempts to forecast population growth have not always been particularly accurate,[28] the trend towards urbanization seems irreversible.[29] Economists generally link urbanization with growth[30] and opportunities for gaining efficiencies in land and resource use; decreasing fertility rates in urban populations will also reduce overall population growth.[31] But cities also support the largest inequalities in wealth,[32] with the largest cities also being the most unequal.[33] Cities have major impacts on the surrounding land: urban expansion is a primary cause of land use change and a significant driver of habitat loss and species extinction.[34] Sustainable development challenges will be increasingly concentrated in cities, particularly in the lower- and middle-income countries where the pace of urbanization is fastest.[35] Cities need to take on an increased responsibility for designing and implementing solutions to the challenges they create and their impacts on the rest of the planet.[36] However, it must also be recognized that many municipal authorities face challenges, such as a lack of guidance from national governments and increasing expectations without the necessary financial support. The remainder of this chapter discusses some of the challenges and impacts presented by an increasingly urban future.

RURAL-URBAN LINKAGES

Urban areas provide centralized functions and public services that are often too costly to provide in rural areas, while rural areas provide cities with relatively inexpensive goods and services, such as food, water, and fuel. Ideally, compact urban areas would allow rural areas to prosper as long as there is adequate infrastructure to facilitate the necessary flows of goods and services. However, in reality, rural-urban linkages rarely operate smoothly and unsurprisingly there is an increasing disconnect between cities and their surroundings.[39] In particular, there are two urban-related factors impacting the health of rural landscapes:

- **Migration** to and from urban areas driven by factors such as economic opportunities, land degradation, and government policies
- **Peri-urbanization** resulting in urban sprawl and slums

1. Migration

Migration from rural to urban areas is often seen as a natural consequence of uneven regional development[40] with gaps in incomes between rural and urban dwellers cited as a major incentive for people to move,[41] often coupled with a more general desire to increase their quality of life.[42] However, alongside the possibility for higher incomes, many other motives affect these migration flows, such as access to improved amenities, educational opportunities, and involvement in "knowledge economies,"[43] and avoidance of climate change[44] and weather-related disasters.[45] There are also countervailing forces that may restrict migration, such as constraints placed on migration by finance, distance, access to information, social networks, and limitations set by government policy.[46] In many countries, rural migrants are regarded as an underclass within cities. At the same time, out-migration from rural areas reduces the tax base and cuts resources available to rural municipalities for development activities. Migration is multi-directional and complex, and includes permanent and temporary movements within rural areas, from small towns to larger cities and between cities. Rural-urban migrants often return to their home area or other rural areas if the urban economy weakens or prices rise,[47] or once they retire.[48]

The decision to migrate therefore depends on a variety of factors operating simultaneously, which range from national or global political decisions to personal or local circumstances, some of which can be traced back to land use decisions. The liberalization of agricultural policies in Sub-Saharan Africa, for example, led to the removal of subsidies and the subsequent failure of some farms, resulting in migration to cities.[49] In some cases, rural-urban migration has resulted in the expansion of forests and other natural ecosystems due to abandoned agricultural land.[50] Alongside global and regional processes, national macro-economic policies based on reform and adjustment also have an impact on rural-urban relationships and the movement of individuals. The flow of rural migrants to cities in China increased following market reforms in 1992.[51] The result was a transition from a planned to a market economy with associated industrialization and urbanization, economic growth, and urban sprawl, and the loss of agricultural land near cities and rural industrialization in areas close to cities.

Box 11.2: Village level impacts of migration in Pakistan and Nepal

Migration can have complex implications for land. In some areas in Pakistan, out-migration of men from mountain villages in search of work has resulted in the degradation of pastures. The women, children, and older people left behind are less able to enforce the traditional user limits, allowing outsiders to take advantage by grazing large numbers of animals. In addition, households lack the necessary labor to keep livestock. Women switch to keeping goats, which are easier to maintain while still managing the household, but browsing by goats causes greater damage to fragile mountain vegetation than cattle grazing.[56]

In Nepal, the current exodus from upland areas to the cities or foreign countries has led to marked changes in the demographics of the hills. Again, the task of managing the land falls to those left behind, mainly women and the elderly. Labor shortages in rural areas often lead to more unsustainable agricultural practices and land use patterns. In spite of this, there have been some positive environmental impacts: lower population pressure and better management measures have promoted forest growth and helped to stabilize slopes as less fodder and fuelwood were collected. However, soils in areas experiencing out-migration, on the slopes or uphill, are now less fertile as there is less livestock and therefore less manure. The villages at the valley bottom, with increasing numbers of people, are also experiencing soil fertility declines due to increased cropping cycles from two to three a year.[57]

with liberalized economies.[52] Increased regional disparities have resulted in land use change in China,[53] including land degradation, pollution from increased industrialization, a reduction in food security as agricultural land is converted or abandoned, and over-intensive farming practices.[54] Conversely, the abandonment of marginal agricultural areas has resulted in the recovery of natural vegetation in some mountain areas.[55]

The impacts of migration on land can be positive. Migration from rural to urban areas can result in a flow of money, technology, and information back to rural areas.

The impacts of migration on land can be positive.[59] Migration from rural to urban areas can result in a flow of money, technology, and information back to rural areas. This may finance innovation in agriculture or diversification towards non-farm activities, thus opening up land for other uses.[60] The relationship between rural depopulation and forest cover is similarly ambiguous and depends on both local and non-local factors.[61] Some studies on rural out-migration support the 'Forest Transition Theory'[62] which highlights how this leads to reforestation as well as agricultural land abandonment.[63] Conversely, out-migration can lead to increased cultivation, particularly when migrants return with cash savings to reinvest in farming or to hire labor in their absence,[64] boosting food supplies but further undermining the productivity of the land. It can also lead to the disruption of environmentally sound management systems based on labor that is no longer available.[65]

2. Peri-urbanization

Peri-urban areas represent the interface between the city and the countryside, a hybrid landscape with both rural and urban characteristics. At best, such areas can represent a useful bridge between the urban and rural, providing services for both communities such as recreational areas, markets or shopping centers, or waste disposal sites. Under certain conditions, peri-urban demands for ecosystem services and recreational areas can result in the regeneration of forests and other natural ecosystems in what were marginal farming areas around cities.[66] However, they can also be barriers. Urban sprawl, loosely defined as dispersed, excessive, and wasteful urban growth,[67] can quickly degenerate into unregulated slums becoming virtual no-go areas apart from those unfortunate enough to live in them. Unregulated and unplanned urbanization, often exacerbated by weak governance structures and the lack of institutional coordination,[68] can lead to land degradation, biodiversity loss, pollution and water contamination, higher levels of crime and congestion, and the spread of disease.[69,70]

The money and power involved in the spread of cities means that peri-urban areas are often predisposed to eminent domain (compulsory purchase), land acquisitions, and tenure changes that can have disruptive social and environmental impacts.[71] For example, informal peri-urban development occupying ecologically valuable *ejido* land in Xalapa, Mexico is threatening remnants of montane cloud forest, which not only have intrinsic biological importance but also regulate local climate and urban microclimate by virtue of their tree cover.[72] Smallholder farmers being taken over by expanding cities in the Peruvian Andes express fears about food security as fertile land disappears under concrete.[73]

Slums account for a significant proportion of urban expansion, particularly in many developing economies. Slums are often framed as the archetype of "over-urbanization" whereby settlements develop informally without adequate infrastructure and sanitation. Some 828 million people live in slums today and the number keeps rising:[74] in sub-Saharan Africa, 62 per cent of the urban population lives in slums,[75] as does half the population of Mumbai, India.[76] Unplanned settlements are often formed by individuals seizing or invading land that does not belong to them; inequitable land distribution, initiated for example through land privatization schemes, can mean individuals are driven to occupy land as a survival mechanism.

Policies to govern uncontrolled urban expansion include spatial development plans (e.g., urban growth boundary, green belts) and accompanying regulations. An urban growth boundary is a common strategy focusing on efficient land use and the preservation of rural functions. This approach requires strong legislation in order to control development and ensure effective implementation, where success depends on development taking place within the existing urban planning framework. Similarly, green belt strategies promote compact cities, which not only reduce the ecological urban footprint but also the cost of providing additional services and infrastructure.

Slum settlements are often located in areas of high environmental risk (e.g., floods or landslides) and are potentially more affected by changing climatic conditions, particularly when built on land considered unsuitable for urban development. At the same time, worsening environmental conditions in rural areas can increase unplanned peri-urban development. Dhaka in Bangladesh is the fastest growing megacity in the world[77] as people migrate from coastal and rural areas often because of environmental factors. Coastal flooding is destroying vegetable crops and rice fields as saline water pushes further inland and river banks erode.[78] Communities move, often first from islands to the mainland,[79] and then frequently into urban slums.[80] This unplanned urban development is being directly stimulated by environmental degradation and the impacts of climate change, which is in turn largely driven by greenhouse gas emissions from the developed countries.

Urban areas in low elevation coastal zones (LECZ) are growing faster than elsewhere. One third of the cities reviewed in a recent study, accounting for nearly two-thirds of urban areas with populations greater than five million, were within 10 meters of a LECZ. Without adequate protection, the impacts of climate change will devastate economies and infrastructure;[81] it is estimated that 400 million urban dwellers are exposed to risks associated with sea-level rise.[82] Urban areas in LECZ and in least developed regions, such as Dhaka, are likely to experience the brunt of climate change-related disasters and effective governance is needed to prepare for such situations.[83] In Africa, countries with over 50 per cent of coastal urban areas vulnerable to climate-related storm surges include Mozambique, Tanzania, Côte d'Ivoire, Equatorial Guinea, and Morocco.[84] While 70 per cent of high-income countries integrate land use and natural risk management, only about 15 per cent of low-income countries do so.[85]

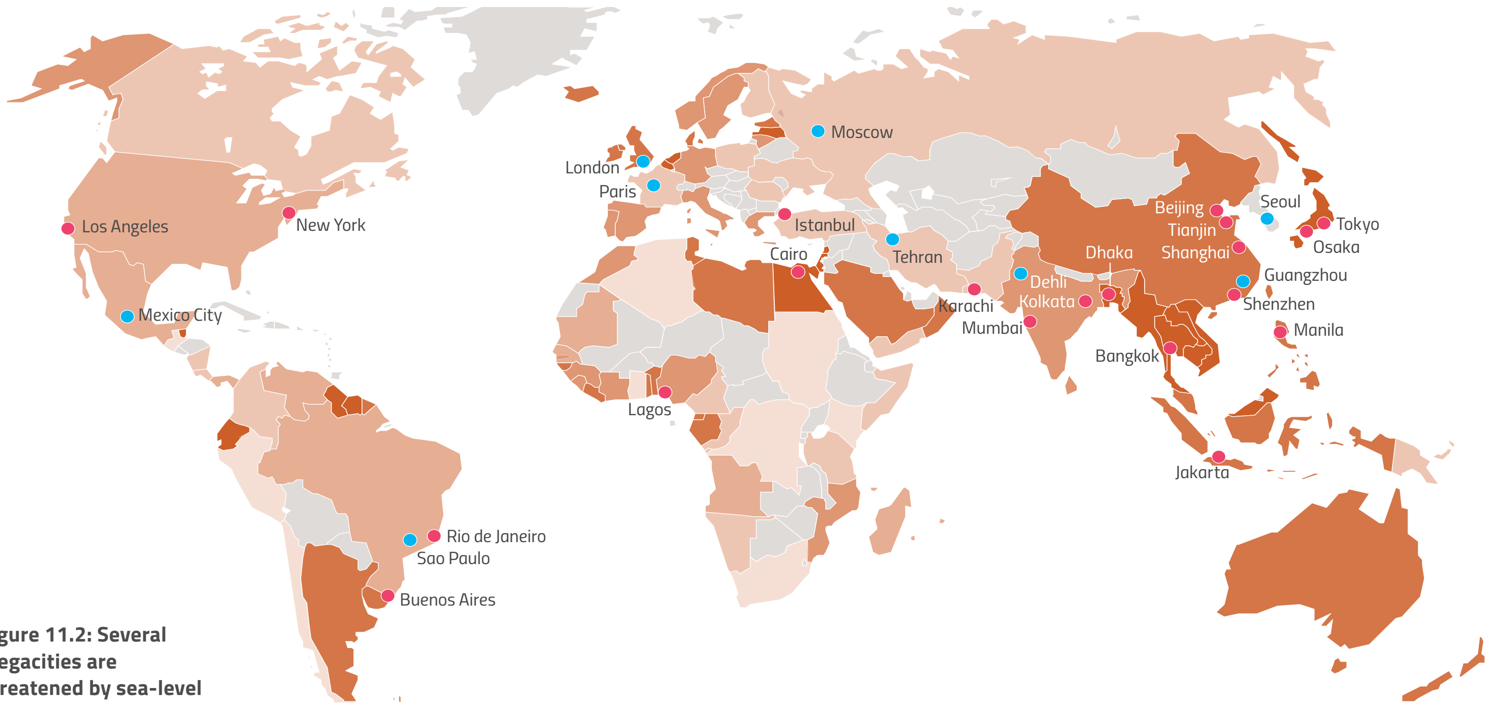

Figure 11.2: Several megacities are threatened by sea-level rise and storm surges: Redrawn from[86]

In low elevation zone

Not in low elevation zone

LAND FOOTPRINT OF CITIES

Cities pack most of humanity into a very small area but have impacts beyond their boundaries. Cities cover just 3 per cent of the Earth's land,[87] about 200,000 km^2 in total, but their limited extent conceals a much larger consumption footprint. Increasing urban and peri-urban expansion, coupled with population growth, changing lifestyles and associated resource demand, have together led to unprecedented levels of consumption and waste generation during the 20th and 21st centuries.[88] Urban footprints spread far and wide: a typical household in a European city is using goods and services that are causing greenhouse gas emissions, excessive water withdrawals, and land use change in dozens of countries around the world.[89] The dense population in cities and the relatively higher wages of many city dwellers[90] also mean that urban consumption patterns are different from their rural counterparts, with higher consumption of meat, dairy, and processed foods taking up proportionately more land resources.[91] The footprint of the city – the impact that the city has beyond its boundaries – has many components, of which six are discussed below:

- **Food impacts**, both directly from land use change and increased pressure to produce food for city dwellers
- **Water use**, with people living in urban areas tending to use proportionately more water than rural dwellers
- **Transport infrastructure**, both from a resource perspective and habitat fragmentation
- **Urban soil sealing** and impacts on the overall water cycle and susceptibility to extreme weather events
- **Biodiversity loss**
- **Climate change impacts**

1. Food impacts

Because of their design and population density, cities cannot provide meaningful amounts of food for their own inhabitants, which means that food must be imported from surrounding areas and, increasingly, from other parts of the world. Whereas in the recent past imported foodstuffs were primarily small, portable, and highly-priced goods, like spices or other luxuries, today the mass transportation of food means that it is more likely to travel longer distances. For example, an ecological footprint analysis of London found that around 80 per cent of food consumed in the city is imported from other countries.[93] A similar footprint for the Netherlands found that to meet the food needs of this small, highly urbanized country requires a land area four times larger than the country as a whole.[94] Food system issues are discussed in more detail in Chapter 7.

Rapid urbanization is also increasingly shifting the impacts of malnutrition from rural to urban areas: food security in cities depends mainly on access to cash, rather than growing or collecting food, and poor urban households in many developing countries spend over half their budget on food. One in three stunted children now lives in urban areas.[95]

But while cities need more land to feed their populations, they are expanding in area and thus reducing the amount of available cropland. Even though the total area may be relatively small, these lands are often the most suitable for producing food to feed the city's population. For example, in Tripoli, the second largest city of Lebanon, urban area increased by 208 per cent from 1984 to 2000, with a concurrent decrease of 35 per cent in nearby agricultural lands, mainly the fertile soils of the coastal plain, which formerly supported citrus orchards.[96] More than 60 per cent of the world's

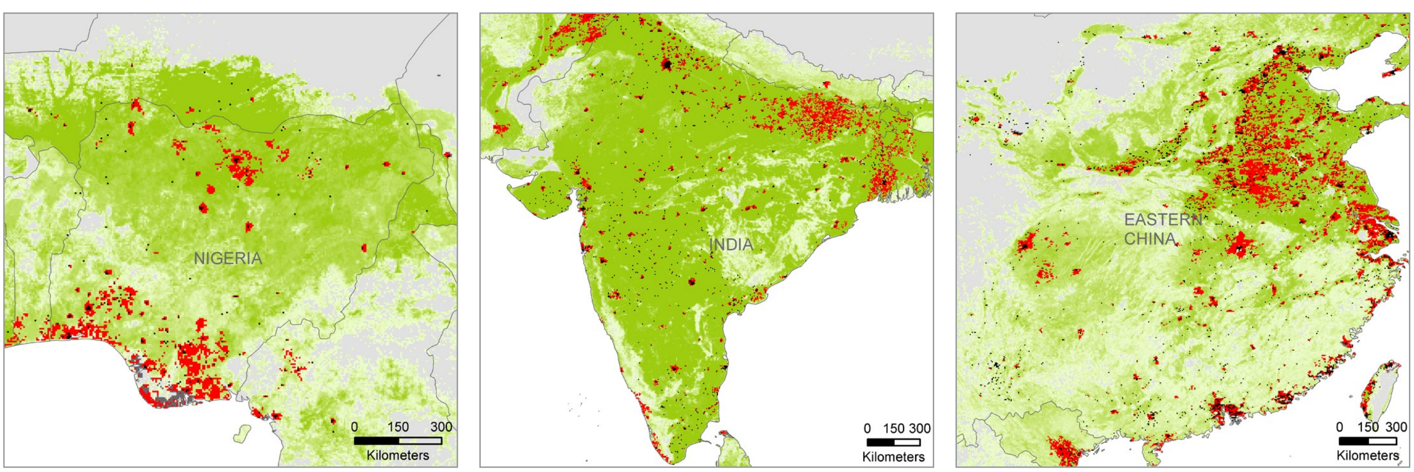

Figure 11.3: Urban area expansion on croplands in Nigeria, India and China: Used with permission[38]

Table 11.1: Global and regional implications of urban area expansion on croplands[102]

Region or country	Expected cropland loss, Mha	Relative cropland loss	Production loss	Productivity compared to regional average
World	**30**	**2.0%**	**3.7%**	**1.77**
Asia	18	3.2%	5.6%	1.59
Africa	6	2.6%	8.9%	3.32
Europe	2	0.5%	1.2%	2.18
America	5	1.2%	1.3%	1.09
Australasia	0.1	0.2%	0.2%	0.94

irrigated croplands are located near urban areas; as cities grow so will the competition for land between agricultural and urban or infrastructure uses. In 2000, a projected 30 million ha of croplands globally were located in areas that are expected to be urbanized by 2030, representing a total cropland loss of around 2 per cent (see Figure 11.3). With the most rapid rates of urban expansion, Africa and Asia are projected to experience 80 per cent of the global cropland loss due to urban area expansion.[97] The impact of these losses is more acute as expansion takes place on prime agricultural lands, much of which is twice as productive as national averages;[98] the United Nations identifies 58 high-fertility countries,[99] 39 of which are in Africa.[100] A 3 per cent loss of these most valuable croplands translates into a 6 per cent production loss in Asia and a 9 per cent drop in Africa.[101]

It is clear that the governance of urban expansion will be critical for securing livelihoods in these agrarian economies, particularly in regard to food distribution networks. On the other hand, by consuming products produced in more efficient agricultural systems, cities can contribute to reducing the total amount of agriculture area.

2. Water use

Although agriculture remains the largest user of water (see Chapter 8), urban water use is increasing due to rising population and per capita usage. Many of these water sources for cities are under threat. Source watersheds for the world's cities cover more than 37 per cent of the ice-free land; 40 per cent of these show moderate to high levels of degradation, which impacts the quality and quantity of water.[103] Furthermore, half of all cities with populations greater than 100,000 are located in water-scarce basins with freshwater sources (rivers, lakes, or aquifers) running dry as more water is extracted than recharged.[104] As a result, an estimated 150 million people currently live in cities with acute water shortages.[105] The situation will likely get worse as the demand for water is projected to outgrow extraction capacity by 40 per cent by 2030; and by 2050, up to one billion urban dwellers could experience water shortages.[106]

The urban water crisis has been ignored for a long time. Urban and agricultural water use planners have paid more attention to accessing additional

Box 11.3: Development of urban water policies[112]

Five generic steps that can be applied in the development of urban water policies:

- **Use of local water supplies**: until they are exhausted. At this point, there is a shift from groundwater to surface water (or vice versa) as initial sources become depleted from combined agricultural and urban use. The construction of reservoirs is important in enabling cities to more fully exploit local surface water supplies.
- **Inter-basin imports of water**: usually a short-term step, as these imports tend to be scrutinized for their environmental and social impacts as well as their cost. As a result, cities turn to water conservation instead of adding new imports.
- **Water conservation**: many cities began conserving water in earnest by the 1980s, with growing attention and investment in water conservation approaches and technologies in recent decades.
- **Water recycling**: particularly recycling and reuse of wastewater or storm-water became a notable contribution to urban water supplies beginning in the 1990s and is expanding rapidly.
- **Desalination**: usually a solution of last resort due to high energy demand compared with other supply options. Desalination only accounts for about 1 per cent of global water consumption, however as cities are faced with limits to water importation and advances in solar power, it is increasingly a more viable option.

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water than they have to conserving and using water more efficiently, which has only recently emerged as an important consideration (see Box 11.3).[108] In contrast to the expected trends in population, urbanization, and GDP, some regions could see economic growth rates decline by as much as 6 per cent of GDP by 2050 as a result of water-related losses.[109] China and India[110] are at the center of the debate on water and urbanization. In China, water resources are becoming increasingly scarce and the quality of the water is seriously affecting the health and livelihoods of the entire nation; despite impressive investments in water infrastructure, policies have not always addressed efficiencies in the long term, or social and environmental conditions.[111]

Many urban centers get their water from surrounding natural areas or have it piped in from watersheds at a considerable distance; land management practices in these areas determine water quality, flow regulation, and in some cases the quantity of water available. In Chapter 8, various management options are described that can help increase the security of urban water supplies, including use of protected areas to maintain healthy functioning watersheds.

3. Transport infrastructure

Rapid urban growth tends to coincide with infrastructure development, particularly for transport networks. In the European Union, motorway kilometers tripled between 1970 and 2000; in India and China, the road network has grown by 4-6 per cent annually over the past decade.[113] In China, for example, 41,000 km of expressways were added to the national transport network and 400,000 km of local and township roads were improved between 1990 and 2005.[114] The global transport sector uses around a quarter of the world's total delivered energy consumption.[115] Transport energy and carbon dioxide emissions have increased by 28 per cent since 2000.[116] Cities influence transport systems both within the city and from peri-urban to urban areas, an intensive resource demand that results in a larger network with impacts on the wider landscape.

Cities can in theory operate highly efficient transport systems that reduce resource use and pollution, however, in reality we see gridlock and catastrophic air pollution occurring throughout the world. Over forty years ago, the philosopher Ivan Illich pointed out that the average speed of an urban car journey in the United States was four miles an hour: the rate of a brisk walk,[117] and in many cities, the speed has slowed even further. Pollution levels from transport are causing a global health crisis: in Delhi and its satellite cities, it is estimated that 7,350-16,200 premature deaths and 6 million asthma attacks occur every year due to particulate pollution, up to a third of which comes from vehicle exhausts.[118] Bad planning decisions quickly make things worse. In South Africa, a policy of building subsidized homes in isolated regions to save money failed to consider how to connect homes to jobs, resulting in residents having to travel by collective taxis, which are expensive and slow due to poor road infrastructure, and cause additional pollution.[119] It should be noted that while outside air quality is higher in rural areas, the use of inefficient and polluting stoves fueled by wood, charcoal, and coal results in damaging levels of indoor air pollution for many rural dwellers.

From a land perspective, the building of major road and rail networks between cities can be even more damaging if routes pass through natural and semi-natural ecosystems, opening these up for rapid and often unplanned development. More than 95 per cent of deforestation, fires, and atmospheric carbon emissions in the Brazilian Amazon occur within 50 km of a road:[120] there are already 22,713 km of state roads and 190,506 km of unofficial roads,[121] including a dense network of private roads spinning off from state roads,[122] known as the "fishbone effect."[123] Over 20 road building projects are taking place in intact forest.[124] Roads like the Belem-Brasilia highway,[125] and the Interoceanic Highway linking Peru and Brazil[126] play a significant role in deforestation[127] and forest degradation, by opening new areas to migrants.[128] Even protected areas are not secure: a planned road through Serengeti National Park in Tanzania would permanently disrupt the world's largest mammal migration and provide open access for poachers.[129] New transport infrastructure to meet the demand of cities also encourages urban sprawl along roadways, further displacing local food production and impacting natural ecosystems. Ensuring that infrastructure policy, planning, and implementation explicitly recognize ecological assets, inside and outside city boundaries, is a key step towards developing sustainable cities.[130]

Global urban land cover in biodiversity hotspots will increase by over 200% between 2000 and 2030.

4. Urban soil sealing

Soil sealing, in an urban context, refers to the covering of soil with impermeable materials, such as concrete, and occurs primarily in urban areas; this not only makes the land unavailable for food production but also undermines most other ecosystem services, particularly water filtration and regulation. Without open soil and vegetation to absorb water, heavy rainfall can quickly lead to flooding,[131] with storm water runoff often contaminated with waste and oily residues.[132] Soil sealing in residential, commercial, and industrial areas reduces soil life,[133] and changes surface albedo (reflection) and heat transfer from evapotranspiration, which can contribute to higher temperatures and increase health problems during heat-waves.[134]

Soil sealing is a global problem: within European cities, it varies between 23-78 per cent,[135] and is regarded as one of the main threats to soil function, with around half of all new urbanized areas within the European Union being sealed.[136] In the Emilia-Romagna region in Italy, it is estimated that from 2003-2008 some 15,000 ha of agricultural land was lost, mainly due to urbanization, equivalent to the crop production potential for feeding 440,000 people.[137] Flood hazards in the region have also increased significantly, particularly from smaller watercourses, necessitating additional investment in flood control.[138]

5. Biodiversity loss

As cities expand, many destroy natural ecosystems while the associated transport and energy infrastructure fragments much of what is left. In 2010, a global meta-analysis of urban land conversion found almost half of the cities studied were within 10 km of a terrestrial protected area; more significantly, the average annual rate of expansion of these cities from 1970 to 2000 was greater than 4.7 per cent.[139] In the United States, urban housing expansion is now considered a major threat to protected areas,[140] with 17 million additional housing units expected to be built within 50 km of protected areas by 2030.[141] Research comparing projected urban expansion against a global list of Alliance for Zero Extinction sites – places where species assessed to be Endangered or Critically Endangered under IUCN Red List criteria are restricted to a single remaining site – found that over a quarter of species in amphibian, mammalian, and reptilian classes will be affected to varying degrees by urban expansion. In total, the habitats of 139 amphibian species, 41 mammalian species, and 25 bird species that are on either the Critically

Box 11.4: Urbanization in biodiversity hotspots

The expansion of urban land area is likely to lead to considerable biodiversity loss, for example:

- Large-scale urbanization in Eastern Afromontane, the Guinean Forests of West Africa, and the Western Ghats and Sri Lanka hotspots could, by 2030, increase urban areas by approximately 1,900 per cent, 920 per cent, and 900 per cent respectively over their 2000 levels, resulting in major biodiversity loss.
- In already diminished and severely fragmented habitats, such as the Mediterranean and the South American Atlantic Forest hotspots, relatively small decreases in habitat can cause extinction rates to rise disproportionately.
- The five biodiversity hotspots with the largest percentages of their land areas expected to become urban are predominantly coastal regions or are islands, which are especially important for endemic species.[144]

Endangered or Endangered Lists of IUCN could either be encroached on or devastated as a result of urbanization.[142]

Urban expansion disproportionately damages wetlands, which tend to be in-filled, drained, or polluted, thus reducing their capacity to regulate water quantity and quality, and buffer against extreme weather events. Wetlands around Harare, Zimbabwe are the water source for half the country's population and responsible for recharging the water table, filtering and purifying water, preventing siltation and flooding, and providing a valuable carbon sink; they are also an important bird sanctuary. However, pressure on these wetlands, from conversion, informal agriculture, fertilizer pollution, and commercial borehole use, has led to an average annual fall in the water table of 15-30 meters over the past 15 years.[143]

The harvesting of fuelwood (usually converted to charcoal) for developing country cities significantly impacts the health of surrounding areas, causing forest degradation and sometimes deforestation. Poverty and the lack of access to alternative energy sources keep many city dwellers dependent on fuelwood. Much of this wood comes from peri-urban and forested areas near cities. Without effective management and regulation, forest degradation and deforestation spread out from urban centers as populations grow with fuel supply chains that are often informal, fragmentary, and illegal.

For example, wood and charcoal accounts for over 80 per cent of household fuel use in Africa, that is over 90 per cent of harvested wood, making it the largest cause of forest degradation in Africa.[146] Around Dar es Salaam, Tanzania, the radius of logging expanded 120 km in 14 years; a deforestation front that started with high quality trees and finally woody biomass for charcoal.[147] Population growth or a sudden influx of migrants leads to rapid increases in fuelwood use as in the case of Abéché, Chad. Kinshasa and Abuja which are experiencing huge increases in urban populations due to conflicts and rural poverty, leading to more rapid deforestation.[148]

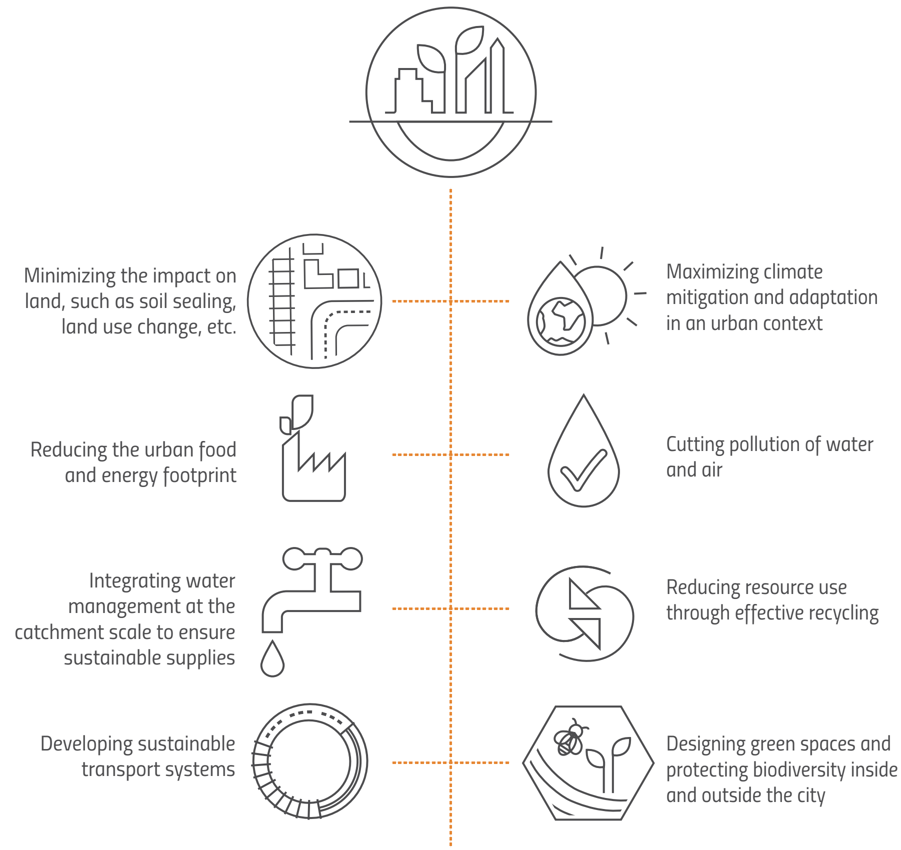
The unsustainable use of fuelwood is not only bad for forests. In 2010, household air pollution from solid biomass caused more deaths than malaria, and the death rate is projected to continue rising.[149] Where the standard of living allows, city dwellers switch to charcoal, which is cleaner at the point of consumption but requires more wood and releases a range of pollutants during production.

6. Climate change

Cities affect the climate both locally and globally, and are, in turn, impacted by climate change. Urban areas alter local climate through the modification of surface albedo and evapotranspiration, and increased aerosols and anthropogenic heat sources, resulting in elevated temperatures[150] and changes in local precipitation patterns.[151,152] Cities are generally warmer than the surrounding rural areas, a phenomenon known as the "urban heat island"; these differences are even greater during heat waves, increasing discomfort and health risks.[153] Cities contribute to global climate change by emitting greenhouse gases from heating, cooling, transportation, and industry. If the complete urban footprint is taken into account, cities are estimated to be responsible for 60–80 per cent of all resource consumption and energy use, and approximately half of global anthropogenic carbon dioxide emissions; they also play a major role in ecosystem degradation.[154] Analysis suggests that urban per capita emissions themselves are often lower than the average for the countries in which they are located.[155] Conversely, urban populations in developing countries tend to generate higher greenhouse gas emissions per capita than surrounding rural populations due to the intensive use of biomass and fossil fuels.[156]

Cities are increasingly vulnerable to climate change risks as they grow, particularly if growth is ad-hoc or unplanned. With land at a premium, many

Figure 11.4: Building sustainable cities



poorer city dwellers settle in sub-optimal conditions such as on flood plains, low-lying coastal regions, by rivers, on steep slopes, and in places with little natural shade or vegetation; while wealthier people can afford to take steps to address climate change impacts such as fortifying and insulating houses, improving storm drains, and other disaster-preparedness measures. Hundreds of millions of urban dwellers have no all-weather roads, no piped water, drains, sewage systems, or electricity, and live in poorly constructed homes on illegally occupied or sub-divided land, with few opportunities for climate-proofing.[157] Climate change will likely bring more floods, droughts, heat waves, and sea-level rise.[158] Emerging coastal cities will have greater areas exposed to flooding: projections for 53 African cities estimated that an additional 11.6 million people will be exposed to storm surges by 2100.[159] Other estimates suggest that 16 million people per year will be subject to floods by 2100, with 10 million forced to migrate.[160]

BUILDING SUSTAINABLE CITIES

"Sustainable urbanization requires that cities generate better income and employment opportunities, expand the necessary infrastructure for water and sanitation, energy, transportation, information and communications; ensure equal access to services; reduce the number of people living in slums; and preserve the natural assets within the city and surrounding areas."[161]

Sustainable Development Goal 11 aims to "*make cities and human settlements inclusive, safe, resilient and sustainable*" while target 11.6 strives to "*reduce the adverse per capita environmental impact of cities.*

"The New Urban Agenda adopted at Habitat III states that "*We envisage cities and human settlements that: … protect, conserve, restore, and promote their ecosystems, water, natural habitats, and biodiversity, minimize their environmental impact, and change to sustainable consumption and production patterns.*"[162]

Distinguishing between urban and rural planning no longer makes sense given the extent to which the two are interconnected; sustainable approaches to managing cities must take into account urban areas as well as rural lands, communities, and the ecosystems that they depend on.[163] Making cities sustainable is possible but long-term planning based on environmental criteria is often unpopular. The World Bank notes that countries facing severe financing constraints may need to choose between "building right" (which may make both economic and environmental sense) and "building more" (which may be what is required socially).[164] Among the steps needed to achieve sustainable cities are:

- **Minimizing the impact on land**, such as soil sealing, land use change, etc.
- **Reducing the urban food and energy footprint**
- **Integrating water management** at the catchment scale to ensure sustainable supplies
- **Developing sustainable transport systems**
- **Maximizing climate mitigation and adaptation** in an urban context
- **Cutting pollution** of water and air
- **Reducing resource use through effective recycling**
- **Designing green spaces and protecting biodiversity** inside and outside the city

1. Minimizing the impact on land

Urbanization can help take pressure off natural and semi-natural ecosystems, but only if sprawl is limited and the rural-urban interface is carefully managed. Compact, well-ordered cities minimize their impacts on surrounding areas by reducing the demand for land-based goods and services. For example, in Singapore planned densities vary by location, use, and infrastructure availability, with higher densities encouraged near metro stations.[165] High-density urban communities also have lower per capita energy use and greenhouse gas emissions than low-density suburban development; transport and heating costs also decline.[166] Philadelphia has developed a green infrastructure plan that will convert 34 per cent of existing impermeable surfaces to "greened acres" by 2036.[167]

Regenerating and redesigning cities rather than expanding into productive agricultural land and natural ecosystems will reduce soil sealing and land use change. Effective urban planning provides opportunities for sustainable economic growth. In the UK, London spent USD 13.4 billion on the Olympics site, turning a dilapidated area into a recreational, entertainment, and commercial center with housing for 8,000 families.[168]

Although close to half of the world's urban dwellers live in relatively small settlements of less than 500,000 inhabitants,[169] the role of small- and medium-sized cities and their contribution to national economies is often overlooked.[170] Ensuring that these smaller cities adopt a sustainable development trajectory from the outset will prevent them from encountering many of the problems faced by the world's bigger cities.[171] Such initiatives are urgently needed as many of these cities are on the cusp of rapid expansion.[172]

2. Reducing the urban food and energy footprint

Cities can provide both positive and negative models for sustainable food production. Tightly-packed communities offer economies of scale and can in theory minimize waste. But if badly planned, food waste and the food footprint can actually increase under urbanization. Strong policies and careful planning are critical to success.

While cities rely on food grown in other places, there are untapped opportunities to maximize efficiencies once food is inside the city. Promoting urban and peri-urban agriculture and maximizing relatively local food production increases nutrition and food security, preserves regional foods, reduces food miles, and helps limit urban sprawl. Cities like Bujumbura in Burundi are including horticulture in the urban master plan.[173] Sustainable food production around cities brings a range of other ecosystem services in addition to food. However, local producers sometimes find it hard to compete economically against larger and more distant farming operations, and sometimes need a measure of support to survive. A global meta-analysis of current urban land conversion noted that the presence of farm subsidies in these areas drives down the average annual urban expansion rate by 2.43 per cent.[174] Farmers are often reluctant to invest in agricultural conservation measures – even with the prospects of productivity increases and reduced water costs – because the associated cost–benefit ratios and payback periods are insufficient. Cities can help tip this balance.[175]

Cities provide opportunities for reducing overall energy use through sharing and optimizing energy and reducing waste with initiatives such as the development of district heating schemes, incorporating energy saving measures into new buildings, and installing energy generating devices including solar panels and electric cells. Smart grids – electricity grids that harmonize supply and demand – offer further savings, combining greater connections within and between countries, drawing on rapidly advancing storage technology,

Figure 11.5
The major elements and flows of a water fund:
Redrawn from[180]

and managing demand flexibility.[176] New technology can connect individual producers and consumers without a centralized utility, making use of surplus energy easier and more efficient.[177] Improvements in storage and efficiency offer new possibilities such as the use of direct current in appliances and photovoltaic cells.[178] Natural solutions, such as urban tree planting, can help reduce household air conditioning bills,[179] along with many other benefits. Water funds183 have been developed over the last 15 years to promote a healthy urban-rural interface. The aim is to bring water users together collectively to invest in upstream habitat protection and land management, and mobilize innovative sources of funding. The major elements and flows of a water fund are illustrated in Figure 11.5.

3. Integrating water management

Maintaining a good flow of clean water is perhaps the most promising opportunity by which city authorities can work together closely and synergistically with neighboring rural communities. Such developments could be integrated with effective sanitation systems within cities. A municipal council or water company that provides incentives to rural communities for protecting and restoring watersheds creates a win-win strategy where cities get cost-effective water supplies and rural incomes rise. It is estimated that one in six major cities worldwide (e.g., roughly 690 cities with more than 433 million people) have the potential to fully offset these conservation costs through water treatment savings alone.[180] Such initiatives can be further strengthened by steps to reduce water usage and waste through education and water pricing policies.[181]

One of the most well-known examples is the package of policies and financial support that links New York City's water system with the management of the three watersheds that supply water to the city. By working with private landowners to promote healthy watersheds, New York has secured the largest unfiltered water supply in the United States, saving the city more than USD 300 million annually on water treatment and maintenance costs.[182]

4. Developing sustainable transport systems

Because they are compact, cities are places where, with good planning and strategic investments, the transport footprint can be minimized through traffic reduction measures, bicycle lanes, mass transit, pedestrian walkways, and financial incentives, such as taxes on private vehicles or subsidies for public transport. Designing more compact cities would reduce urban transport costs.[184] These changes are as much about culture as technical knowledge or policy models: for instance, cities like Amsterdam and Cambridge have long placed an emphasis on cycling, whereas in Toronto a mayor was voted into office partly on a promise to remove bicycle lanes following opposition from car drivers.

The practical problems of commuting by car are creating a gradual change in attitudes. Bangkok and Delhi had both reached virtual gridlock until the opening of their metro systems. Some analysts are already predicting that the world has reached a peak in per capita car use and urban rail patronage and urban rail services are now on the rise, even in the traditionally car dependent cities of North America and Australia.[185] Cheap public transport systems and the use of new technologies are changing attitudes to urban transport. An OECD study that modeled the use of self-driving cars in Lisbon found that shared autonomous vehicles could reduce the number of cars needed by 80-90 per cent. The reduction in cars will also free up urban space: up to a quarter of the area of some American cities are devoted to parking.[186]

5. Maximizing climate mitigation and adaptation

Compact urban development, coupled with high residential and employment densities, can reduce energy consumption, vehicle miles traveled, and carbon dioxide emissions.[187] The city of Dongtan, near Shanghai, seeks to become the world's first purpose-built eco-city complete with sustainable transportation, efficient water systems, green spaces, and the overall goal of being carbon neutral. Once completed, the city is expected to consume 64 per cent less energy when compared to a similar modern city of its size.[188]

Redirecting investment from carbon-intensive industries to climate-smart solutions, such as renewable energy and micro grids, is an important way in which the financial sector can support sustainable cities. This requires a sophisticated understanding of carbon risk, and an appetite to seek out the most appropriate renewable and low carbon investment opportunities. Investments of this type are being promoted by international bodies such as the OECD, IMF, and World Bank.[189]

Cities will also rely on ecosystem services in surrounding areas to enhance adaptation to climate change.[190] For instance, shoreline mangroves can help to buffer coastal cities against increased storm events;[191] well-managed dryland vegetation minimizes dust storms and dune formation;[192] and forests on steep slopes stabilize snow and soil.[193] Within the city itself, numerous options exist for utilizing ecosystems services, such as increasing natural or green areas to absorb excess rain[194] and planting trees for shading.[195]

6. Cutting pollution

Air and water pollution from our cities is having terrible impacts on human health. But experience shows that many of these can be reversed; rivers in Europe are far cleaner than they were a few decades ago and many are seeing aquatic life return. The quality of drinking water is often higher than in rural populated areas. Land management is critical to water management: four out of five cities could reduce sediment or nutrient pollution by a meaningful amount (at least 10 per cent) through forest protection, pastureland reforestation, and agricultural best management practices. This could lead potentially to an extra 10 Gt per year of carbon dioxide mitigation.[196]

7. Reuse and recycling

Recycling provides important social and environmental benefits that reduce pressure on land-based production activities and their impacts. Recycling just three metals – ferrous, aluminum, and copper – yields an annual savings of 572 million tons of carbon dioxide when compared with extracting and processing new metals.[197] Recycling plastics reduces the enormous pollution load that they create: an estimated 250,000 tons of plastics are now found in the world's oceans.[198] Cities also have the opportunity to implement proven and cost-effective strategies for recycling and re-use. Recycling has three major drivers: (i) an economic incentive (often among the poorest in society); (ii) a voluntary element such as the separation of waste or visits to local recycling centers, primarily learned behavior, and (iii) laws and policies that strongly encourage recycling. While the recycling market is complicated and the value of materials is chronically unstable, recycling continues to grow around the world. Roughly 4 Gt of waste material is recycled every year around the world,[199] still a miniscule proportion of the potential.

8. Maximizing green spaces and protecting biodiversity

As described in Chapter 9, cities can address biodiversity losses by reducing their impact on the wider landscape. Urban areas can also engage with nature more directly by creating green spaces. The existence of trees, parks, and gardens is not incompatible with compact cities, and indeed integral to some of the world's most densely populated urban areas. Trees have multiple benefits such as reducing water runoff and CO_2 emissions, providing air purification and aesthetic values while improving the quality of life in overcrowded areas. In Lisbon, Portugal, the combined benefits associated with street trees, including cleaner air, energy savings, increased property values, and carbon dioxide reduction, amount to USD 4.48 per USD 1 invested.[200]

Some cities are going further and prioritizing green spaces in their designs for expansion. Singapore promotes its green image with green infrastructure plans as one of the key reasons that it continues to attract large amounts of investment.[201] South Africa has identified nine key areas in its green economy programme including increased recycling, urban farming, and non-market interventions to avoid urban sprawl.[202] At the city level, this is matched by interventions like the Green Goal Action Plan for the 2010 World Cup in Cape Town, and plans to redesign Johannesburg to reduce greenhouse gas emissions from transport.[203]

In addition to parks and green spaces within urban areas, peri-urban green spaces may play a key role in environmental protection (e.g., watersheds), recreational activities, and the protection of local biodiversity; sometimes with comparatively lower opportunity costs by virtue of being located in areas of steep slopes or frequently flooded terrains.

CONCLUSION

Cities are and will likely continue to be drivers of economic growth, requiring large public investments. They will also continue to have impacts on land resources and associated ecosystem services that make up the natural infrastructure on which they depend.[204] It is projected that 65 per cent of all urban land area in 2030 will have been urbanized in the first three decades of the 21st century.[205] Urban development decisions are long-term and hard to reverse. Policies to ensure sustainable urbanization are urgently needed given the current trends.

The growth in the importance and extent of cities is transforming our approach to governance. As economic activities become more dispersed as a result of privatization, deregulation, and increasing globalization, new strategic alliances among cities are being formed as a green alternative to traditional national territories.[206] Greater collaboration between cities in sharing best practices will be vital for developing sustainability. Some cities are already engaging in cooperative partnerships and beginning to take a more active role in resource management and impacts on the regional or even global scale. For example, city responses to GHG emissions include the C40 Cities Climate Leadership Group and the World Mayor's Council on Climate Change.[207]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Part Two

CHAPTER 12

DRYLANDS

Drylands cover 41 per cent of the land surface, produce 44 per cent of the crops, and contain over 2 billion people and half of the world's livestock. Drylands are often regions of water scarcity yet with immensely rich biodiversity, including some of the most iconic species. They are also home to a diverse human culture including some of the world's largest cities.

Rural communities in drylands are often poorer than elsewhere and the land is more vulnerable to degradation from climate change and direct human pressures. Poor management can lead to desertification. We know how to manage drylands sustainably, but often do not achieve this in practice; policies and agricultural systems need to be transformed if we are to avoid the continued loss of health and productivity in the drylands.

INTRODUCTION

Drylands cover approximately 41 per cent of all land.[1] They are used most commonly for livestock production, and rangelands cover three-quarters of the drylands, while nearly 20 per cent are used for rain-fed and irrigated farming. Drylands include some of the most productive areas on the planet, but also some of the most fragile, where minor alterations in conditions can result in dramatic changes in ecology and subsequently in human well-being. Today, drylands face increasingly acute threats from the over-use of resources, poor management, and a changing climate. Dryland degradation costs developing countries an estimated 4-8 per cent of their national domestic product each year.[2] Understanding drylands is critical to achieving their long-term sustainable management. Here some key biophysical and social characteristics of dryland landscapes are summarized, including:

- **Water scarcity and unpredictability**
- **Specialized soil life adapted to dry and extreme conditions**
- **Underlying role of fire in shaping many dryland ecosystems**
- **Adaptive capacity of species and ecological interactions in arid regions**
- **Social and cultural adaptation to living in the drylands**
- **Vulnerability to climate change**

1. Water scarcity and unpredictability

Drylands are arid, semi-arid, and dry, sub-humid areas[3] that receive less precipitation than the evaporative demand, and plant production is thus water limited for at least a substantial part of the year. Water scarcity has shaped dryland ecosystems, their biodiversity, and human cultures.[4] The distinction between drylands and deserts is complex with hyper-arid deserts generally excluded from the definition of drylands; slight changes in the management of drylands can result in desert formation (desertification).

Dryland characteristics are also influenced by the extreme unpredictability in rainfall. As the climate gets drier, weather patterns tend to become more uncertain with high variability from one year to the next. Rainfall data over a 30 year period from the Zarqa Basin in Jordan's Baadia region shows a mean precipitation of approximately 270 mm per year with a low of 50 mm in the driest years and a high of 600 mm in the wettest.[5] This 12-fold difference between the low and high is not uncommon in drylands. Such variability in humid climates would cause severe ecological stress but in the drylands it has been accommodated over time by various species adaptations, including opportunistic behavior to take advantage of moisture as and when it is available

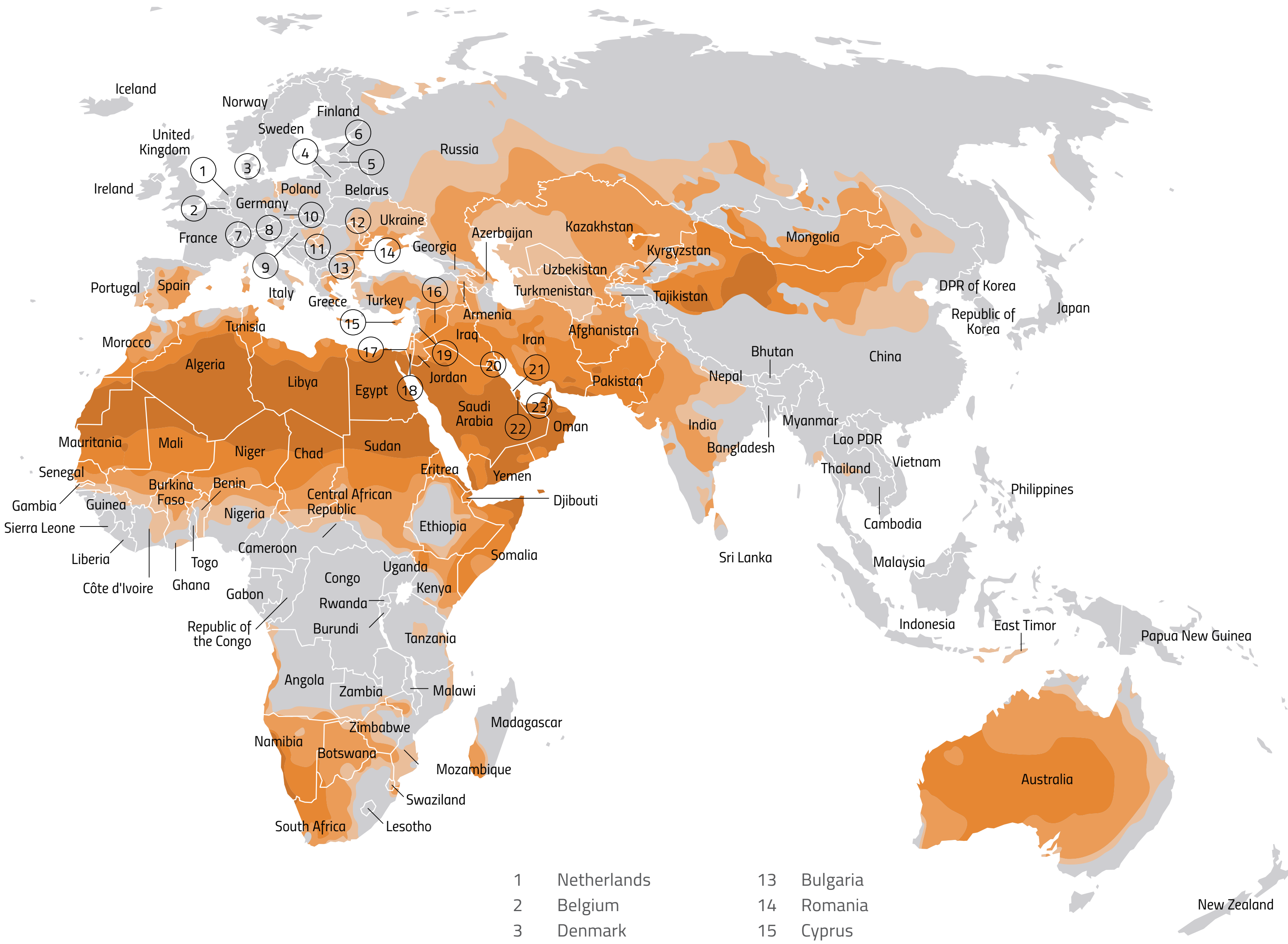
Box 12.1: Defining the drylands

Drylands are defined in various ways, even within the United Nations. Here the Aridity Index (AI) is used: annual average precipitation/potential evapotranspiration. Between 0.5<AI<0.65, drylands are classified as dry, sub-humid, and often naturally dominated by broad-leaved savannah woodlands, sometimes with quite dense tree canopies, or by perennial grasses. Dry, sub-humid lands make up 18 per cent of the world's land surface while semi-arid areas (0.2<AI<0.5) account for 20 per cent of the land surface with their potential evapotranspiration between 2 and 5 times greater than mean precipitation. Arid lands (0.05<AI<0.2), about 7 per cent of land, have at least 20 times greater potential loss to evapotranspiration than actual mean precipitation and support minimal vegetation.[6,7] Using these definitions, drylands cover between 39-45 per cent of the planet's land surface.

Figure 12.1: World map of the drylands[8]

Key

- Dry sub-humid areas
- Semi-arid areas
- Arid areas
- Hyper-arid areas



1 Netherlands
2 Belgium
3 Denmark
4 Lithuania
5 Latvia
6 Estonia
7 Switzerland
8 Austria
9 Hungary
10 Czech Republic
11 Serbia
12 Moldova
13 Bulgaria
14 Romania
15 Cyprus
16 Syria
17 Palestinian Territories
18 Israel
19 Lebanon
20 Kuwait
21 Bahrain
22 Qatar
23 United Arab Emirates

2. Specialized soil life

Dryland soil ecosystems and their species have developed specialized interactions in response to the harsh conditions. In savannas, for example, termites play a vital role in recycling organic matter and maintaining soil porosity, particularly in the driest and most nutrient-poor soils. In many drylands, vegetation grows more vigorously and is more drought resistant around termite mounds.[9] Bacteria in the guts of large herbivores play a similar role in maintaining soil fertility, digesting vegetation and accelerating the process of nutrient cycling; this inter-dependence between larger animals, insects, and grasslands is responsible for some of the world's most cherished landscapes, like the Serengeti in Tanzania and the Asian Steppe.

At the same time, dryland soils face a range of important management challenges that are characteristic of or amplified by dry conditions, including crusting and compaction, restricted soil drainage, wind and water erosion, low fertility, and soils that are shallow, stony, saline, or sodic.[10]

3. Underlying role of fire

Natural fires are another defining feature of many drylands. Natural fire regimes have driven many ecological adaptations to the extent that suppression or changes in fire regimes can lead to significant and often harmful ecological change. Some dryland plants rely on fire for growth or reproduction, including many grasses which recover more rapidly than shrubs after fire events, or species that require heat to germinate their seeds. Where fire is restricted, it can lead to a medium-term increase in woody biomass,[11] often at a cost to ecosystem productivity and overall biodiversity. Restrictions can also produce a large fuel-load that can ultimately result in more severe and ecologically harmful fires and invasion by alien species.[12]

Fire is frequently used as a management tool in dryland production systems, for example, to encourage fresh growth of pastures or to remove brush that can harbor parasites. In parts of East Africa, efforts to suppress traditional practices of fire management have led to extensive bush-encroachment and the return of the disease-bearing tsetse fly which have rendered large areas of grassland inaccessible to domestic herds.[13] On the other hand, the continuous use of fire can change nutrient availability and species composition,[14] making fire management one of the critical tasks for maintaining healthy drylands in many regions.

4. Adaptive capacity of species and ecological interactions

Dryland biodiversity is often relatively low, although there are exceptions like the succulent karoo in southern Africa. Furthermore, recent surveys in apparently species-poor drylands (e.g., in the Sahara)[15] find higher levels of endemism and diversity than once thought. Species develop physiological[16] and behavioral[17] strategies to cope with dramatic variations in temperature, drought, and fires. Four main categories of adaptation are recognized: drought escapers (species that migrate in search of water and vegetation), evaders (deep-rooting plants), resistors (cacti that store water), and endurers (frogs that go dormant during drought periods). For example, some plants have evolved the capacity to store water in roots or leaves, to root deeply in search of water, or to lie dormant through the drought season. Similarly, some dryland animals minimize water loss through physiological adaptations; some aestivate (undergo prolonged dormancy) during the driest season while others migrate to more humid regions.[18] The huge herds of grazing animals on the Serengeti plains will run towards distant lightning as rainstorms stimulate plant growth. Research provides empirical evidence that intact dryland biodiversity supports ecosystem function[19] and plant diversity increases multi-functionality in drylands.[20] Biological soil crusts, consisting variously of cyanobacteria, fungi, lichens, and mosses, are the dominant ground cover over large areas and play an important but still poorly understood role in the ecology of dryland environments.[21]

Much dryland biodiversity is highly threatened. Two large species of dryland mammals are now extinct in the wild: the Sahara oryx (*Oryx dammah*) and milu deer (*Elaphurus davidianus*) although the latter has now been re-introduced in China. Seventy more species of dryland mammals, birds, reptiles, and amphibians are listed as critically endangered by the IUCN.[22] Cacti, the most quintessential of dryland plants, are among the most threatened taxonomic plant groups with almost a third of the species under threat, and their decline linked to growing human pressure.[23]

Box12.2: Cactus species at unusual risk of extinction

Cacti are among the most threatened plant taxonomic groups assessed to date, with 31 per cent of 1,478 evaluated species considered to be under threat of extinction, demonstrating the high pressures on biodiversity in arid lands. Both the distribution of threatened species and the drivers of extinction are different from those found in other plant groups and in animals. The most significant threats come from dryland conversion to agriculture and aquaculture, their collection as biological resources for commercial markets, and residential and commercial development. The dominant drivers of extinction risk are the illegal and unsustainable collection of live plants and seeds for horticultural trade and private ornamental collections, along with eradication by smallholder livestock ranching and agriculture.[24]

5. Social and cultural adaptation

Human societies that have thrived in the drylands for centuries are usually highly adapted to the twin challenges of water scarcity and climatic uncertainty. Clothing, building design, and lifestyle strategies are all designed to minimize the difficulties of living in conditions of water scarcity. Farming and pastoralist adaptations to drylands include strategies such as planting drought-resistant crops or practicing water harvesting and selective irrigation. When necessary, individuals or communities undertake regular nomadic movements or occasional migrations in response to short-term weather patterns or long-term climatic shifts.

Bedouin pastoralists in Jordan have traditionally used herd mobility to track resources across the landscape, taking advantage of different resource patches according to the prevailing weather, and using opportunistic strategies to capitalize on the most productive years.[25] The Sukuma people in Tanzania set aside areas (*ngitili*) for private or communal grazing or fodder reserves to see them through dry periods.[26] The *hima* system in the Arabian Peninsula, now largely abandoned, is one of the oldest forms of "protected areas" in the world, established to halt and reverse land degradation.[27] Dryland farming practices include agroforestry and land fallows that conserve both soil moisture and fertility, practices that are for example increasingly being adopted in India.[28] Many studies show how agroforestry creates micro-climatic variation within fields and farms, in otherwise vast and relatively homogeneous landscapes, that enhance biodiversity and can help buffer against climate risks.[29]

While humans and other species have developed survival strategies in the face of the most challenging conditions in the drylands, these lifestyles are vulnerable to change and deterioration. Traditional sustainable management practices are declining due to a mix of social, cultural, and demographic changes, increasing competition for land resources, and sometimes a lack of legal or formal access to land.

Box 12.3: Pastoralists in dryland Uganda

It is June in Moroto, a dryland district in northeastern Uganda, and it is the peak of the rainy season. Agro-pastoralists from the Karimojong ethnic group have planted sorghum crops in fields near their homesteads and the young men have moved westwards with their herds of cattle, sheep, and goats to graze seasonal pastures. During the rainy season the distant pastures briefly provide the most nutritious fodder of the year and can be accessed due to the presence of surface water along the migratory routes. The Karimojong rely on locally-adapted, drought and disease-resistant varieties of sorghum. They herd equally well-adapted livestock over large distances to take advantage of unpredictable and patchy grasslands. Rainfall here reaches over 800 mm per year on average; higher than London (750 mm) or Paris (600 mm). However, it is not the level of rainfall that determines the drylands but the potential of the land to lose water through evaporation and transpiration. Moroto's average annual temperature of 22°C means that evapotranspiration rates are high and the region is classified as semi-arid. Since water is the source of life, the capacity of dryland ecosystems to minimize evapotranspiration (i.e., capture and store water) determines how they function.[30]

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6. Vulnerability to climate change

The increase in the number and severity of climate events will make drylands more vulnerable to ecosystem changes and land degradation. Between 1951 and 2010, a small increase in drought frequency, duration, and severity was observed, especially in Africa, while drought frequency decreased in the Northern Hemisphere.[31] Unlike other extreme events, droughts develop slowly over large areas.[32] Their impacts cascade through the hydrological cycle, affecting soil moisture, reservoirs, river flows, and groundwater. Ultimately, droughts impact all sectors of society and the natural environment (e.g., wildlife habitats) over varying timeframes.

Climate change is likely to lead to more water scarcity and reduced crop yields in drylands. Climate change is a significant driver of land degradation and scientists predict that drylands will expand considerably by 2100.[33] Many traditional land management practices increase resilience to climate change and adaptation strategies in the drylands can be transferred to other regions experiencing increased aridity.

THE VALUE OF DRYLANDS

Although the term "drylands" evokes an image of scarcity and harsh conditions, these areas provide a wide range of important benefits to society, including cultural identity, and habitat for important wild plant and animal species. Few people doubt the importance of biodiversity in the world's savannas or the value of fine fibers like cashmere and alpaca wool produced in dry grasslands.

There has been a tendency to dismiss drylands as unworthy of investment and to categorize them as low productivity lands. Several countries have even legally classified them as "wastelands." However, research and field trials in India and China demonstrate that apparently low value drylands can yield high returns. A combination of agricultural reforms and investment in research, education, roads, and electricity in China has stimulated growth in the non-farm rural sector, which in turn supported agricultural development and job creation for urban migrants.[34] Similarly, in India, rural non-farm employment grew and poverty declined in response to dryland infrastructure investments, especially so in places where literacy rates were increased.[35] Five key dryland values are:

- **Food** from wild species, crops, and livestock
- **Water resources** including some of the world's most important watersheds
- **Homeland** for many indigenous people, local communities, and more recent settlers
- **Cultural values** to society
- **Other ecosystem services** from drylands

1. Food

The drylands support about 2 billion people.[36] An estimated 44 per cent of croplands and 50 per cent of livestock worldwide are found in the drylands.[37] Shrublands and grasslands support extensive livestock production which often overlaps with croplands, forests, and woodlands in the drylands. In dryland countries like Afghanistan, Burkina Faso, and Sudan, agriculture generates almost a third of GDP. In Mali, Kenya, Ethiopia, and numerous other African countries with extensive drylands, the livestock sector provides over 10 per cent of GDP; in Kyrgyzstan and Mongolia, the figure is closer to 20 per cent.[38] Drylands can also supply subsistence and wild harvested foodstuffs, a safety net for communities to survive lean periods or drought: these so-called "famine foods" are often the only source of nutrition available when times are hard.[39]

2. Water resources

Drylands include globally important watersheds that supply clean water to millions of people. Over one third of the world's major river basins have at least half their extent in the drylands, and many have their sources upstream in areas with greater precipitation.[40,41] In these areas, river systems that collect and channel water are of critical importance to human survival and require careful management. However, many of these dryland water resources are under pressure. The Yangtze River, the longest in Asia, begins in the high-altitude drylands of the Tibetan Plateau, supplying water for irrigation, sanitation, transport, and industry; and now to the world's largest hydro-electric power station, the Three Gorges Dam. The Yangtze Delta generates around one-fifth of China's GDP,[42] yet the river is increasingly polluted and silted with soil from poorly managed land upstream, reducing water quality, and intensifying flooding.[43]

3. Homeland

Drylands are home to about one-third of humanity.[44] The vast majority – some 90 per cent – of the dryland population lives in developing countries.[45] Their livelihoods vary from the very traditional to the ultra-modern: rural communities directly or indirectly manage land and are intimately connected with its ecology, while urban dwellers live in megacities like Los Angeles, Cairo, and Karachi. Although it is common to think of people living in drylands as being highly attuned to their environment, modern city dwellers are largely insulated and unaware of their ecological footprint. Yet the way in which drylands are managed directly affects these urban centers and their inhabitants. Land degradation and desertification can compromise the safe and regular supply of clean water and air, food and fuel as well as opportunities for recreation and eco-tourism.

4. Cultural values

Dryland communities embrace an astonishing array of cultures, from the San people of the Kalahari to the glitz of Las Vegas. Many ancient religious traditions are rooted deep within drylands. The three great monotheistic faiths of Judaism, Christianity, and Islam developed there and are still in evidence with mud-built mosques in Mali, Christian monasteries in Armenia, and Jerusalem itself a desert city. Other faiths have been influenced by their place in the drylands, such as Hindu and Jain temples in Rajasthan and Buddhist temples in Ladakh. Many smaller faith groups are also found in drylands. In southern Madagascar, the Mahafaly and Tandroy communities are working with local authorities and the government to conserve the sacred forests of Sakoantovo and Vohimasio, part of the dry spiny forests that have exceptional biodiversity value.[46]

Traditional desert cultures are often nomadic, frequently moving in a regular pattern for water and grazing. Nomadic people still roam in Central Asia, sub-Saharan Africa, and the Middle East, in many cases in spite of government efforts to settle them. The nomadic spirit is deeply ingrained in modern culture: for example, businessmen in Kuwait City still take to their tents in the spring. The drylands preserve some of the oldest libraries in the world, as in Timbuktu, and an array of coveted arts, handicrafts, and jewelry. In the 21st century, dryland cultures are continuing to expand and renew themselves, with cultural celebrations such as the Sahara's nomadic Tuareg people and their annual Festival in the Desert.

Box 12.4: Cultural and physical impacts of desertification in Jordan

The Bedouin inhabitants of Jordan's Baadia experience lower agricultural productivity, biodiversity loss, and the decline in water supplies as a result of desertification. Vegetation in the Baadia has declined by half since the 1990s, directly impacting livestock production and contributing to a decline in biodiversity, including risks to 49 medicinal plant species that have significant market value, particularly for women. Desertification has led to declines in water infiltration, which is felt not only by the Bedouin but also by downstream consumers, including a large part of Jordan's industrial sector. There are other external costs of desertification in the Baadia, such as the sedimentation of dams that supply power, the release of greenhouse gases, and loss of the capacity of soil to store carbon.[47]

5. Other ecosystem services

Food and water are not the only values that drylands provide to society.[48] Natural vegetation and organic crusts are important and cost-effective stabilizing features in controlling erosion, sand and dust storms,[49] and desertification. Similarly, drylands play an important role in mitigating climate change through carbon storage in soils.[50] Despite arid areas having low plant biomass, and hence relatively low organic carbon in vegetation and soil, inorganic soil carbon increases as aridity increases. Dryland soil organic reserves represent 27 per cent of the global total.[51] Dryland forests and woodlands also contribute to national economies through the provision of fuel, timber, and non-timber forest products, and indirectly through watershed protection and other ecosystem services.[52] The extent of forests in the drylands has until now been underestimated by 40-47 per cent; these additional 467 million hectares increase current estimates of global forest cover by at least 9 per cent.[53] Drylands also contain unique and globally important biodiversity,[54] including the source plants (crop wild relatives) of many of our most important crops, such as wheat, barley, coffee, olives, and many fruit trees.[55]

LAND DEGRADATION AND DESERTIFICATION IN THE WORLD'S DRYLANDS

Because of the fragile conditions, land degradation in the drylands is both more serious and harder to reverse, and can progress in some cases into desertification, dune formation, and ecological collapse. History and literature provide many examples of environmental mismanagement in the drylands, which contributed to events ranging from the collapse of the Mayan Civilization a millennium ago[56] to the American Dust Bowl in the 1930s as described in John Steinbeck's *Grapes of Wrath*.[57] Yet these lessons are largely ignored and dryland degradation continues at a rapid pace; indeed it is such a major environmental concern that a global agreement has been established to halt and reverse it: the United Nations Convention to Combat Desertification (UNCCD).[58] Desertification has been described by UNCCD as one of the greatest environmental challenges of our time and a threat to global wellbeing and human security.[59] A growing number of countries, particularly in the developing

Box 12.5: Desertification

Desertification is a complex phenomenon with still much uncertainty about definitions, causes, and extent. According to the text of UNCCD (1994)[60], **"desertification" means land degradation in arid, semi-arid, and dry sub-humid areas** resulting from various factors, including climatic variations and human activities. Combating desertification includes activities that are part of integrated sustainable development, aimed at the:

1. prevention and/or reduction of land degradation;
2. rehabilitation of partly degraded land; and
3. reclamation of desertified land.

world, are expressing their concerns about the closely-related challenges of desertification, land degradation, and drought and their impacts on migration, conflict, and overall human security.

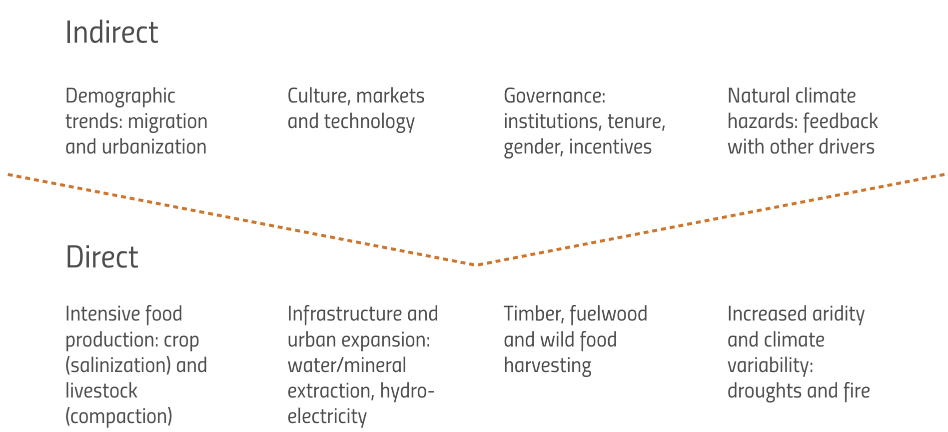
Estimates of the extent of land degradation in the drylands differ considerably, although figures are converging on moderate to severe degradation in 25-33 per cent of all land,[61] with perhaps a higher incidence in the drylands. The absence of a standard global assessment and monitoring system[62] contributes to this variance and leads to a divergent understanding of land degradation and widely differing range of estimates.[63] A study in 2007 estimated that there was severe degradation on approximately 10-20 per cent of drylands.[64] A more recent analysis of 25 year trends, using remote sensing to measure inter-annual vegetation, found land degradation hotspots covering about 29 per cent of global land area, with dryland-dominated biomes affected to an above-average extent.[65]

Causes of desertification

Many inter-related factors contribute to desertification, including population growth, demands for greater levels of production, technologies that increase resource exploitation, and climate change. An analysis in China found that a combination of socio-economic factors and to a lesser extent climate were the main drivers of desertification in drylands, but the relationship between various factors is complicated and varies between regions.[66] Major influences on dryland health and productivity include climate, fire regime, grazing, agriculture, and atmospheric carbon dioxide levels.[67] Desertification is driven by increasing demands to produce food, fuel, and fiber combined with a reduction in the total area of agricultural land available and declines in soil fertility and water access. When desertification happens as a result of intensive management practices and efforts to increase productivity, it is often associated with a misunderstanding of dryland ecology and a failure to manage soil fertility and moisture appropriately. Traditional agricultural approaches may no longer be enough to meet rising demand, but they are often being replaced by more damaging and less sustainable alternatives.

The practice of leaving land fallow in Sudan's drylands has been widely abandoned due to rising population pressure and the demand for food. National policies encouraging intensive agriculture have led to the widespread clearance of land for mechanized farming under monocultures, the removal of trees, and abandonment of traditional crop rotations and other sustainable management practices.[68] Drylands cultivated in this way rapidly lose soil biodiversity – fungi, bacteria, and other organisms – which is important for recycling

Figure 12.2: Drivers of desertification



nutrients and maintaining organic carbon in the soil; declining organic carbon means less nutrients and less water is retained in the soil, negatively impacting food production and leading to land degradation.

In Australia, as in other dryland countries, one of the most significant drivers of desertification is salinization. Increased salinity is caused by land clearing, mainly for agricultural production, and occurs when the water table rises and brings natural salts to the surface. This is largely the outcome of employing farming practices developed in the temperate lands of Europe and based on shallow-rooting crops and pastures.[69] In the year 2000, 5.7 million hectares of Australia were assessed as having a high potential to develop salinity, with the salt-affected area predicted to reach 17 million hectares by 2050 if there is no remedial action.[70]

There is a close relationship between poverty, land degradation, and desertification, and although dryland populations may have historically practiced sustainable land management, many are finding it increasingly difficult to do so. There are numerous reasons for this: from rural population growth to a breakdown in local governance and the adoption of unsuitable farming practices and crop selection. Poverty in the drylands is often rooted in the historical neglect of areas regarded as "low potential," creating a self-fulfilling diagnosis as resources are channeled elsewhere leaving drylands starved of investment. Poverty levels in the drylands, measured in terms of literacy rates and health indices, are above average in many countries. Adult female literacy rates in the humid lands of West Africa, for example, are around 50 per cent but drop to 5-10 per cent in the drylands. In the drylands of Asia, infant mortality rates are around 50 per cent above the mean.[71]

Another important driver of land degradation is weak land tenure and ineffective governance over natural resources, particularly in communally managed areas[72] like grasslands and dry forests. These lands have historically enjoyed strong governance through customary arrangements and practices, such as the coordination of harvesting forest and rangeland products, and the establishment of rules to prevent malpractice.[73] In many cases, these institutions are weakening as the result of emerging state powers that undermine customary authority and fail to provide a viable alternative.

Strengthening governance of tenure is fundamental for the increased uptake of sustainable land management practices. This often requires innovative and specialized approaches to accommodate the unique governance requirements in the drylands, where resource sharing, communal management, and mobility are critical livelihood strategies. Hybrid governance arrangements, which combine elements of traditional governance with the modern state apparatus, are increasingly being utilized. Improved governance can provide a platform for the effective blending of traditional institutions and knowledge with the relevant science and more formal institutions. It also plays an important role in supporting the equitable development of value chains connecting the many values of drylands with markets in ways that promote rather than erode sustainability.[74]

Costs of desertification

Desertification is a global threat that impacts heavily on the livelihoods of millions of people both in and outside the drylands. The true cost of desertification is frequently underestimated due to the unknown scale of these external and downstream impacts. Costs include those that directly impact human health and well-being, including food and water security, as well as the more intangible costs in terms of culture and society, all of which are a result of losses in biodiversity and ecosystem functioning.

There are many challenges in estimating the cost of desertification at local and national scales, and any attempts to identify a global figure must be treated with caution. Nevertheless, a few examples have been published in recent years. A study in fourteen Latin American countries put the figure for losses due to desertification at 8-14 per cent of agricultural gross domestic products (AGDP) annually,[75] and another study estimated the global cost of desertification at 1-10 per cent of AGDP annually.[76] Some assessments differentiate between the direct costs that result from decreased land productivity and the indirect economic costs known as externalities. Direct costs have been estimated at 2 per cent of AGDP in Ethiopia, 4 per cent in India, and up to 20 per cent in both Burkina Faso and the USA.[77] Indirect costs may be felt far from the source of degradation and can include the disruption in water flows, and contributions to climate change, sand and dust storms, and other phenomena.

Land degradation can disrupt water cycles and diminish water quality through the siltation of rivers and reservoirs. Degraded landscapes are prone to flooding as rainwater runs off rather than soaking

© Tim Gimbert. Source: UNEP, WMO, UNCCD (2016).

into the soil, increasing the loss of top soil and biodiversity, and in extreme cases can lead to inundation of downstream communities and land.[78] Soil organic matter plays an important role in water retention and as it declines so does the capacity of soil to hold moisture. The rate of water infiltration can also be reduced by surface compaction, loss of soil invertebrates, and other factors related to desertification, leading to drier soil, lowering of aquifers, and soil erosion. As a result, the incidence of drought can increase independent of changes in rainfall, simply due to reduced capacity of the land to capture and hold water. It has been estimated that on severely degraded land as little as 5 per cent of total rainfall is used productively.[79]

Sand and dust storms (SDS) occur when high winds impact dry and degraded soils. Sand storms occur relatively close to the ground whereas dust storms can rise kilometers into the atmosphere and be transported long distances. They impact human health, agriculture, infrastructure, and transport; the economic losses from a single SDS event can be in the order of hundreds of millions of USD. About 75 per cent of global dust emissions come from natural sources, such as ancient lake beds, with the rest coming from anthropogenic sources, mainly ephemeral water bodies. However, the removal of vegetation, loss of biodiversity, and disturbance of the sediment or soil surface (e.g., by off-road vehicles, livestock) will increase susceptibility to dust generation. It is estimated that SDS have increased 25-50 per cent over the last century due to a combination of land degradation and climate change.[80] Major dust-bowl events can occur through a combination of prolonged drought and poor management. The ecological impacts are diverse: under different circumstances, dust can increase drought or stimulate rainfall, provide valuable nutrients to rainforests or harm distant coral reefs. The inhalation of dust particles can cause or aggravate asthma, bronchitis, emphysema, and silicosis, while chronic exposure to fine dust increases the risks of cardio-vascular and respiratory disease, lung cancer, and acute lower respiratory infections. Fine dust also carries a range of pollutants, spores, bacteria, fungi, and potential allergens, thus leading to a host of other diseases and medical complaints.[81]

The largest areas of high dust intensities are located in a so-called "dust belt" stretching from the west coast of North Africa, over the Middle East and Central/South Asia to China; other affected areas include central Australia, the Atacama Desert in South America, and the North American Great Basin. Places where humans are contributing to the extent and frequency of SDS events include the southern Sahel, Atlas Mountains and Mediterranean coast, parts of the Middle East, the high plains of North America, Argentine Patagonia, and parts of the Indian sub-continent. Simulations suggest that global annual dust emissions have increased by 25-50 per cent over the last century due to land use change and climate change.[82]

Besides these visible impacts of desertification, society can be affected in less visible ways through the increase in food prices when agricultural productivity is reduced or when poverty contributes to migration, both domestically and internationally. Desertification has also been implicated in conflict[83] as a result of increased competition over scarce resources with climate change as an additional contributing factor,[84] although the causes of conflict are generally complex. When desertification leads to lower food production, it contributes to national poverty and the vulnerability of the poorest communities. This can create a vicious circle since the poorest farmers also face the greatest challenge in addressing land degradation.[85]

Perhaps the least tangible cost of desertification is the loss of cultural and aesthetic values associated with the drylands, and yet in many cases this is the cost that finally drives people to act. Land is more than a place to produce food or supply water; for many people, it is inextricably connected to their cultural identity and dignity, and many rural communities feel a sense of responsibility towards the land.[86] Assigning a number to such losses is impossible, although methodologies have been used to estimate what people would be willing to pay to avert the cost. As an elderly Bedouin woman responded to the question of why she was investing her time in rehabilitating the rangelands, "I want to open my door in the morning and see the beauty of nature in front of me."[87]

Reclaiming the land in the Kubuqui Desert, Inner Mongolia, China Well established protection belt along the highway 25 years later. The original sand dunes can be seen in the background.

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Desertification and climate change

Soils store more carbon than the combined total of the worlds' biomass and atmosphere, and a substantial part of this carbon is in the drylands (see Table 12.1). When land is degraded, carbon can be released into the atmosphere along with other greenhouse gases, like nitrous oxide, making land degradation one of the most important contributors to climate change: about one quarter of all anthropogenic greenhouse gas emissions come from agriculture, forest, and other land use sectors.[88] Climate change is projected to increase aridity in some of the drylands, with a higher frequency of droughts in the drylands, and there is "medium agreement but limited evidence that the present extent of deserts will increase in the coming decades."[89] As more and more productive land is degraded or lost to urban expansion, there is a risk that a growing proportion of future land use change will take place in the drylands, increasing its contribution to climate change.

Climate change can exacerbate poverty and further undermine the capacity of people to manage the land and livestock sustainably.[91] The poorest people on Earth are the most vulnerable to climate change,[92] and yet for the most part they contribute the least to this threat. Since the drylands include a disproportionate number of the world's poor, they are likely to be among the most affected by climate change. Many dryland communities have well-developed practices of resource sharing that help them to spread risk. In some pastoral communities, this includes cultivating debts and obligations over many generations and vast distances, so that in times of hardship they can call on the support of people who may be less affected. Mongolian pastoralists have a long history of reciprocal arrangements that enable herding families to spread climate risks, such as blizzards and drought. However, there are signs that these institutions are coming under pressure from economic forces and changing relationships between herders and the state.[93]

Table 12.1: Role of dryland soils in storing carbon[90]

	Biomass Carbon	Soil carbon		
		All Soil C	Soil Organic C	Soil Inorganic C
Global	576 Gt	2,529 Gt	1,583 Gt	946 Gt
Drylands	83 Gt	1,347 Gt	431 Gt	916 Gt
Portion in drylands	**14%**	**53%**	**27%**	**97%**

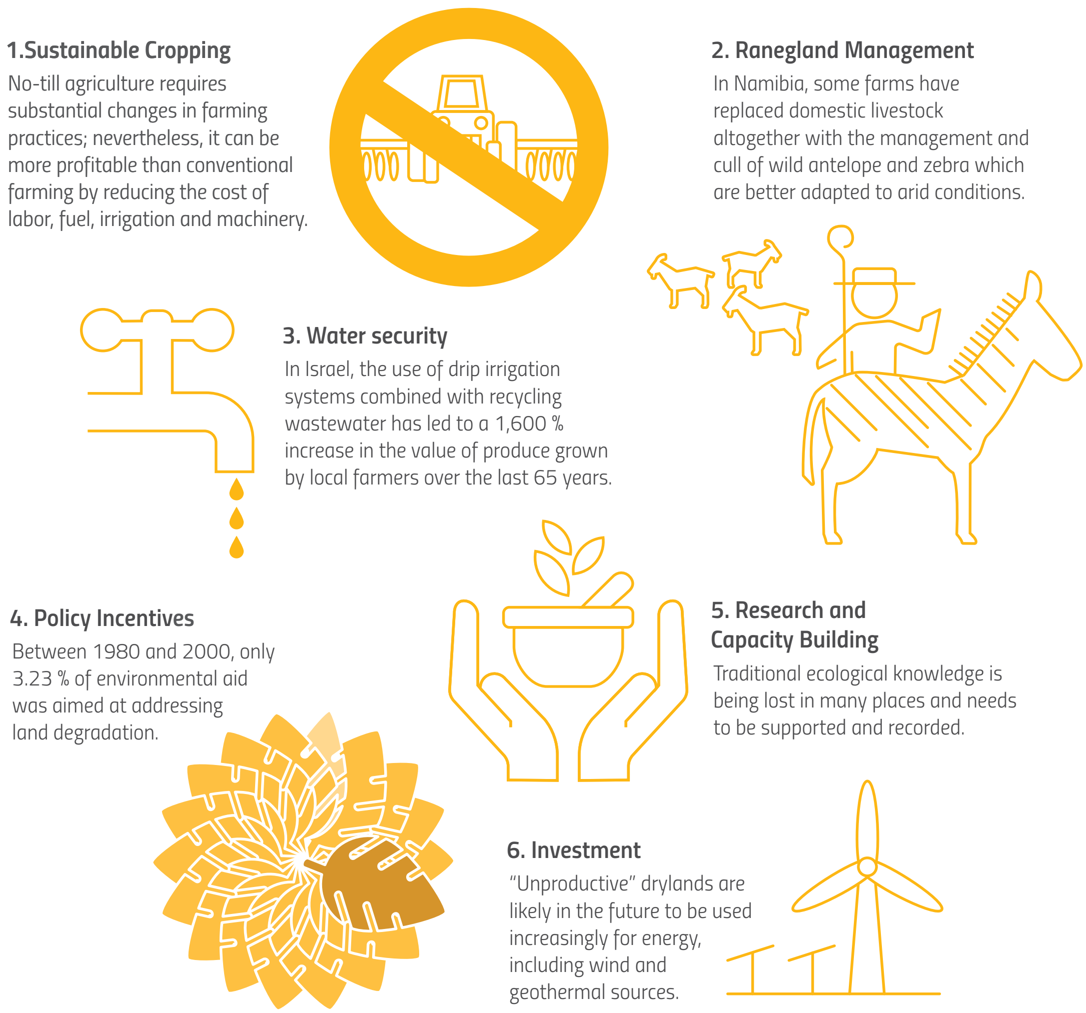
MANAGING DRYLANDS SUSTAINABLY

There is a wealth of management experience to build upon and achieve a major overhaul in the way ecosystems are valued, protected, and managed. The linkages between desertification, climate change, and poverty help to focus attention on responses that deliver multiple benefits. Addressing these challenges together would create positive feedbacks by capturing atmospheric carbon in the soil, halting and reversing land degradation, closing agricultural yield gaps, and increasing the overall resilience of communities and ecosystems in the drylands. It is crucial to ensure that soil carbon is fully accounted for and monitored as an indicator of progress not only towards combating desertification but also towards reversing climate change and biodiversity loss.[94]

Because land degradation is often the result of multiple drivers, responses need to be tailored to particular situations. Simple responses, such as tree planting, are not always effective and land abandonment does not necessarily lead to recovery.[95] Sustainability requires many steps, from holistic management approaches to crop selection and production, livestock raising, and water conservation as well as a suite of enabling factors. These include:

- **Sustainable cropping**, including choice of species and management practices
- **Rangeland management** to avoid over-grazing and degradation
- **Water security** through improved management and conservation
- **Policy incentives** and legal changes including improved security of tenure and land rights
- **Research and capacity building** to fill knowledge and skills gaps
- **Investment** to reverse land degradation in the drylands

Figure 12.3: Managing drylands sustainably



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1. Sustainable cropping

Many of the elements of "sustainable intensification"[96] in drylands are already well known and described in Chapter 7: nutrient conservation, the use of manure, compost, and mulches, fertilizer micro-dosing, integrated pest management strategies,[97] selection of suitable and sustainable crop mixes, and a variety of soil conservation techniques are all available, aimed at more fully harnessing ecosystem services for long-term food security.[98] Fallows, which have long been integral to maintaining soil fertility and boosting soil moisture in the drylands, are showing some signs of revival despite a global decline in recent years.

No- or low-till agriculture minimizes soil disturbance and maintains crop residues and other organic matter on the soil surface where it helps to reduce evaporative losses and increase infiltration. Evidence shows that no-till agriculture can lead to a greater concentration of soil organic carbon near the surface which often translates into improved productivity. The impact of no-till on the overall soil carbon balance is still not fully understood, but there is clear positive benefit for climate change adaptation.[99] No-till agriculture requires substantial changes in farming practices; nevertheless, it can be more profitable than conventional farming by reducing the cost of labor, fuel, irrigation, and machinery. No-till agriculture is practiced to the greatest extent in the drylands of the world's leading grain-exporting nations, such as Australia and Argentina, and in the US where it accounts for 22.6 per cent of all cropland areas.[100]

Agroforestry is another proven approach to sustainable land management in the drylands. Trees on farms provide shade for humans, crops, and livestock, deliver nutrients and help stabilize soils, provide emergency animal feed and other raw materials; trees can also bear edible fruits and nuts. Agroforestry underwent a decline in the 20th century due to changes in socio-economic conditions, public policy, and land tenure as part of an alternative vision of agricultural development based on large-scale mechanization and mono-cropping.[101] However, research shows that trees are increasing once again on farms worldwide, most notably in Brazil, Indonesia, China, and India. Some 43 per cent of agricultural land globally has at least 10 per cent tree cover.[102] In Niger, agroforestry has undergone somewhat of a renaissance with over 5 million hectares restored through the revival of simple practices of selective protection of high-value trees within farming landscapes.[103] Farmers are using a variety of techniques to encourage regeneration or the planting of native tree species, including the Zaï technique, which encourages tree planting in small holes filled with manure, usually in combination with stone bunds as part of the Farmer-Managed Natural Regeneration approach.[104]

2. Rangeland management

The most widespread land use in drylands is extensive livestock production or pastoralism. Traditional pastoralists use herd mobility to track resources as they are made available by the rains. In this way domestic herds mimic the behavior of wild ungulates (hooved animals). Pastoralists maintain both natural and artificial infrastructure for water supply, including deep wells, tanks, and surface ponds. Land is prone to degradation around these water points and oases, particularly when people are encouraged to settle permanently with their livestock. Pastoralists often have elaborate customs

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and arrangements governing the use of water and pasture, enabling equitable communal resource use over vast areas and in some cases across international boundaries.[105] Poorly planned water infrastructure projects can undermine these traditional systems.[106] Several countries are taking measures to strengthen local regulation of resource use by embracing hybrid governance systems that link customary tenure with state institutions, in some cases involving tools like remote sensing and telecommunications to enable more efficient rangeland planning. Spain's 1996 "Vias Pecuarias" Act has revived transhumance movements (seasonal movement of people with their livestock) through the protection of an ancient network of 120,000 km of livestock tracks – a livestock corridor that would circumnavigate the Earth 3 times – leading to major improvements in biodiversity and ecosystem services.[107]

Rangeland management may be improved by the selection of well-adapted species or mix of herbivore species, chosen for their genetic potential (e.g., drought resistance) and ability to utilize a range of ecological niches; this could include disaggregating herds to avoid over-grazing and loaning animals to others to build or rebuild herds as a form of social capital.[108] In Namibia, some farms have replaced domestic livestock altogether with the management and cull of wild antelope and zebra which are better adapted to arid conditions.[109]

3. Water security

The management of water is central to effective management of land in the drylands. As discussed in Chapter 8, land management practices can reduce and capture run-off, reduce evaporation, boost the water-holding capacity of soils, and increase the water-use efficiency of crops. However, run-off representing a loss in one place may be a vital resource for people living downstream, and decision-making has to take place at the right scale to ensure equitable and sustainable outcomes throughout the landscape.

There is a great diversity of water harvesting practices in the drylands, many of which have been known for centuries. Water harvesting is influenced by topography and soil type, and can be applied at different scales. Small-scale measures, sometimes called micro-catchments, are used to capture run-off within fields and include practices like planting-pits and contour bunds. These work by slowing down the rate of run-off and encouraging localized infiltration. Larger-scale measures are used for capturing run-off outside individual fields and include dams and ponds for community use. These macro-catchments usually require water storage and in the drylands, where evaporative losses are great, this can include sub-surface storage in cisterns. In some soils, sand-dams are used to trap sand, which in turn holds water, thereby effectively creating sub-surface storage.[110] Where water is stored in macro-catchments or harvested from rivers and aquifers, irrigation techniques are then required to apply water to the land. This can include irrigation on a grand scale, although such schemes are inefficient, costly, and challenging to manage, and have many environmental costs. Smaller-scale irrigation can be more carefully controlled to supplement rainfall at critical times in the growing cycle by boosting growth or extending the growing season.[111]

In Israel, the use of drip irrigation systems combined with recycling wastewater has led to a 1,600 per cent increase in the value of produce grown by local farmers over the last 65 years.[112] But wastewater use often entails the risk of increasing salinization and efficiency receives a further important boost if desalinized water is used.[113]

4. Policy incentives

Promoting investments in the drylands depends first on creating the enabling conditions, ranging from supportive laws, policies, and institutions within countries to international agreements and donor commitments. However such conditions, for the most part, currently do not exist. Drylands have generally been left out of mainstream development efforts: between 1980 and 2000, only 3.23 per cent of environmental aid was aimed at addressing land degradation.[114] The challenges to growth in the African drylands persist due to fundamental development gaps, combined with the frequency of drought and other shocks. The population of Africa's drylands is projected to increase by between 65 and 80 per cent in the next 15 years;[115] this, combined with increasing outside investment in large-scale industrial agriculture and extractive industries, has the potential to exacerbate land and soil degradation. Degradation in turn increases the human impacts of drought and water scarcity, which often divert resources from long-term development into more costly short-term and reactive measures. Although it is anticipated that economic growth in the drylands will be significant in the medium-term, this may not keep pace with population growth and climate change-induced vulnerability.[116]

Divergent policy priorities between sectors can lead to harmful consequences, especially when land, water, trees, wildlife, and other resources are managed for different goals. This is particularly problematic given the scale of drylands and the potential misunderstanding about the most appropriate development pathways. Improved coordination between sectors, such as agriculture, wildlife, forestry, and water, driven by high-level political leadership and guided by knowledge and evidence, is needed to ensure closer collaboration and more joined-up action on the ground.

A critical policy element in encouraging sustainable dryland management is the need to improve resource rights and tenure security, giving land managers the freedom and legitimacy to implement long-term sustainable management strategies. For example, the success of forest restoration projects is greatly increased if local communities are confident that they will retain access to the resulting benefits. However, securing tenure frequently requires innovative solutions that reconcile statutory law and customary rights. Stronger local institutions can provide a vital interface between modern and traditional systems, and may be the key to improving local governance overall, along with improved access to markets and other services. In several countries, this is being facilitated by government decentralization which allows for greater participation in local-level decision making and greater respect for local rights and responsibilities. The *Voluntary Guidelines on the Responsible Governance of Tenure*, produced by the Food and Agriculture Organization of the United Nations,[117] have been endorsed by over 100 countries and provide an excellent platform for strengthening land rights. In Mongolia and Kyrgyzstan, for example, public policy supports the establishment of Pasture User Groups for rangeland governance, an important mechanism for ensuring community representation and the coordination of management activities.[118]

Formal and informal agreements to enhance dryland conservation efforts also influence tenure. Worldwide about 9 per cent of the drylands (~5.4 million km^2) are formally protected, slightly below the global average of 12.9 per cent. While early protected area policies were frequently exclusionary, many protected areas today protect the rights of resident human communities. Non-governmental approaches, such as Indigenous and Community Conserved Areas (ICCAs), and quasi-governmental approaches such as Indigenous Protected Areas are gaining recognition as a tool for legally recognizing tenure in the drylands and for promoting synergies between economic use and conservation objectives.[119]

Many drylands are effectively protected through traditional land management practices that sustain the biodiversity on which local livelihoods depend. These de facto protected areas are often overlooked by governments and thus remain vulnerable to competing interests. Designating them as ICCAs could offer communities greater potential to capitalize on the environmental benefits of their production system and further incentivize sustainable land management. Formally recognizing

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these lands as ICCAs could also help establish standards for sustainable management and improved monitoring as well as provide incentives to retain sustainable practices.[120] The so-called communal or land conservancies, most fully developed in Namibia, create a way for communities to gain economic returns from tourism linked to wildlife and provide an innovative model, particularly for dryland countries with low human populations.[121]

5. Research and capacity building

Scientific knowledge on dryland production systems remains underdeveloped and is often side-lined in favor of management approaches that have been developed for humid lands. This is compounded by inadequate data on dryland environments and economies, which allow important decisions to be made in an information vacuum. The lack of funding for dryland development coincides with a lack of support for dryland research; our understanding of the rates and causes of desertification remain woefully incomplete. The complexity of risk-adapted strategies for dryland management and the value of local knowledge and practices need renewed attention; traditional ecological knowledge is being lost in many places. Greater efforts are needed to combine local with emerging scientific knowledge through appropriate partnerships, participatory learning, and more effective dissemination of information and technology.[122]

Finally, for investments to be mobilized, major efforts are often needed to upgrade the skills of professionals, including extension services and peer-to-peer learning, in the drylands. This includes professionals working in the public sector providing advice to land users as well as those who are the repositories of the local knowledge that is vital for enhancing dryland resilience.

6. Investment

Business as usual in the drylands will see continuing desertification and vulnerability, combined with heightened risks from climate change, contributing to greater social problems of poverty, migration, and conflict. In 2011, the United Nations published a report noting that drylands had become "investment deserts" where chronic under-investment was driving under-development and poverty.[123] Meanwhile, the Sustainable Development Goals adopted in 2015, and particularly target 15.3 on Land Degradation Neutrality,[124] demonstrates a growing willingness and commitment to halt and reverse desertification. This enthusiasm has to be matched by the capacity and resources to act in accordance with national development priorities. Our understanding of how to adapt investments to the drylands is constantly improving and offers reason for hope.

Dryland problems are not automatically solved by the availability of finance: serious desertification problems in comparatively rich countries, like the United States, show that the problems are not confined to the developing countries. But the extent of human deprivation in many drylands in the developing world should not be underestimated nor should the absence of the most basic conditions for human development.

One area that needs particular attention is how to capitalize on or leverage multiple values. Dryland ecosystems provide many benefits to humanity beyond the obvious provisioning services of food, fuel, fiber, and building materials. The rehabilitation of rangelands in the Jordanian Baadia have shown modest improvements in livestock production and marketable biodiversity, like medicinal plants, but vastly greater benefits to groundwater flows, carbon storage, and reduced sedimentation in hydropower dams, all of which are enjoyed by people other than those responsible for their protection.[125] Incentivizing the most sustainable land management practices in the drylands will require a shift from maximizing output of single commodities towards the optimization of a range of inter-connected ecosystem goods and services.

Moving towards an economy based on balancing multiple land-use values may imply additional challenges for developing profitable markets. Many dryland communities are able to generate substantial secondary income through ecotourism, and if managed correctly, this can often be integrated with other activities such as sustainable livestock production. Elsewhere land managers can tap into markets for high-value products, like fruits, oils, and herbs, or receive payments for ecosystem services. All of these rely on the creation of value chains as well as new skills and sources of finance to enable dryland communities to capture a greater proportion of the value-added benefits of their labor.[126]

Improving markets for sustainably managed products also requires attracting the right investors. Drylands have been particularly at risk of large-scale foreign land acquisitions in recent years, aided by the comparatively poor tenure security and in some cases the weak political voice of the inhabitants.[127] Smaller scale transfers of land are also increasing, leading to unplanned or unregulated changes in land use. Governments can do more to mobilize investments that support existing land users to improve management and develop landscape-scale plans for integrating crop farming, grazing, forest and wildlife management, and the protection of wetlands, and so on. Particular effort is required to mobilize and incentivize local entrepreneurs to


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develop small- and medium-sized enterprises to help strengthen and diversify rural livelihoods.

Small-scale investments by farmers are vital to future sustainability. Dryland farmers and herders invest in many different ways on a relatively small scale that is multiplied thousands of times across a landscape. These investments can be hard to value but represent a significant and diverse portfolio of capital, including labor and social capital. The seven million hectares of agroforestry that have been established in Niger was achieved through thousands of individual acts by small farmers across a vast landscape.[128]

Other forms of investment will have a role in determining the future of the drylands. Today a major source of fossil fuels, in the future, the drylands will become increasingly important for various types of renewable sources. Deserts are already used for siting large-scale solar photovoltaic power stations,[129] with some arguing that this could eventually be the largest global energy source. Such developments already challenge conservation managers to protect fragile ecosystems,[130] but "unproductive" drylands are likely in the future to be used increasingly for energy, including wind[131] and geothermal[132] sources. Integrating energy production, mineral extraction, and other global demands with more traditional farming and livestock-raising could present significant opportunities in the future.

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CONCLUSION

A strategic agenda for managing drylands sustainably should revolve around the three established pillars of sustainability: social, environmental, and economic.

1. **Environmental sustainability** in drylands requires a major overhaul of the natural resource sector, integrating agriculture and environmental management, increasing awareness of dryland issues, and not treating food production as an extractive industry. Soil is produced slowly in arid conditions and often regarded as a finite, non-renewable resource; in the future, agriculture must ultimately put back into the soil as much as it takes out. It is particularly important to broaden our understanding of biodiversity, above and below ground, and to develop agriculture practices around the recognition that organic carbon, the prime indicator of soil fertility, is itself a part of biodiversity. Farmers, as stewards of soil carbon, are at the heart of the effort to address the biggest environmental challenges of our time: biodiversity loss, climate change, and land degradation.

2. **Social sustainability and stability** in the drylands must be strengthened through the development of human capital, including improved access to basic services like education, health, and security. It should also include secure land tenure, improved social protection, and better management of and planning for the profound social pressures currently underway, such as urbanization, rural poverty, and the continued marginalization of women. Social sustainability requires effective institutions for the proper governance of natural and economic resources, and will only be achieved when human rights are respected as the foundation for people-oriented development.

3. **Economic sustainability** must build upon, and ultimately contribute to, ecological and social sustainability. It requires investment in value chains that reflect the essential diversity of dryland production systems, including capitalizing on environmental services and the certification of sustainably produced goods. This includes supporting the development of small- and medium-sized enterprises that increase added value locally and create jobs for the growing urban poor. It also requires an effort to overcome transaction costs, particularly those associated with access to information and technology transfers. For this, enabling investments from the public sector are needed in order to unlock private sector engagement and to overturn the legacy of under-investment. Economic sustainability in the drylands must be built around sound risk-management, including the efficient management of soil and water, and the strengthening of locally-proven land management practices.

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Part Three
A MORE SECURE FUTURE

This first edition of the Global Land Outlook has focused on the links between land and human security: in the sense of food and water security; safeguarding of soil and biodiversity; defense of communities and individual livelihoods; security of tenure and gender equity; protection of marginalized people at the urban-rural interface; safety from drought, floods, and other weather-related disasters; reassurance in the right to retain cultural and spiritual identity; and, underlying all the above, social and political security. Land-based natural capital is under pressure and this is threatening to destabilize many of these aspects of human security.

Part Three presents pathways for change, summarizing the critical recommendations from Part Two and outlining strategic priorities for implementation, recognizing that decisions and investments made today will influence land use and management tomorrow. We expect that this concluding part of the *Outlook* will help foster a new vision and agenda for action to ensure a more secure future.

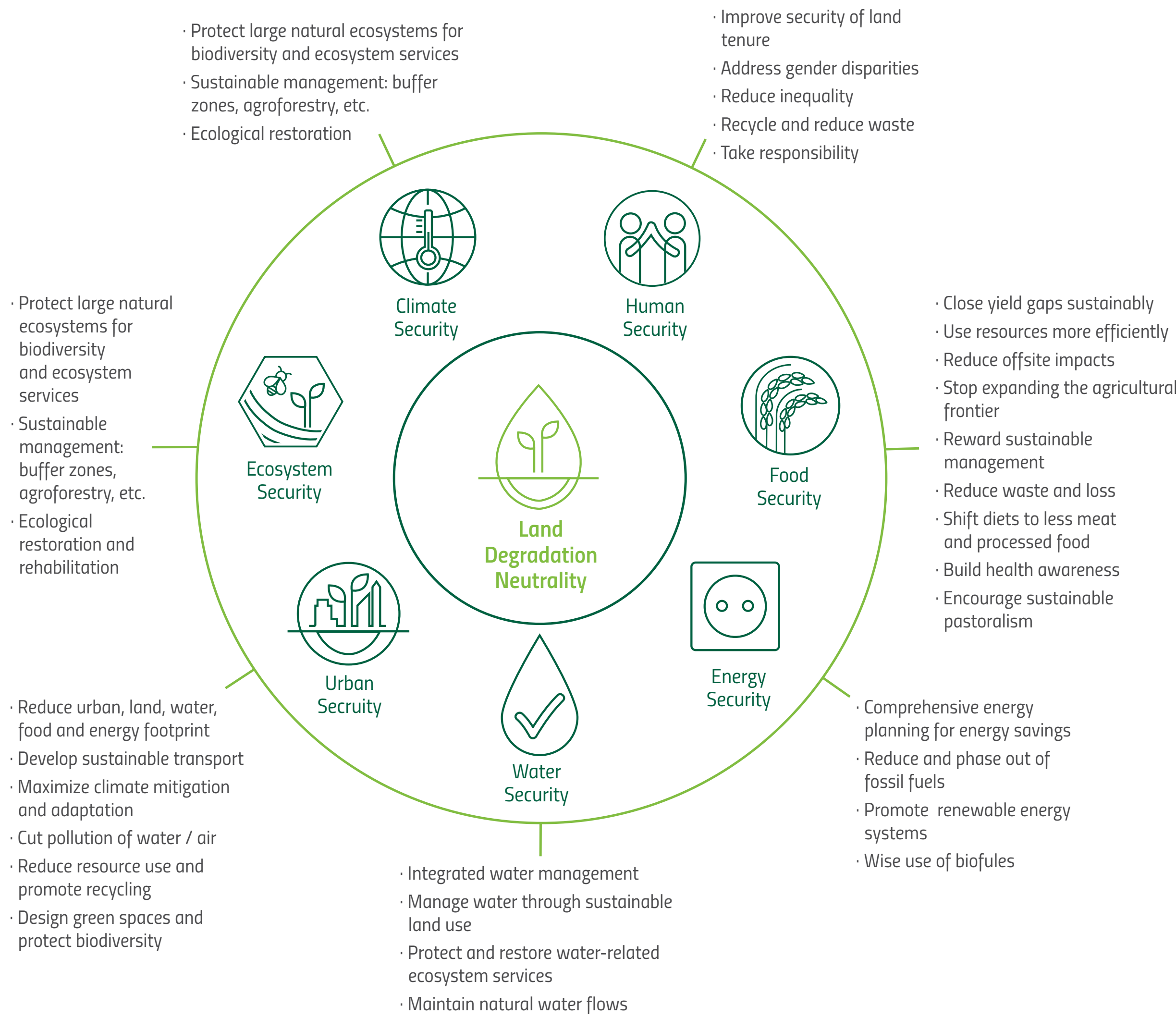
A MORE SECURE FUTURE

Recognizing that the world is at a critical juncture pushing against planetary boundaries, we argue that a broader, landscape approach to management, which considers and integrates a wide range of land use strategies, can help reverse many of the current negative trends in land degradation. Addressing the drivers and impacts of land degradation continues to be a challenge; many political and economic forces remain committed to business-as-usual pathways.

The fact that we know how to relieve many of the pressures on land resources is a good start, but without concerted action that brings all sectors and stakeholders on board we will not succeed in realizing change.

Under the auspices of the 2030 Agenda for Sustainable Development, innovative programmes around the world are taking shape to halt and reverse land and soil degradation. Part Three highlights the responses needed as well as the responses needed to achieve the target of Land Degradation Neutrality, and the related objectives of poverty reduction, food and water security, biodiversity conservation, climate change mitigation and adaptation, and sustainable livelihoods.

Figure 1: Land-based action to improve overall human security



INTRODUCTION

We are all decision-makers in our daily lives and can empower ourselves to act knowing that our choices have consequences. Steering the transition toward more efficient, and thus more sustainable land use, involves an understanding of the impacts of management decisions at all scales, the creation of appropriate incentives for sustainable consumption and production, and a greater capacity to adopt and scale up better land management practices. We can catalyze the shift needed to move from the current "age of plunder" toward an "age of respect" – one that accepts a world governed by biophysical limits and seeks to maintain life within those boundaries.[1]

Nature offers us many opportunities by which we can transform the way we consume, produce, work, and live together without compromising socio-economic and environmental security for current and future generations.

Here we set out some of the guiding principles upon which individuals, communities, corporations, and countries can make informed decisions that will define the future quality of life on the planet, and describe how these principles underpin an integrated landscape approach to sustainable development. But before this, we briefly describe the concepts and ambition underlying Land Degradation Neutrality, target 15.3 in the Sustainable Development Goals.

Figure 2: Land-based actions to achieve multiple Sustainable Development Goals

Land use planning at landscape level
Multiple partners working together at a landscape scale to achieve food and water security, biodiversity conservation, climate mitigation and adaptation and sustainable cities

Conservation, sustainable management and restoration
A focus on the conservation, sustainable management and restoration of the land base is the central tenet of a more secure future

Creating the enabling environment
Addressing massive global economic inequality, lack of tenure security, unequal gender relationships, particularly in agriculture, and the need for long-term work for small farmers

Increased efficiency and the reduction of waste
A focus on efficient agriculture to reduce pollution and resource use, renewable energy sources, and sustainable levels of production and consumption

Land Degradation Neutrality (LDN)

The UNCCD defines LDN as "*a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems.*"[2] The primary objectives are to:

- Maintain or improve natural capital stocks and ecosystem services
- Maintain or improve productivity in order to enhance food, water, and energy security
- Increase the resilience of the land and populations dependent on the land
- Seek synergies with other social, economic, and environmental objectives
- Reinforce the responsible and equitable governance of land tenure

Effective LDN strategies will also act as an SDG accelerator to achieve many of the broader aims of the 2030 Agenda for Sustainable Development. A conceptual framework (see Annex One) was developed to provide guiding principles for those countries that choose to pursue LDN.[3] These principles help prevent unintended outcomes during design and implementation of LDN measures. While there is inherent flexibility in its application, the fundamental structure and approach of the conceptual framework are fixed to ensure consistency and scientific rigor:

- Land use decisions are based on multi-variable assessments, considering land potential, land condition, resilience, social, cultural, and economic factors.
- A response hierarchy is applied in planning LDN interventions to avoid, reduce, and reverse land degradation.
- An inclusive, participatory process is used to include relevant stakeholders, especially land users, in designing, implementing, and monitoring interventions to achieve LDN.
- Responsible governance regimes need to be in place that protect human rights, including tenure and gender equality, and ensure accountability and transparency.
- Monitoring trends in land degradation uses three core indicators (i.e., land cover, land productivity, and carbon stocks), complemented and enhanced with other relevant indicators.

LDN is a simple but revolutionary idea that links many global goals and targets by avoiding future degradation and moving towards sustainable land management, while at the same time massively scaling up the rehabilitation and restoration of land and soil. It is also a powerful concept that will encourage us to rethink and hopefully redefine our relationship with nature.[4]

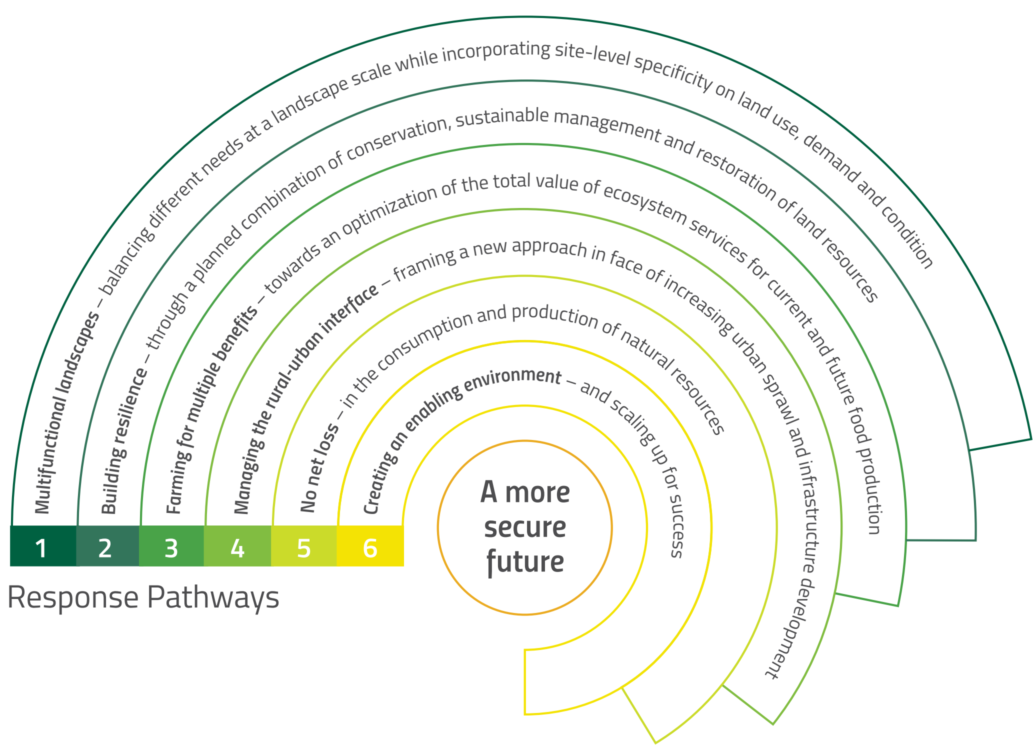
As of mid-2017, over 100 countries were using the LDN framework to set individual targets, identify prescriptive measures, and establish monitoring protocols to achieve and surpass a position of "no net loss" of healthy and productive land. Lessons are being drawn from experience in 14 pilot countries.[5] As part of the LDN target setting programme, countries can apply a standardized approach to reporting SDG indicator 15.3.1 ("*Proportion of land that is degraded over total land area"),* one which focuses primarily on the use of three sub-indicators adopted by the UNCCD Parties in 2013:6 land cover and land cover change, land productivity, and carbon stocks above and below ground. Because land degradation is subjective and context-specific, these core indicators are considered necessary but not sufficient and should be complemented and enhanced by other relevant indicators at the national and local levels.

RESPONSE PATHWAYS

In Part Three, we look at six response pathways that producers and consumers, governments and corporations can follow to stabilize and reduce pressure on the land base, and achieve a more secure and equitable future. For each pathway, we introduce the concept, describe key tools to help achieve success, and highlight illustrative case studies:

1. **Multifunctional landscapes:** balancing different needs at a landscape scale while incorporating site-level specificity on land use, demand, and condition
2. **Building resilience:** against climate change and other shocks through a planned combination of conservation, sustainable management, and restoration of land resources
3. **Farming for multiple benefits:** towards an optimization of the total value of ecosystem services for current and future food production
4. **Managing the rural-urban interface:** framing a new approach in the face of increasing urban sprawl and infrastructure development
5. **No net loss:** in the consumption and production of natural resources
6. **Creating an enabling environment**: for scaling up small successes into transformative regional and global change

Figure 3: Response pathways for a more secure future



RESPONSE 1: Multifunctional landscapes

Key concepts

- **Individual areas of land often need to be prioritized for particular uses – food production, ecosystem services, transport, biodiversity conservation, etc. – but these areas must be balanced so that at a landscape scale a full range of goods and services are produced**
- **Achieving this balance requires land managers to think beyond their own management unit, balancing needs and negotiating trade-offs between different stakeholders**
- **Tools exist to help achieve a successful landscape approach, including land use planning**

WHAT'S NEW?

Most attempts at achieving "multifunctional landscapes" try to fit all the values into a single parcel of land, with the result that none of the potential functions are really developed to an optimal extent and usually one particular use predominates over other values. A landscape approach recognizes that specialization is important and acceptable in individual sites as long as the required suite of goods and services are represented and harmoniously integrated at a landscape scale. This is challenging in places where planning is weak or where there is a strong tradition of individual rights that fail to recognize common values. Getting it right involves a combination of well-known tools as well as new approaches to collaboration.

A landscape approach[7] represents a commitment to multifunctional land use planning and management that promotes healthy economic growth, strong environmental stewardship, and social cohesion and stability. It encourages planners and decision-makers to set priorities, manage trade-offs, and coordinate action across the various land-based sectors while engaging all relevant stakeholders.[8] Managing trade-offs at a landscape scale will ultimately decide the future health and productivity of our land resources.

A multifunctional landscape approach does not try to deliver every good and service from a single site – an impossible task – but recognizes that specialization is needed at a site scale. However, for an area to supply a full range of services over the long term, site-level uses must be balanced within the landscape.

Underpinning a move towards more sustainable land management is the recognition that actions at the local level impact the surrounding land and water. Therefore, in a world of competing interests, many different goals need to be integrated within a single landscape: for example food production, the maintenance of water resources and various ecosystem services, biodiversity conservation, poverty alleviation, human well-being and other forms of social and economic development.[9] For true sustainability, some degree of coordination and cooperation among different land users is needed.

Therefore, while the ideal scale for planning is at the landscape or watershed level, it will be the sum total of local actions and collaborations on the ground that will shape our future. It is impossible to always have win-win outcomes and a critical element in achieving sustainability is the ability to maximize complementarities through negotiation and stakeholder engagement.

In conjunction with national and regional spatial planning, interactive and adaptable land use planning processes need a strong bottom-up component where different but overlapping interests can best be integrated within a multifunctional landscape. The willingness of communities to consider such approaches differs markedly around the world. In historical landscapes, with generations of interaction and collaboration, such integration is understood at an intrinsic or cultural level and will be relatively easy. In more recently settled areas, or cultures with a history of individualism, major social and cultural changes may be needed before the idea of community-wide cooperation is accepted or achievable. In many countries, implementing a landscape approach will require new or changes to existing policies, legislation, and regulation, and the adoption of appropriate instruments and institutions to support integrated management planning for soil, water, and biodiversity resources. Addressing tenure and gender issues and providing incentives for sustainable management are two critical elements for success.

Box 1: Integrated landscape management[15]

Integrated landscape management (ILM) is built on the principles of participation, negotiation, and cooperation, and long-term collaboration among diverse stakeholders to achieve multiple objectives. By coordinating strategies between different levels of government, ILM can create cost efficiencies and also empower communities. It can enhance regional and transnational cooperation across ecological, economic, and political boundaries. Five key features characterize ILM, all of which facilitate participatory development processes:

1. Shared or agreed management objectives which encompass multiple benefits from the landscape: agreement on the principle of working at a landscape scale, plus a way of facilitating discussion and negotiations. Broad participation ensures a more democratic process and locally appropriate planning objectives. Defining near-term targets can initiate collaboration, and allow shared learning to build confidence and trust. A recognized forum is needed for discussions to take place, where everyone feels comfortable.[16]
2. Field practices that are designed to contribute to multiple objectives: this does not mean that all objectives need to be met on a single piece of land, but that management of one area should not undermine aims in other sites, and wherever possible should contribute to wider landscape aims (such as ecosystem services).
3. Management of ecological, social, and economic interactions to realize positive synergies and minimize negative trade-offs: approaches need to be based on understanding of many different issues: ecosystem services, development priorities, conservation and restoration opportunities, and the interactions between social, economic, and environmental forces shaping land use change.[17] Spatial information, such as maps, and monitoring bio-physical factors, and socio-economic and cultural variables, provides critical information.
4. Collaborative, community engaged planning, management, and monitoring processes: stakeholders in different sectors and at different scales must work together to coordinate action, align goals, or reduce trade-offs. This often entails new ways of working together, structuring local institutions and arrangements to support community and stakeholder empowerment. Once implementation is underway, effective monitoring and evaluation of the results is needed, followed by a process of adaptive management as necessary.[18]
5. Re-configuration of markets and public policies to achieve diverse landscape objectives: supportive market institutions, public policies, and investment programmes can encourage synergies and reduce trade-offs among landscape objectives. This might mean, for example, rewarding land owners or users for management actions that provide others with benefits. Other important elements involve establishing secure systems of use, access rights, and property rights for farmers and communities. To be effective, cooperation between government agencies at all scales is necessary to align sectoral policies, finance and investments, and regulations.

Landscape approaches and the concept of integrated land management have developed quickly over the past few decades. Over 80 communities of practice have been documented relating to the management of watersheds, forests and other ecosystems, ecological restoration, climate-smart land management, indigenous landscapes, agricultural green growth, and city-region food systems;[10] such processes are taking place throughout the world.[11,12,13] Integrated landscape management aims to reduce land use conflicts, empower communities, and achieve development objectives at a large scale. It is built on the principles of participation, negotiation, and cooperation, and requires long-term collaboration among different groups of stakeholders to achieve the multiple benefits required from the landscape.[14]

The assimilation of energy and transport infrastructure in land use planning at the urban-rural interface and at regional scales will also be crucial in promoting economic growth and sustainable development. For example, green or low-impact infrastructure in urban and peri-urban areas will influence future population distributions, helping to reduce urban sprawl and the loss of productive agricultural land, natural habitat, and its biodiversity.

Land use planning: A key tool for achieving multifunctional landscapes

Land use planning is the systematic assessment of land and water potential, land use alternatives, and socio-economic conditions in order to formulate and implement the best land use options.[19] Its main purpose is to select and put into practice those land uses that will best meet the demands of people while safeguarding soil, water, and biodiversity for future generations. Land use planning can provide a blueprint for policy, advocacy, and action at various scales as well as support and trigger effective response pathways, such as ecological restoration or tenure reform. It can be employed as either a driver of, or response to, change – both of which acknowledge the need for change, improved management, or different patterns of land use due to changing circumstances.

Land use planning is about doing the right thing in the right place at the right scale.

Land use planning at the landscape, watershed, or regional scale can be a powerful instrument to further the conservation, sustainable management, and restoration of land resources; provide more rational land use allocations that lead to greater resource use efficiency and the reduction of waste; and create the preconditions or enabling environment needed to encourage policies and practices that address land degradation at the scale required. In order to be an effective tool that delivers multiple benefits, land use planning must be:[20]

- **Empirical**, based on an understanding of land cover and its multiple functions to help ensure more efficient allocations of limited resources.
- **Inclusive**, engaging stakeholders involved in or affected by land use and management practices.
- **Integrative**, mainstreamed and implemented across sectors, guided by a long-term vision for managing trade-offs and reconciling potential conflicts with national development strategies.
- **Applicable**, as a single planning instrument at a landscape, watershed, or regional scale that accounts for the cumulative and downstream impacts of future land uses.
- **Supported** by policy responses, institutions, and incentives based on rights, rewards, and responsibilities to balance economic development and environmental stewardship.

Box 2: Land use planning at the local and national levels

In **Tanzania**, the Village Land Act (1999) and the Land Use Planning Act (2011) establish the legal framework for land use planning at village level. Village land use planning and management regulates the use of land resources, enhances security of land tenure, resolves conflicts relating to communal lands, and improves land husbandry measures according to the priorities and capacities of stakeholders. The participatory approach enables direct involvement of stakeholders in the different planning phases, which include participatory rangeland resource mapping, individual village land use planning, negotiation of land allocation, and the preparation of land use agreements.[21]

In **Denmark**, the Spatial Planning Act (2007) ensures that the overall planning synthesizes the interests of society with respect to land use and contributes to protecting the country's nature and environment, thus achieving sustainable development with respect for people's living conditions and the conservation of wildlife and vegetation. Spatial planning aims towards appropriate development of the whole country and the individual administrative regions and municipalities, based on overall planning and economic considerations; creating and conserving valuable buildings, settlements, urban environments, and landscapes; preventing pollution of air, water and soil and noise nuisance; and involving the public in the planning process as much as possible.[22]

The formulation and implementation of land use planning and processes each comprise a range of activities. The formulation requires a broad assessment of current land uses as well as the main limitations and opportunities for development. After a land use zoning or spatial plan is elaborated, specific policies, programmes, and initiatives are identified to achieve the desired results (e.g., payments for ecosystem services, market-based instruments, taxes, subsidies, regulation).

A clearly defined framework and roadmap then facilitate implementation and monitoring to identify and correct mistakes, and improve the ongoing process. For example, land use planning can serve to evaluate and screen preliminary land use options when setting national development priorities or selecting projects at a local or sub-national levels.

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Land use planning can also include social programmes to compensate for exclusion from protected areas or other forms of land use, or to encourage investments into non-agricultural income activities, such as eco-tourism or communal forest management.[23] Frequent among these are the integrated conservation and development projects (ICDPs) that combine rural development with biodiversity conservation goals.[24] NGOs are often lead actors in designing and implementing ICDPs in partnership with local and/or national government as demonstrated in this case study of Central American countries.

Box 3: Land use planning to promote sustainable land use and conservation of tropical forest[25]

Selva Maya is a region of tropical forest covering a vast area of Belize, Guatemala, and Mexico. It is exposed to a number of pressures, such as forest fires, illegal logging, the exploitation of flora and fauna, and the advancing agricultural frontier. The main challenge is to protect the Selva Maya in the long term, through sustainable resource use. Land use planning, taking environmental protection into consideration, is one activity within a larger programme devised to promote protection and sustainable use of this area. Participatory land use planning has been conducted at the community level (Guatemala) and in *ejidos* (communally owned land in Mexico). This approach enables civil society groups to contribute to the development of the plans. It raises the level of acceptance of the plans and significantly improves their chances of successful implementation. Land use planning, in this context, leads to the subsequent development of management plans for sustainable use and forest protection, as well as of agro-ecological projects that develop capacity on sustainable agriculture, promotion, and marketing of products. The indirect benefits extend to improved environmental governance of the region, including cross-sectoral collaboration between governmental and non-governmental actors within each country, in particular to improve forest-fire prevention, cross-border ranger patrols, and alternative income sources for local communities.

RESPONSE 2: Building resilience through a combination of conservation, sustainable management, and restoration

Key concepts

- **Healthy, functioning and diverse ecosystems help to mitigate and adapt to climate change and other environmental pressures**
- **Agricultural land, forests, grasslands, urban and peri-urban areas, and other cultural landscapes can also contribute to planetary resilience, if managed correctly**
- **Where land degradation is advanced, ecological restoration or rehabilitation is needed to restore, or partially recover, ecosystem services**
- **Many tools for ecosystem protection, good management, and restoration exist and need to be employed in a consistent and coordinated manner**
- **It is critically important to halt net conversion of natural ecosystems and vegetation**

WHAT'S NEW?

Different land uses are often seen as being in competition: in particular conservation is resisted and seen as an obstacle to other forms of land use. However, when resilience and long-term productivity is brought into the equation it becomes clear that the options of *conservation*, *management,* and *restoration* are all parts of a single whole in terms of landscape scale sustainability. This perspective is embraced by the concept of land degradation neutrality which, in particular, identifies the critical need to maintain large areas of our natural ecosystems that can be managed under a landscape approach.

Building a resilient planet, addressing land degradation, the loss of biodiversity and ecosystem services, and climate change requires a portfolio of responses, which can be classified under three main management strategies:

- Conservation: maintaining biodiversity and ecosystem services by conserving large natural ecosystems in protected areas and through other effective area-based conservation measures, such as forest watershed conservation and restoration for low-cost, high-quality urban water supplies. Systematic planning can help achieve conservation outcomes through the identification and protection of natural areas with significant biodiversity values, by redirecting development away from natural areas, and by mitigating the impacts of other land uses on these areas.

- Management: the widespread adoption and scaling up of sustainable land management practices is needed to reduce soil degradation and associated offsite impacts, e.g., by avoiding overgrazing, using cover crops, residues and organic compost, water harvesting, sustainable forestry including agroforestry, and adopting low- or no-tillage farming. The main challenge is to make sustainable land management happen in practice and especially in such a way that producers see and profit from the benefits. Mechanisms to stimulate this involve effective stakeholder participation, improved tenure systems, affordability of alternative technologies, legislation and regulation as well as payments for environmental services.

- Restoration: major efforts are needed to restore ecosystem functioning in working landscapes, to support a healthy mosaic of natural and semi-natural components that provide essential services, including those for food production, e.g., pollination, pest control, water and nutrient regulation. Land use planning and policies that incentivize ecosystem restoration or rehabilitation can rely on instruments such as land use zoning to create restoration areas or designate land use and management restrictions within existing ones.

Approaches to conserving natural and semi-natural ecosystems

There is an active debate about how much of the world's land surface should remain in a natural state to ensure the future sustainability of the planet, and about exactly what "natural" means in these circumstances. Two main tools for conserving natural ecosystems are recognized:

Protected areas: the Convention on Biological Diversity (CBD) defines a protected area as: "*A geographically defined area which is designated or regulated and managed to achieve specific conservation objectives*."[30] IUCN has a related definition: "*A clearly*

Box 4: How much conservation do we need?

There is a growing recognition among scientists, indigenous people, and civil society that there must be a limit to the human transformation of the environment in order to safeguard the provision of ecosystem services for future generations. Some argue that we need to conserve half of the Earth in a natural state and that these areas need to be fully representative in terms of ecosystems and biodiversity;[26] it is not enough to conserve mountains tops, deserts, and ice fields. Natural areas need to be linked through biological corridors or other forms of connectivity to avoid ecosystems becoming isolated and genetically impoverished over time.

Aichi target 11: Currently, the main international guidance is from the CBD, which set the following target in 2010: Target 11, aiming to improve the status of biodiversity by safeguarding ecosystems, species, and genetic diversity. It states: "*By 2020 at least 17% of terrestrial and inland water, and 10 % of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas, and other effective area-based conservation measures, and integrated into the wider landscape and seascape.*"[27]

The aim of increasing area of conservation has been supported by the Sustainable Development Goals. SDG target states: "15.1: *By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements*."[28]

Currently around 15 per cent of global land is in a protected area, with an unknown amount in "other effective area-based conservation measures" (OECMs), as stated in Aichi target 11. Given that the 17 per cent goal was set before an OECM was defined, the area target agreed by the international community will likely increase after 2020, although this debate is ongoing. [29] Two questions are intertwined: how much land should be retained in a near-natural state and how should this be managed?

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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."[31] The CBD and IUCN recognize these as equivalent.[32] The details of what "counts" as a protected area are determined by national policy and laws. For example, countries differ in their view of the relationship between indigenous territories and protected areas. Six management categories are recognized, ranging from strictly protected areas set aside to protect biodiversity where human visitation is strictly controlled; to protected landscapes where people and nature co-exist in cultural landscapes. Protected areas can also be managed under a number of different governance types including by governments, communities, indigenous peoples, various profit or not-for-profit private enterprises, or a range of shared governance models.[33] Research shows that if protected areas are adequately resourced and effectively managed, they prevent the loss and degradation of natural land cover.[34,35] Protected areas have also slowed the rate of species loss;[36] there is evidence that some species would probably be extinct without targeted conservation interventions within protected areas.[37,38,39]

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Box 5: Sustainable rangeland management in Tanzania[40]

Population growth and declines in land productivity have increased pressure on land use. As a result, there are a growing number of conflicts occurring between different land users often related to insecure tenure, poor development of land markets, degradation of soil and water resources, deforestation, and increased migration of people and livestock. The sharing of resources (e.g., water, grazing land) and the movement of livestock across village boundaries is the norm, given that lands held by individual villages are usually insufficient to sustain rangeland production systems. However, the breakdown of traditional, local governance regimes has led to higher levels of unsustainable land use, and undermined rural development.

The Village Land Act and the Land Use Planning Act established a legal framework for land use planning at the village level, which helps regulate and improve the use of land resources. It does so by providing conflict resolution mechanisms, improved land tenure security, and the improvement of land husbandry measures, according to the priorities and capacities of stakeholders. The negotiation and protection of rights to resource access of pastoralists, agro-pastoralists, and crop farmers take the form of reciprocal agreements (transhumant herds manure farmers' fields; farmers' livestock are raised in neighboring pastoral areas). Carefully negotiated livestock movements support local livelihoods and sustainable rangeland management, and contribute to national economic growth. In addition, the Act strengthened local level decision-making through institutional capacity building at the district and village levels. Participatory land use management teams were established and trained as part of the process to better manage land, and deal with land use conflicts.

Other effective area-based conservation measures: a new category, emerging from debates within the CBD and still in the process of being finally defined. OECMs recognize that many areas of the planet must be retained in a natural state for reasons other than conservation and that effective broad-scale planning efforts need to understand and quantify these contributions to ecosystem services.[41] A preliminary definition is: "*A geographically defined space, not recognized as a protected area, which is governed and managed over the long-term in ways that deliver the effective and enduring in-situ conservation of biodiversity, with associated ecosystem services and cultural and spiritual values*."[42] OECMs include places that are not being managed primarily for biodiversity conservation but which nonetheless have important conservation values and a reasonable expectation of being maintained in their current state for the long term.[43] It remains unclear how OECMs will be incorporated into national and international land management targets, but they open up more possibilities for retaining natural vegetation, making the target of preserving half the world in a natural state more attainable.

Global policy initiatives to increase restoration

The Bonn Challenge is a global aspirational challenge to restore 150 million hectares of the world's degraded and deforested lands by 2020 and 350 million hectares by 2030.[44] It is a vehicle for addressing national priorities such as water and food security and rural development while contributing to the achievement of international climate change, biodiversity, and land degradation commitments. Regional implementation platforms for the Bonn Challenge are emerging around the world, including Initiative 20x20 in Latin America and the Caribbean, AFR100 for Africa, and ministerial roundtables in Latin America, East and Central Africa, and the Asia-Pacific region. The Bonn Challenge is overseen by the Global Partnership on Forest Landscape Restoration, involving over 20 institutions. It already has commitments in excess of two-thirds of the 2020 goal, for instance 2 million hectares from Rwanda,[45] 12 million hectares from Cameroon,[46] 12 million hectares in Brazil,[47] and 13 million hectares from India.[48] The Bonn Challenge builds on the experiences of major restoration initiatives that have already proved effective, such as the case of the Republic of Korea.[49] It is not a new global commitment but rather a practical means of realizing many existing international commitments, including the CBD's Aichi Target 15, the UNFCCC REDD+ goal, and now SDG target 15.3 on land degradation neutrality.

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Box 6: Incorporating climate-smart regional planning using a collaborative approach

The Trifinio territory is a historically marginalized area on the border of El Salvador, Guatemala, and Honduras, containing 45 municipalities and 800,000 people, mainly dependent on subsistence farming. Slash and burn agriculture and poor infrastructure have led to widespread ecosystem degradation. Restoration is in the interest of all three countries, since the watersheds provide each with hydropower and municipal water. The region also has high biodiversity values, including endemic species found in the Montecristo Cloud Forest. In 1987, a tri-national agreement was made to finance research, regional capacity, reforestation, and flood control in Trifinio. But after nearly 30 years of cooperation, while some progress had been made, efforts were hindered by centralized approaches, which excluded local communities. Challenges remained, including extreme poverty, overexploitation leading to land and watershed degradation, and increased climate variability.

In 2014, these challenges were addressed through direct engagement of the people working the land, assisted by the Mesoamerican Agroenvironmental Program of the Tropical Agricultural Research and Higher Education Center (CATIE-MAP), a regional center that champions the Climate-Smart Territory (CST) model of integrated landscape management. The CST model assumes that rural people depend heavily on natural resources and are thus affected by ecosystem quality, implying that management needs the involvement and buy-in of local actors. The boundaries of the landscape are defined by how stakeholders interact with ecosystems. Commonalities in land use create a group bounded by a shared sense of place. The resulting stewardship establishes the unit's authority to guide and lead land use decisions to address challenges including from climate change. The input of people with intimate knowledge of local climate change helped decide how best to target investments, build land use planning capacity, and support climate change resilience on the ground.

By supporting multi-stakeholder platforms, CATIE-MAP builds the capacity of local people to improve the management of natural, human, and social capital, thus increasing climate change resilience. To open market opportunities, CATIE-MAP works to strengthen producer organizations and associated value chains. Practical and easy-to-use innovations in the management of water, solid waste, soil management, and crop production empowers local people to contribute to larger conservation goals while accessing a more reliable and nutritious source of food. It gives a historically marginalized population critical leverage in the design of policies that directly affect their livelihoods.

Box 7: Land restoration in Israel through privatization and economic incentives[50]

The Northern Negev in Israel is at the interface between arid and semi-arid climate. Due to good soil quality, the area has been exploited for rain-fed field crops, grazing, and agroforestry for thousands of years. However, years of neglect and turmoil after the demise of the Byzantine Empire has left the ecosystems and farmlands profoundly degraded. Traditional land use and ownership were disrupted during the creation of the state of Israel, with land transformed to public rangeland, intensive agriculture, or forestry leaving a large area under disputed ownership. Traditional livestock management suffered under deteriorating rangeland productivity due to intensive grazing, excessive land tilling, and misguided forestry practices.[51,52]

Private farms for mostly rain-fed extensive agriculture were created to improve management of open rangelands. Selected Jewish and Bedouin farmers were allocated 100 ha farms (50 year leases), linked to detailed management proposals. Private initiative coupled with scientific advice and ad hoc learning applied on two properties, Yattir Farm[53] and Abu Rabbia Farm,[54] allowed cheap, rapid, and effective restoration of biological productivity, range improvement,[55] and creation of enhanced grazing potential. Planting of olive orchards, other fruit trees, medical plants, and silvopasture trees enhanced watershed protection, soil and biodiversity conservation, and economic potential.

The impact of improved farm management was significant on both farms. Soil recovery and terrace agroforestry reduced erosion, and increased carbon sequestration into biomass and soil organic matter. Farm income has risen due to higher fodder availability,[56] income from olive oil, and other agroforestry products.[57] More biodiversity increased ecosystem resilience and provides a significant ecotourism potential.[58] The well documented recovery from a limited number of low-cost restoration measures make widespread application of such initiatives a promising option for large-scale restoration of agro-ecological landscapes.

Photos: Stone terraces across dry riverbeds at Aby Rabbia Farm create ideal conditions for olive and other agroforestry trees (left). Planted Acacia victoriae trees at Yattir Farm together with conservation management and manure application allowed tripling range productivity within 20 years (right).

RESPONSE 3: Farming for multiple benefits

Key concepts

- **Efficient agriculture is critical to global food supply, but the huge land area dominated by croplands and rangelands makes these areas vital for ecosystem services as well**
- **A fundamental shift in agricultural practices is required to give better recognition to and support for wider ecosystem and social services provided by these lands**
- **Such a shift could be of critical value to the half billion small farmers existing often in more marginal areas, and who are currently in danger of being displaced**

WHAT'S NEW?

Farmers have for generations been judged almost entirely on their ability to produce food, as abundantly and cheaply as possible, with any other benefits regarded as "extras" which are sometimes compensated for, but often not. Expanding the scope of agriculture to include a broader range of benefits, and bringing ecosystem services and cultural values into the heart of farmers' enterprise, would be as profound a shift as the wave of industrialization that began after 1945.

Agriculture plays the most fundamental and irreplaceable role in human society by providing food. The modernization of agriculture over the last seventy years – a process still underway – has reduced the risk of global famine during a period when human populations have increased at unprecedented rates. However, these increases in yields have come at a heavy price, in terms of offsite impacts, pollution, energy use, and a global food system that has increased inequalities and driven many smaller farmers out of business. These impacts are in turn undermining the sustainability of the global food system. Changes in consumption patterns, diets, and expectations, have undermined many of the increases in productivity per unit of land area. The side effects of modern agriculture are eroding the ecosystem functioning upon which food production ultimately relies, meaning that whatever the efficiencies attained today, the long-term sustainability of agriculture is under threat.

Small farmers, the backbone of rural livelihoods and food production for millennia, are under immense strain from land degradation, insecure tenure, and a globalized food system that favors concentrated, large-scale, and highly mechanized agribusiness. Many individual farmers feel locked into the current system because their margins are so tight that any deviation can result in bankruptcy. Many of the world's smallest farmers have neither the capacity nor the capital to make significant changes.

These costs are not inevitable and shifts are occurring. There are ways of growing food without excessive environmental costs, both through modifications to conventional systems and alternative production pathways where yields are fast approaching those of more intensive systems. A new deal for farmers is therefore required, comprising four main elements:

1. Policies that help switch the emphasis of food production towards land stewardship for the provision of multiple benefits.[59]
2. Development and application of methods that measure farm output in terms that are more than just yield per area, but include nutritional value, and wider values in terms of both the costs to environment and society, and benefits of a healthy landscape.[60]
3. Pricing policies that achieve a balance between the needs of consumers to access healthy and nutritious food and producers to stay in business.[61]
4. Targeted support, including through Payment for Ecosystem Service schemes and similar schemes that offer positive incentives for multifunctional land management.[62]

Most of the elements outlined above have already been developed or are in use. The question is primarily one of scaling up, an issue discussed below.

This new deal will also change the perceptions and values of the half billion small farms. Of the 1.3 billion people employed in agriculture, roughly a billion operate farms of less than 2 hectares, which provide much of the food eaten by urban residents in developing countries.[63] These small-scale farms support livelihoods and enforce cultural identity often with no viable alternatives for the farmers concerned. In cases where rural communities want to stay on and work the land, incentives can help maintain their position. Small farmers with an intimate knowledge of and feeling for their particular land are often in a good position to adopt sustainable land management policies. Yet historical trends suggest that many will disappear in the next few years, driven out by economies of scale, urbanization, changing expectations in rural communities, and in some cases by deliberate policies ranging from agricultural subsidies that favor consolidation to land grabbing.

These half billion small farms play a critical role in providing food for rural households – perhaps a fifth of the world's population – who are among those least able to meet this demand by entering the cash economy. In addition, small farms and grazing herds are increasingly operating on marginal agricultural land. While abandonment might provide opportunities for the restoration of more natural ecosystems and the accompanying ecosystem services, in other cases farmers themselves play or could play a critical role in maintaining these services. A shift from farming solely for food production towards farming for multiple purposes would provide extra incentives and a lifeline for many millions of the poorest land managers, itself an important positive outcome.

Sustainable intensification

Research drawing on data from 85 projects in 24 countries calculated that 50 per cent of all pesticides are not necessary for agricultural benefit.[64] Resource-conserving agriculture can be highly efficient, as can labor-intensive, lower external-input small farms, frequently producing higher yields than conventional systems.[65] Intensification of agriculture, often blamed for many environmental problems, is not bad in itself, but rather it is the type of intensification that is important.[66] The concept of "sustainable intensification" is gaining increasing attention from policy-makers,[67] including in particular integrated nutrient and pest management approaches, which are already being used on many millions of farms.

Evidence shows that higher yields can be achieved despite reductions in pesticide use,[68] pest management can be assisted by ensuring intra-specific crop diversity,[69,70] and efficient agriculture does not require large-scale monocultures.[71] These types of intensification strategies can help address both food insecurity and biodiversity decline.[72] These gains become even more apparent if calculations of agricultural efficiency include values such as net nutritional benefits, offsite impacts on the use of water and energy, rather than just productivity per area.[73] Yet there is comparatively little investment for research into lower external-input systems, and they remain significantly undervalued. There are a variety of reasons. In part there has been opposition from vested interests but also a poor understanding of comparative externalities and the productivity of small farms, leading to lack of support in trade and agricultural policies.[74]


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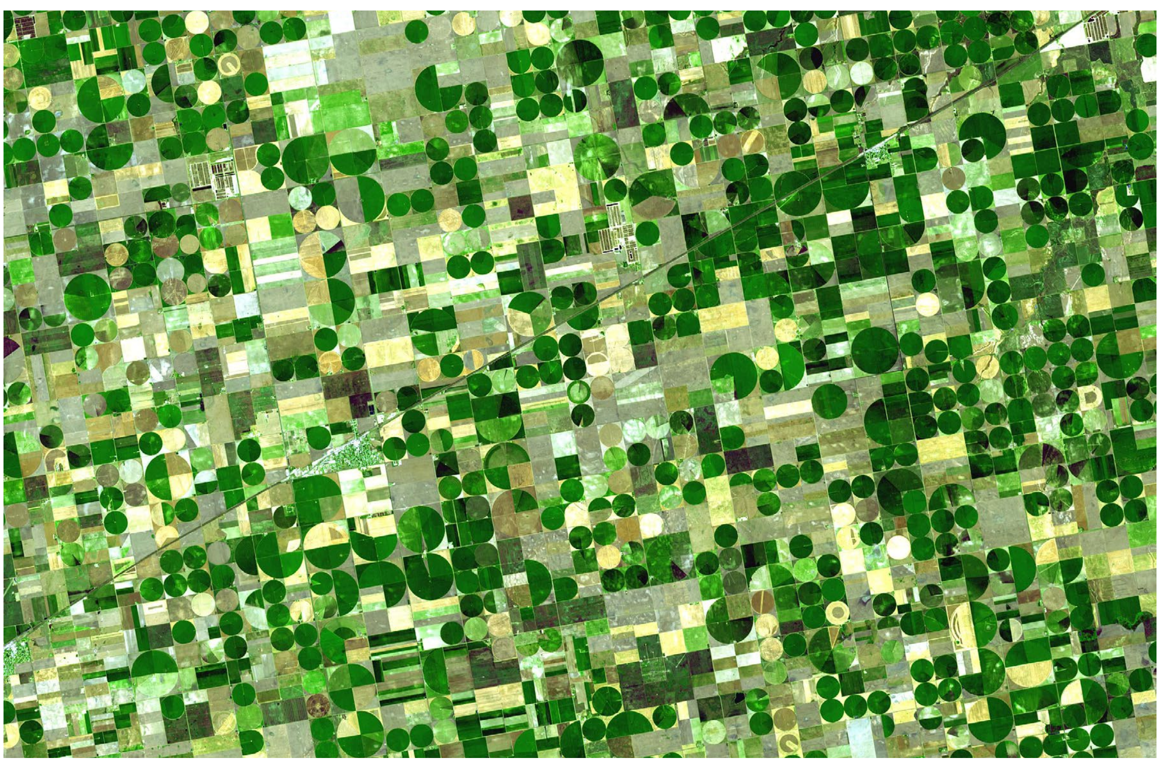
Box 8: Going organic at the state and national level

In parts of the world, organic agriculture is moving from the margins to be a major or sole mode of production.

India: In January 2016, Sikkim became India's first state to go fully organic. It took 10 years for Sikkim to convert 75,000 hectares of farmland into certified organic farms.[75] The state now produces 800,000 tons of produce, accounting for nearly 65 per cent of all of India's 1.24 million tons of organic produce. Sikkim is a model state for the world because nature's services are protected while demonstrating that going organic does not mean falling productivity nor is development compromised. The five steps illustrate how other states can follow.

Bhutan: In 2011, the mountain nation of Bhutan announced a lofty goal to make the country's agricultural system 100 per cent organic by the year 2020. If successful, it would be the first country in the world to go wholly organic in its food production. With only 700,000 people living within its borders, most of whom are farmers, the only challenge is to demonstrate that the benefits outweigh the costs and that yields are not affected by using only natural fertilizers. Bhutan's organic strategy is to take a step-by-step approach, advancing region-by-region, product-by-product recognizing that new innovations are essential to find ways to naturally eradicate diseases and improve crop yields.[76] Simultaneously, if organic produce is to be economically viable, the capacity for certification needs to be developed within Bhutan.



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RESPONSE 4: Managing the rural-urban interface

Key concepts

- **Cities designed for sustainability can reduce the environmental costs of transport, food supply, and energy as well as offer new opportunities for recycling and resource efficiency**
- **Rural-urban migration can also take pressure off the land, particularly in marginal areas least suited for intensive production**
- **Particular challenges relate to managing the rural-urban interface: cities bring new pressures to bear on the surrounding landscape in terms of resource demands and pollution, but also offer chances for targeted support to rural communities**
- **As cities grow, deliberate and planned cooperation with people in surrounding landscapes will increase the chances of positive synergies developing**

WHAT'S NEW?

Environmental analyses usually treat cities as a problem or ignore them altogether. Yet soon over half of the world's population will live in cities and the ways that cities are planned and managed has and will have profound impacts on the rest of the planet. By focusing explicitly on the interface between city and country – both immediately in the peri-urban or suburban areas but also through consideration of the wider urban footprint – this Outlook focuses attention on the places which will have the greatest impact on the way that land is managed for the rest of the 21st century and beyond.

Urbanization is taking place at an unprecedented rate, and this increase looks set to continue, altering the balance between rural and urban dwellers in ways that have never been seen before. This presents numerous challenges, as outlined in Chapter 11, but also presents a range of opportunities to improve livelihoods within cities and to reduce their footprint, which is often global in reach.

These challenges and opportunities are perhaps greatest in the new cities including emerging medium-sized cities.[77] Large cities with a long history – like Paris, Washington, or Buenos Aires – have already made many of their decisions about natural resource use. However, cities that are currently expanding rapidly, including megacities like Lagos[78] but many smaller cities in countries like China, still remain largely unnoticed by the rest of the world and debates about sustainability.

Urban areas interact with rural communities in two distinct ways: in peri-urban areas and immediate rural surroundings, and on other land areas that may be very distant through demands for food, energy, and other materials.

Decisions taken over the next few years will determine their future transport policies, energy policies, resource use, and overall footprint. It is much more cost-effective to start with a plan for a sustainable city than to try and retrofit one in the future.[79]

In those peri-urban areas, urbanization brings new pressures and demands but also fresh opportunities. There will likely be a net cost in terms of land use due to new buildings, roads and rail, and other infrastructure development.[80] Traditional land uses may also be affected by new demands for ecosystem services, such as watershed protection, landslide control, or recreational areas, so that farms may be converted back to forested watersheds and natural areas to ensure water supply and create areas for city dwellers to go walking. Protected areas close to urban areas are expanding around the world and play an important role in reconnecting city dwellers to the natural world.[81] Municipal authorities have a key role to play in extending their planning beyond the city boundary, to consider how the competing demands for land can be balanced within the city. Tools such as green belts that limit urban spread or Payments for Ecosystem Service schemes can all help to optimize land use in the areas surrounding cities. Positive support and incentives for locally-grown food, such as subsidized farmers' markets, can help small producers to compete against larger, more distant food enterprises, thus reducing the overall food footprint.[82]

Cities impact more remote areas as well, both within countries through demand for food, transport links, and energy but also to an increasing extent in terms of land-intensive imports from other countries. Positive initiatives, such as certified sustainable or fair trade products, can help to ensure that negative aspects of the distant urban footprint are minimized.[83]

Sustainable cities require a new style of municipal leadership; thinking globally but acting locally. At a time when national governments are in many cases reducing their influence, cities are sometimes taking over leadership in innovation. Where state or national governments have been unable to take steps to reduce environmental impacts of urban development, positive models have come instead from city councils. This is seldom straightforward; cities often do not have the budget or expertise to take over the role of the state, and may be hampered by national level policies, but the political landscape is changing. Building this capacity, particularly in developing countries undergoing rapid expansion, is a key priority for the immediate future.

Box 9: Cities taking the initiative

Throughout the world, urban areas are showing initiative in addressing land-related challenges.

Bogotá, Colombia: the capital city enjoys clean water courtesy of several protected areas and other conserved watersheds. Over 80 per cent of the population receive their drinking water from Chingaza National Park, an area where valuable *paramos* vegetation is conserved.

Seoul, South Korea: Bukhansan National Park, close to the capital city, receives up to a staggering 10 million visitors a year, predominantly Korean citizens. Despite major urbanization only being a generation old, Korea's city dwellers have learned to appreciate and use natural areas in urban hinterlands throughout the country.

Australia, the United States, and others: a national network helps city dwellers to support local producers, through farmers' markets, Community Supported Agriculture (CSA) schemes whereby individuals contract with farmers to buy regular supplies of food, and through local box schemes.

RESPONSE 5: No net loss in the consumption and production of natural resources

Key concepts

- **Applying the concept of no net loss switches the emphasis from a narrow focus on yield to a broader perspective of the total benefits from food production**
- **No net loss in healthy and productive land means no net negative environmental or social impacts offsite**
- **No net loss in food processing and retail is an aspirational target recognizing the need to minimize the current levels of food waste and loss within the system**
- **The concept of no net loss will be a major challenge but if accepted would help to revolutionize approaches that reduce pressure on land resources**
- **The concept of no net loss is discussed below in terms of food production but has clear application in other natural resource sectors, such as forestry, mining, hydropower, and dryland management**

WHAT'S NEW?

Dramatic increases in crop yields have been accompanied, paradoxically, by equally dramatic costs to environmental and human health, such as accelerated land and soil degradation, water shortages, pollution, and the loss of species and natural habitats. In spite of food production increases, we are now experiencing widespread food insecurity in what should be a world of plenty. Attempts to address these issues have largely been reactive, piecemeal, and ineffective. This Outlook proposes a more comprehensive and serious response.

Around the world, inefficiencies and waste in the production and consumption of land-based commodities and the value chains that connect them significantly increase pressures on land resources, hindering the full realization of their biological and economic potential. No system is perfect and losses are bound to occur. But by pursuing a strategy of no net loss, we can incentivize a certain amount of restoration and other remedial actions needed to balance net costs in terms of leakage from agricultural systems or wastage further down the food distribution chain. The 10 steps, elaborated in Chapter 7, for addressing some of the land challenges for the modern agricultural systems are summarized here.

While most of these issues have already been addressed, here we look at the role of global value chains, shifting diets, and food waste/loss as they provide immediate opportunities to relieve pressure on land resources.

Box 10: Ten steps for greater food security

1. Close the gap between actual and potential yield in all environments
2. Use land, water, nutrients, and pesticides more efficiently
3. Reduce offsite impacts of food and non-food production
4. Stop expanding the agricultural frontier
5. Shift to more plant-based and whole food diets
6. Raise awareness about health, sustainability, and responsibility
7. Reward sustainable land management practices
8. Reduce food waste and post-harvest losses
9. Improve land tenure security and gender equity
10. Implement integrated landscape management approaches

Global values chains in agriculture[84]

Agribusiness has changed dramatically in the last 50 years and now involves complex networks, known as Global Value Chains (GVC),[85] usually spanning many countries.[86] GVCs account for about 80 per cent of global trade, and 30 per cent of the value-added in developing country economies.[87] The main outcome of this type of market arrangement is that trade has displaced many environmental pressures from developed to developing countries where governance and the enforcement of environmental standards are often weaker.[88] Most value chains are demand-driven, with major supermarkets as the chief buyers and large traders acting as intermediaries. Supermarkets have expanded rapidly throughout the world[89] and retain the power[90] to determine prices and influence production practices as a result of their economies of scale. Food producers are often forced to engage with companies via contract farming agreements, which set the terms for what, how much, when, and at what price goods will be purchased.[91]

The Chinese government has outlined a plan to reduce its citizens' meat consumption by 50 per cent in order to improve public health and significantly reduce greenhouse gas emissions.

Given the fierce competition in the retail sector, companies must assure that their operations are cost-effective. They implement private and public standards in their supply chains, to ensure quality standards and compliance with desired social and environmental performance. These standards have positive impacts by assuring consumers that food meets a set quality level and that production has not created negative socio-environmental impacts. However, the standards can also represent a burden on small farmers' livelihoods. They often do not have the financial and technical resources to comply with rigorous standards, thus risk being excluded from a retailer's value chain. At the same time, their welfare is affected by other business practices, such as delays in payments, price points that encourage bulk sales (e.g., buy one, get two promotions), and cosmetic standards (e.g., shape/color of the fruits and vegetables).[92]

Thus small producers must either comply or exit the value chain and enter into traditional or informal markets.[93] When neither option is lucrative, the only option left is for smallholders to sell, often to companies involved in large plantations, leading to the further consolidation of agricultural lands. Alternatively, farmers may try to expand output to make up for lower profits which, in developing countries, often leads to land-use change and deforestation. The power imbalance between buyers and producers is distorting markets and squeezing small farmers out of business. Public policies to address this imbalance can include financial mechanisms that incentivize sustainable agriculture; laws to ensure fair deals between supermarkets and small farmers; and policies to help farmers overcome market failures that prevent them from accessing more distant markets.

Encourage dietary shifts away from land-intensive foods with long value chains, such as animal products, processed foods, and out-of-season fruits and vegetables. A shift away from land, water-, and energy-intensive commodities will help increase food security and long-term sustainability. At the same time, it would decrease food prices in developing countries while reducing the health-related costs of overconsumption and environmental degradation. Reducing food miles would also reduce land pressures: in "short-chain" systems, food passes directly from producers to consumers, such as in subsistence farming, farmers' markets, or where school-meals programmes source local food.

Governments and corporations have a key role to play in awareness raising and encouraging dietary changes, such as the adoption of meat-free days and non-dairy milks/products, vegetarian school meals, and persuasive dietary guidelines. For example, the Chinese government has outlined a plan to reduce its citizens' meat consumption by 50 per cent in order to improve public health and significantly reduce greenhouse gas emissions. If successful, the new dietary guidelines would reduce per capita meat consumption between 14-27 kg a year.[94] These types of initiatives can focus on the role of nutrition in the development of chronic disease; physiological reasons we are drawn to foods that do not support health; environmental consequences of food choices; or the holistic rationale for whole food, plant-based nutrition. These awareness-raising strategies have already helped millions of people around the world transition to plant-based diets.

Reducing food waste and loss throughout the food supply chain is the responsibility of consumers, producers, corporations, and governments to help alleviate land system pressures. About one third of the food produced is lost or wasted. In the developing countries, food losses mainly occur post-harvest or during processing, storage, and transport while in developed countries food losses are primarily at the retail and consumer levels.

The main reason for consumer food waste in wealthy countries is that people can afford to waste food. Consumers in industrialized countries throw away up to 40 per cent of the food they buy, and organic matter in landfills generates 20 per cent of all methane emissions,[95] a potent greenhouse gas. This type of behavior is encouraged by multiple factors, such as restaurants that serve buffets at fixed prices and retail stores that offer incentives for large purchases of a single commodity. When not consumed, food disposal is often seen as cheaper and easier than using or re-using, such as composting waste into nutrient-rich fertilizer.

Consumers in the developed world also expect a wide range of products to be available, which increases the likelihood of some of them reaching their "sell-by" date and thus being wasted. One effective approach to reducing waste is to develop markets for "sub-standard" products whereby commercial and non-profit organizations could arrange for the collection and sale or use of discarded foodstuffs that are still safe, taste good, and have nutritional value. Changes in consumer attitudes will only come about through education, awareness, and public sector initiatives that are supported by the marketing and retail sectors. Consumers are generally willing to buy irregular or damaged produce as long as the taste is not affected.[96] One approach to reducing this type of waste is selling fruits and vegetables directly to consumers – without having to pass the quality standards set up by supermarkets on weight, size, and appearance – through local farmers' markets, food cooperatives, and community-supported agriculture initiatives.

Finally, consumers can tackle food waste in a meaningful, systemic way, incentivizing change through cuisine. This has been done for thousands of years in food cultures around the world, founded on diversity and resourcefulness in the field and supported by creativity and culinary techniques. In the past, this meant taking advantage of what the land could readily supply seasonally and resulted in a food system ruled by diversity and efficiency.[97]

Reducing post-harvest losses, including food left to rot in the fields and that which perishes during storage and transport due to a lack of infrastructure. This results in reduced income for small farmers and higher prices for poor consumers in food-insecure countries. Food losses generally occur in the early stages of the value chain and vary according to the crop and harvesting technique. These can occur as a result of financial, labor, or technical constraints in the field, or market and infrastructure limitations that prevent adequate storage, processing, and distribution.[98] Strengthening the supply chain through the direct support of farmers and investments in infrastructure, transportation, as well as in an expansion of the food and packaging industry could help to reduce the amount of food loss.[99]

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RESPONSE 6: Creating an enabling environment and scaling up for success

Key concepts

- **Creating an enabling environment means supporting the right underlying social and economic conditions that allow progress, particularly those relating to stakeholder engagement, land tenure, gender equality, and the availability of sustained investment and infrastructure**
- **Most of the techniques and practices needed to achieve Land Degradation Neutrality and no net loss in sustainable consumption and production are known and tested, but there are major challenges in scaling up small enterprises to a landscape scale**
- **Once these pre-conditions are in place, a conscious process for scaling up good practices embedded in the design of projects and programmes needs to be implemented. An eight step process for scaling up is described**

WHAT'S NEW?

There is a lot of talk about the need to scale up best practices in sustainable land management, but projects rarely plan a scaling-up strategy. Tools are available including scale considerations in the design and planning phase, the use of peer-to-peer learning, and information dissemination through local modes of communication, but most often the financing for these types of activities is lacking. Small, inspirational projects have a role to play but are no longer enough. We need to go to scale.

Despite decades of research and work on sustainable land management,[100] the evidence and analysis presented in this Outlook show that we are still losing ground in terms of global land health and productivity. This is far from inevitable: many examples of successful management exist. Yet the multitude of small-scale projects has not substantially translated into large-scale adoption. While some of the inertia can be accounted for by the many vested interests relying on the business model of the current food system, these obstacles are not immoveable. Technologies that nurture the adoption and spread of sustainable land management rely on approaches and institutions that enable and empower people. An enabling environment helps foster shared responsibility in managing trade-offs so as to balance economic development with environmental sustainability. Issues like participatory processes and tenure and gender equality can seem a long way from the technical details of soil management or supply chains but are central to overall success in scaling up. Below we outline some of the most important elements.

1. Stakeholder engagement: A landscape approach can help reconcile different perceptions and ensure that land is not viewed solely in utilitarian or financial terms, but also managed in ways that account for the indirect or intangible ecosystem services that provide cultural identity and a viable future for the rural sector while protecting multiple functions of land. Several elements are considered important:

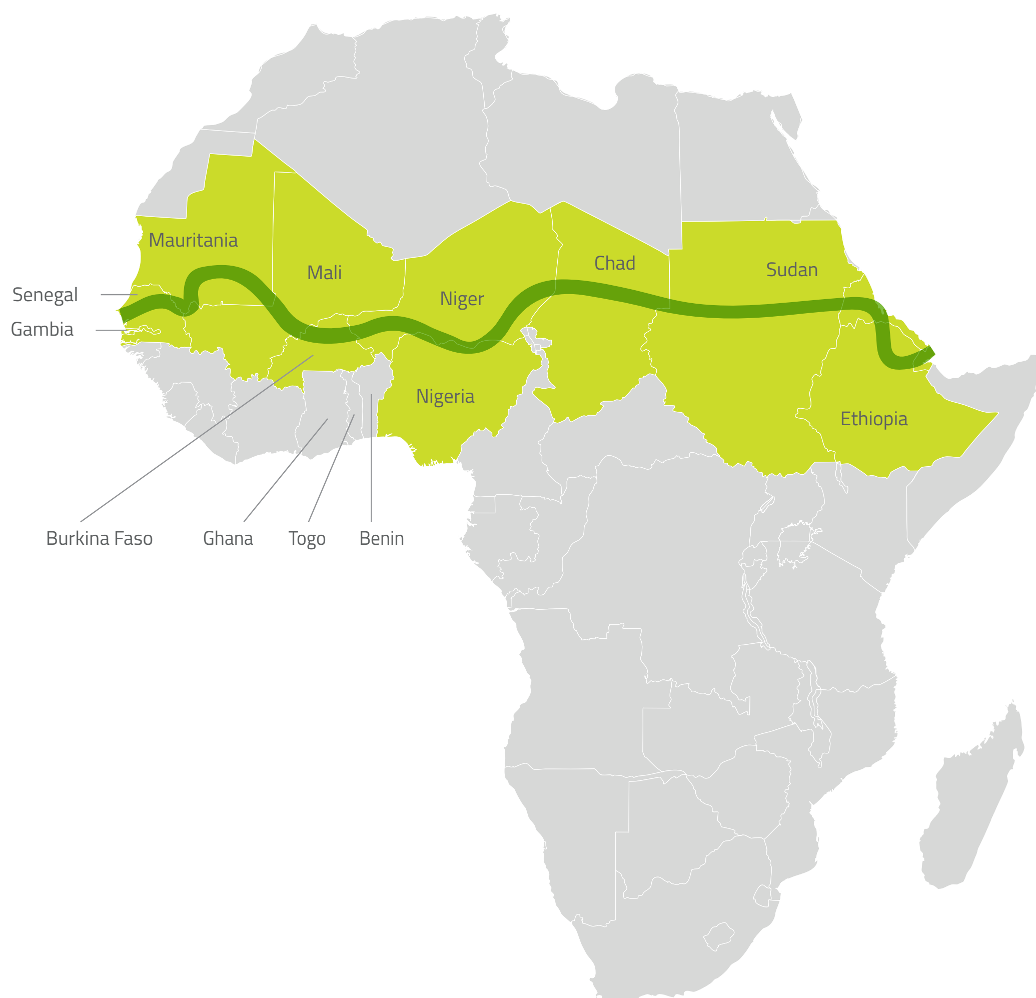
- Negotiating trade-offs and developing the structures and institutions that endure and that all stakeholders respect and are prepared to work with. These may be existing arrangements, such as local government bodies, traditional community councils, religious and farmers' organizations, or may be established especially for the purpose of scaling up.
- Addressing inequities in tenure, gender, access, income, and social justice. Sustainable management in the long term depends on everyone having a stake and being respected. The rights of religious and cultural minorities, and the rights of women and children, usually need particular attention.
- Supporting a viable future for the rural sector, such as access to markets, energy, and infrastructure. Rural transformation is resulting in larger, more consolidated land holdings and the displacement of small-scale farmers.
- Recognizing wider needs: land is not a purely biophysical resource but is also imbued with many historical, cultural, emotional, and spiritual values, and a sense of belonging.
- Addressing the moral and ethical imperatives: there is also a powerful ethical case that humans do not have the right to drive species and ecosystems into extinction.

Box 11: Building a great green wall in Africa

As early as the 1980s, Thomas Sankara, then President of Burkina Faso, proposed re-greening the Sahel. In 2007, the *Great Green Wall for the Sahara and Sahel* initiative was adopted by African Union. The initiative is a harmonized regional strategy[101] to create a mosaic of green and productive landscapes across North Africa, the Sahel, and the Horn. Farmers will manage the natural regeneration of forests, croplands, and grasslands. Where degradation is severe, active restoration is needed, involving communities in selecting native species. The Wall will cross arid and semi-arid zones to the north and south of the Sahara: a 15 km wide belt of 7,775 km from Dakar to Djibouti, with a core area of 780 million hectares, supporting 232 million people. Around 10 million hectares will need to be restored each year.[102] The wall aims to reverse land degradation by 2025 and achieve regional transformation of the land by 2050.

Many changes have already taken place:[103,104]

- Ethiopia: 15 million hectares of degraded land restored, improving water catchments and land tenure security; with incentives for communities to participate.
- Burkina Faso, Mali, and Niger: about 120 communities involved in re-greening; more than two million seeds and seedlings planted from fifty native species.
- Nigeria: 5 million hectares restored including 319 km of windbreaks; 20,000 jobs created. In northern Nigeria 5,000 farmers have been trained in regeneration and over 500 youths employed as forest guards.
- Senegal: 11.4 million trees planted; 1,500 km of firewalls; 10,000 ha using assisted natural regeneration; in all 24,600 hectares of degraded land restored.
- Sudan: 2,000 hectares of land restored.



Box 12: China's great green wall

Deserts cover almost one fifth of China, with more areas at risk of desertification, especially in dry western China, which is also among the poorest regions. The livelihoods of 400 million people are threatened or affected by degradation and encroaching deserts. Rapid industrialization and urbanization have eaten up farmland, compounding an already severe problem. Timber extraction has exposed vulnerable land to encroaching sands. A prolonged drought in northwestern China has made things worse, intensifying dust and sand storms.

Since 1978 a *Great Green Wall* of trees, shrubs, and grasses has been planted in the Kubuqi Desert to protect northern cities, costing USD 6.3 million, and slowing desertification from roughly 3,400 km^2 a year in the 1990s to some 2,000 km^2 a year since 2001. According to a government survey, by 2010 12,452 km^2 of desertification-prone lands had been rehabilitated, although in some areas desertification has increased.[105]

The Kubuqi Desert is one of the world's wettest deserts and sand is relatively moist at 20 cm depth Saplings of Xinjiang poplars and willows are protected by wooden frames, sunk in the sand, where roots help to stabilize mobile dunes. Local farmers, formerly skeptical, are now supportive of restoration.[106] However, desertification remains serious and restoration only partially successful.[107] Planting has generally been with monocultures of non-native species and many died; one pest outbreak killed a billion poplars.[108] Strategic changes are needed if the huge ambitions are to be fully realized.

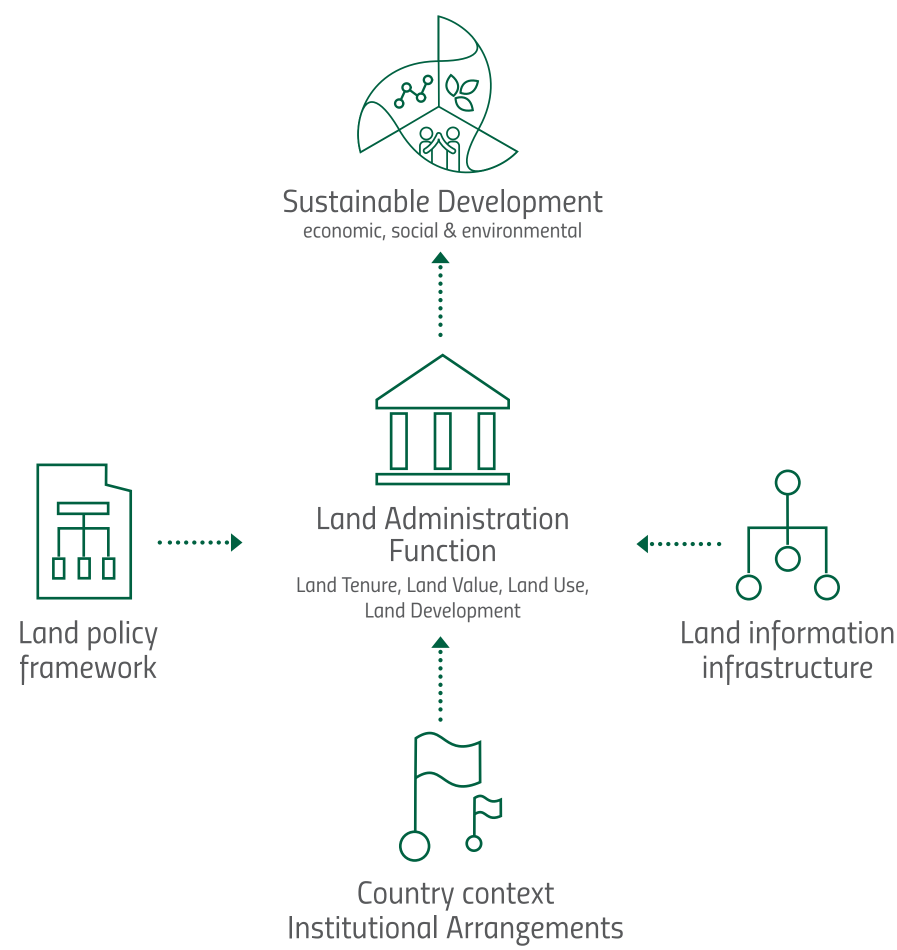
2. Land tenure and gender equality: Weak governance of tenure is a major constraint in planning for and achieving sustainable development; it can lead to land degradation and exacerbate conflicts over the use of land resources. Conversely, secure resource rights and land tenure contributes to the uptake of sustainable land management practices. Insecure land tenure still exists around the world, even though many countries have completely restructured their legal and regulatory frameworks for land administration, in many cases harmonizing modern statutory law with customary rights.

In many developing countries, more effective policy and legal reforms are needed to safeguard these rights for smallholders, rural communities, indigenous people, and women. In some cases, this includes empowering traditional and customary land users within formal land administration systems to increase their confidence in making long-term investments in the land. Equal rights for both women and men to hold and use property are a cornerstone of social, political, and economic progress.

It is widely acknowledged that women play a pivotal role in conserving and managing land resources. While some countries have recognized women's land rights in their constitutions and laws, in most developing countries, the predominance of patriarchal systems relegates women to minority positions, ensuring that women only have access to land and related resources through their spouse or male relatives. This system of primary (male) and secondary (female) access to land – through which rural women suffer insecurity of land tenure – impacts the way men and women manage natural resources both individually and in communal areas.

Land is a critical resource for women, particularly when they become heads of household, which may occur through male migration, abandonment, divorce, or death. In both urban and rural settings, secure property rights for women can mean the difference between dependence on natal family support and the ability to form a viable, self-reliant, female-headed household. Equally, ensuring women's land rights during marriage may afford them greater claims on the disposition of assets in the case of divorce or death of their husband.[110]

Figure 4: Land administrative functions for sustainable development:
Redrawn from[109]



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Box 13: Empowering women and small producers in the Peruvian Altiplano[111]

The Peruvian Altiplano is one of the world's poorest areas. High climatic variability, high altitude, land fragmentation, and limited access to markets and financial resources drive highly diverse and complex potato-based farming and low productivity livestock systems, in which the main goal is the minimization of food vulnerability and climate-related risks. Farming is on family-owned smallholdings and communal land, which provide an average annual income of USD 517 (±183) per capita per year.

In order to improve farm productivity and family income, and reduce vulnerability by improving resilience of farming systems, an integrated systems approach was used and three activities selected to organize value chains for quinoa cropping, dairy farming, and trout farming. The work involved over 120 rural communities and best practices were selected based on the climate, the human and natural resources of the region, and the competitive advantage of production options based on improving market opportunities, income, and women's empowerment. The organization of producers' groups, technical support, improved market access through value-added products, social participation, availability of credit for investment in productive activities, and livelihood diversification were critical factors promoting scaling up.

Producers were encouraged to dedicate more resources to quinoa production, formerly a low priority crop for consumption. 1,175 families participated in organic quinoa production, which received supervised credit support plus processing and marketing assistance. Due to an increase in planted area, higher yields, and more exports, annual net family quinoa income increased from USD 72 to USD 700 from 2006 to 2011. Milk production increased substantially with additional forage, feed, and the introduction of small silos. Fourteen producer-run cheese factories raised annual dairy income per family from USD 29 to USD 767 by 2011; the factories themselves generated an average yearly income of USD 3,328 per participant family.

The project also organized 84 families in seven groups, and provided training and credit to start trout farms; women's participation was close to 50 per cent. The groups planned and managed the production process, built the basic infrastructure, standardized the product, managed production costs, and marketed their produce. Over five years, the farms produced 4,421 tons of trout with a gross value exceeding USD 11 million. Annual income per participating family ranged from USD 784 to USD 7,788.

Land tenure is an important factor in land use planning given that selected land use options may pre-determine a pool of potential users, or vice versa, where the type of land tenure or governance regime narrows the range of land use options. In turn, land use planning can improve governance by fostering:

Policy and legal frameworks: Policy and legal reforms need to ensure security of land tenure and resource rights for smallholder farmers, women, and rural communities. This involves pro-poor land policies and laws that ensure tenure and enforcement mechanisms, while empowering smallholder farmers to make use of the law. Land often belongs to a "community," which may include different ethnic groups and land user types, so defining land rights often needs to account for traditional governance systems and instruments of negotiation.

Conflict or dispute resolution: The nature and scope of conflicts must be characterized before intervention occurs. Decisions must be enforceable, and adjudications provided. Resolution mechanisms are only likely to be successful if viewed by citizens as legitimate. The means of accommodating the "losers" of the dispute or conflict must also be provided.

Redistribution: Access and land allocation patterns must be identified, along with sources of available land, if distribution is an option. Rental markets should provide access to all, including indigenous peoples and women. When appropriate, land redistribution should be accompanied by a transparent tenure granting process supported by the planning and provision of rural infrastructure.

Land administration: Overall, there is a need to improve the efficiency of land administration systems, specifically:

- Establishing systems for registration and titling of existing rights, providing cadastral services, improving land surveying, and capacity building in local communities to support identification and management (including registration) of customary rights;
- Formalizing and securing land transactions, and regulating land markets;
- Establishing simple and fair procedures for land transactions and their formal registration; developing mechanisms for regulation of land markets (giving priority to local communities, allowing local bodies to define rules regarding land sales to members outside the community, etc.); maintaining land information systems and undertaking regular land valuation exercises.

Box 14: Land tenure for customary rights holders in Uganda[112]

Rights of customary land owners were secured through the adjudication, demarcation, and registration of customary land in Kasese District, Uganda. Previously, customary rights holders did not feel secure and would not invest in the land because of fear of eviction. For the implementation of the Voluntary Guidelines on Responsible Governance of Tenure of Land, Fisheries and Forests (VGGT), FAO supported the issuance of Certificates of Customary Ownership (CCOs) to customary rights holders comprising men and women. This involved: customization of the VGGT Open Tenure software to respond to Uganda legal and policy requirements; training and capacity development of District staff and Area Land Committees with involvement from Makerere University students; sensitization and mobilization of communities; fieldwork for adjudication and demarcation of land rights; and data processing and uploading to the community server. Over 5,000 households comprising approximately 30,000 people directly benefited from this initiative including women and marginalized individuals who now enjoy improved tenure security. There was also a significant reduction in land-related conflict among beneficiaries as well as increased capacity to access capital and planning in the district.

3. Sustained investment and infrastructure: A secure flow of investments, via long-term and predictable funding mechanisms, are necessary but not sufficient in order to manage land resources sustainably at a landscape scale. Infrastructure, such as markets (credit), transportation, and energy, is often required to improve productivity and reduce natural resource inefficiencies and waste. The public sector must take a lead role in providing the rural infrastructure, and in some cases the extension services, needed to encourage or ensure ongoing private sector investments in sustainable land management.

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Secure resources are needed to manage sustainable landscapes and provide the appropriate infrastructure. This will entail structuring investments within a broader socio-economic model that guarantees greater societal benefits while at the same time providing reasonable private benefits, including access to credit and markets:

- A new generation of enlightened public policies, reflecting both public and private gains aiming to limit or curtail unsustainable practices or those with heavy environmental or social costs, while providing positive encouragement to more sustainable alternatives
- Achieving more equity between the needs of consumers and producers in value chains
- Directing investment towards more sustainable and less land-intensive products, valued in social and economic terms

Box 15: India adopts the world's first national agroforestry policy[113]

In 2014, India became the first nation in the world to adopt a national agroforestry policy, which promotes the practice of integrating trees, crops, and livestock on the same plot of land. Farmers have been growing trees on their farms for generations to maintain healthy soil and secure supplies of food, timber, and fuel. But the practice of agroforestry has been declining sharply in India in the past few decades. Agroforestry has the potential to achieve sustainability in agriculture while optimizing its productivity. The new policy talks of coordination, convergence, and synergy between various elements of agroforestry, scattered across various existing missions, programmes, and schemes under different ministries – agriculture, rural development, and environment. The policy will be implemented through an integrated agroforestry mission or board. Besides, the policy also talks about security of land tenure, promoting research and capacity building, felicitating participation of industries dealing with agroforestry produce and offering incentives to farmers.

Box 16: Investing in plant protein agriculture[114]

As plant-based diets and meatless meats are becoming more popular with wealthy and urban consumers, primarily for health and environmental reasons, a number of large multinational food corporations have established venture capital funds to support innovative forms of protein and ways of producing food. These funds are meant to increase their exposure to a fast-growing segment of the protein market and food entrepreneurs who are focusing their efforts on developing products and technologies that will help change our existing food system. One example is the vegan *Impossible Burger*, which when compared to beef uses 95 per cent less land, 74 per cent less water, and creates 87 per cent less greenhouse gas emissions; furthermore it is 100 per cent free of hormones, antibiotics, and artificial ingredients. Its distinct iron-like, meat flavor is due to the addition of heme, a molecule found in high concentration in animal blood, which is extracted from the roots of legume plants.[115]

Tyson Foods has launched a USD 150 million venture capital fund to complement its existing investments and focus on companies that are developing breakthrough technologies and business models such as Beyond Meats, a company making hamburgers, chicken, and other traditional meat products out of high protein vegetables. Similarly, General Mills established a fund that has taken positions in start-up companies such as Kite Hill, an alternative dairy company that is making yogurt, ricotta, and even cream cheese out of nut-milk. Campbell Soup invested USD 125 million in Acre Venture Partners which has issued USD 10 million series A round of preferred stocks for Back to the Roots, a company making home-growing mushroom kits as well as organic cereal. Kellogg has set up a USD 100 million fund aimed at investing in emerging food brands that embrace new consumer-driven technologies that could lead to long-term, mutual growth opportunities, such as Rhythm Superfoods that makes snacks from kale, beets, broccoli, seeds, and nuts. According to Dow Jones VentureSource data, venture capital firms invested USD 420 million in food and agricultural companies during the first three-quarters of 2016. In 2015, these investments totaled nearly USD 650 million.

Box 17: Farmer managed natural regeneration in Africa[116]

Currently, there are efforts under way to upscale on-farm natural regeneration as well as tree planting to develop new agroforestry systems in 17 countries in Africa and several countries in Asia. Natural regeneration is less costly than tree planting and can produce returns more quickly. In times of financial scarcity, these are strong arguments for a bigger emphasis on natural regeneration. But an accelerated effort is needed to expand the reach of these systems to transform the farms of tens of millions of the poorest farmers. The accelerated scaling-up of existing natural regeneration successes is a pragmatic way forward. It will help achieve the ambitious restoration targets, which cannot be achieved with the business-as-usual approach limited to tree planting projects. Unless the conditions are created in which land users are willing to invest their scarce resources in the protection and management of on-farm or off-farm trees, the battle against climate change, ecosystem degradation, and famine and malnutrition can't be won.

There is a lot of talk about the need to scale up best practices in sustainable land management, but projects rarely plan a scaling-up strategy. They may have a budget for farmer study visits, but not one for radio programs, which reach many farm households. Most steps proposed for scaling up require only modest funding, but they all require patience, persistence, creativity, and local champions.

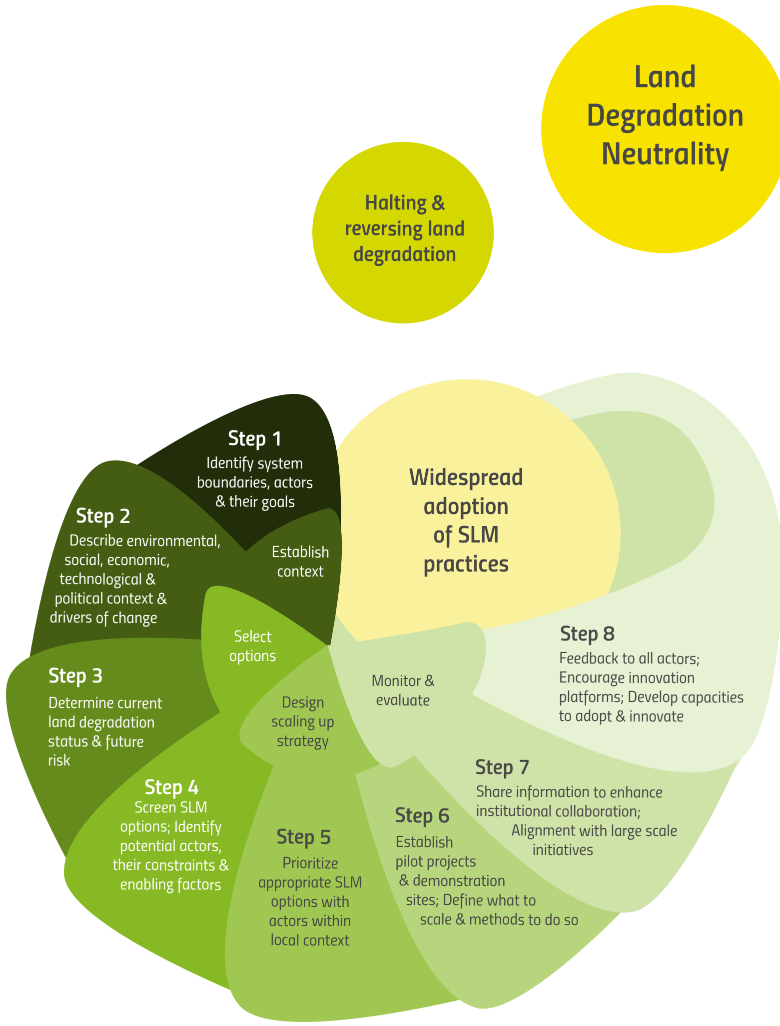
Box 18: One farmer kicks off a large-scale restoration initiative in South Africa[123]

Intensive goat farming has degraded more than 1.5 million hectares of subtropical thicket in the Eastern Cape province of South Africa resulting in a desert-like open landscape with surface temperatures reaching 70 °C. The reduction or loss of virtually every ecosystem service provided by the thicket led to declining farmer incomes and a depressed local economy. The challenge was how to restore the health of the ecosystem to maximize both environmental and economic benefits.

In the early 1970s, a livestock farmer near Uitenhage took one small but important step towards addressing this challenge. He had built a barn at the bottom of a degraded slope which then flooded whenever it rained heavily. He decided to try and restore the slope back to a dense thicket to increase rainwater infiltration and prevent the flooding of his barn. Using cuttings of the indigenous succulent tree – the elephant-food tree *(Portulacaria afra)* – he and other farmers began to regenerate the thicket structure; soil quality and carbon stocks improved, and the animal carrying capacity of the land and income increased 10 times.

Based on the evidence from these pioneer farmers and ranchers, the South African government decided to invest in large-scale restoration of degraded thicket. The Subtropical Thicket Restoration Programme was established and approximately USD 8 million was spent between 2004 and 2016. Farmers, reserve managers, government officials, and scientists joined forces to work out how to upscale restoration efforts. To date, more than 10,000 hectares have been planted with elephant-food tree cuttings within nature reserves, on private land, and across the Addo Elephant National Park. A large experiment of more than 300 quarter-hectare plots spread out over more than 1,000 km was also established. And it all started with one farmer.

Figure 5: **Stepwise framework for scaling up best practices:** Adapted from[119]



Scaling up framework to halt and reverse land degradation[117]

In theory, successful small-scale projects can be transformed into broader changes in practice, yet this has proven challenging. The World Overview of Conservation Approaches and Technologies (WOCAT)[118] is an established global network that supports innovation and decision-making processes in sustainable land management (SLM). Understanding why particular innovations take off and finding the most effective ways of scaling up successful innovations is essential for achieving sustainability. Evidence suggests that many pilots and demonstration projects often lack the critical elements to be successful at larger scales, such as stakeholder engagement, design features, or technical capabilities. Figure 5 synthesizes some of the key steps in scaling up SLM practices from the local to the national and beyond.

The scope for scaling up SLM practices needs to start with an assessment identifying the biophysical, social, or administrative limitations (Step 1). An inclusive process is recommended to engage all actors in land management decisions by collectively diagnosing the environmental, social, economic, technological, and political contexts, and identifying the main drivers of degradation (Step 2). The current state of land degradation, both in terms of biological and economic productivity, is then clearly defined (Step 3).

A screening of potential management options is next, using criteria such as improvements in crop selection or biomass productivity, economic cost/benefits, and social and cultural acceptance (Step 4). In parallel, SLM options and their potential scale are prioritized in terms of previously demonstrated successes or the local enabling factors (Step 5). Next pilot projects and demonstration sites should be established (Step 6) with a clear idea of what elements are being scaled up and the financing needed (e.g., technology, process, or organizational).

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Sharing information, peer-to-peer learning, and developing collaborative partnerships are important (Step 7), including how roles are allocated or shared among diverse stakeholders (e.g., farmers, NGOs, extension agencies, private sector, administrative units, donors, research organizations). Finally, a process and protocols for monitoring and evaluation are essential, both to provide feedback to actors and for adaptive management responses (Step 8).

Determining whether there is a sound basis for successful scaling up depends largely on the evidence available. This can include innovative practices with minimal objective evidence; a promising practice with anecdotal reports; a model that has positive evidence in a few cases; good practice with clear evidence from numerous cases; best practice with evidence of impact in multiple contexts; or a proven policy principle.[120] In many cases, these innovations are driven by "champions" that are able to gain much-needed social, political, and financial support. This framework also recognizes the importance of multiple-actor mechanisms in scaling up SLM practices, which can be used as vehicles for further adaptation and innovation, moving beyond a simple scaling out of one particular intervention.[121]

Science and traditional knowledge play a major role in understanding under what contexts (e.g., biophysical, socio-economic, political, financial) a particular option, such as conservation agriculture or agroforestry, is likely to be adopted, scaled up, and sustained.[122] This can help avoid disappointments associated with many development projects that have run their course and lack follow up, resulting in the abandonment of interventions that were supposed to be self-sustaining. In conjunction with an overarching national framework for land degradation neutrality which strives to implement transformative projects, this framework can serve to further align incentives for short-term private and local benefits, often within one growing season, with long-term public and more diffuse benefits.

CONCLUSION: THINKING AHEAD

In an angry, unstable, and increasingly dangerous world, getting land management right needs to be an urgent priority for everyone if humanity is not just to survive but thrive. The numerous practices and actions highlighted in this Outlook serve as a timely reminder of proven, cost-effective response pathways that will allow us to realize a prosperous and more sustainable future based on rights, rewards, and responsibilities.

The first edition of the *Global Land Outlook* provides an overview of the state of global land resources, looks at some trends, and suggests an agenda for action, a new deal for land managers. Some key themes have emerged during its preparation, but many questions still remain unanswered. History is full of unexpected game changers: inventions, ecosystem collapse, and apparently trivial things like changes in taste and fashion that suddenly make or break an entire industrial, commercial, or agricultural sector. By their nature such things are hard to predict. Below are some critical questions that we believe could radically shift the direction of land use over the next few years and decades.

Will small farmers survive?
Currently, there are over one billion small farmers. Current trends suggest that many, perhaps most, will disappear under a wave of consolidation into bigger, more profitable enterprises. Is such a change inevitable? Will people want to continue farming a few hectares of land when other opportunities become available? Will job opportunities open up in new sectors of the economy or will the loss of these farms result in destitution? If small-scale agriculture is to survive, it will need positive recognition and support through government policies, consumer choices, and extension services. The future remains very uncertain.

What is the future for genetically modified crops?
The industry and some governments think they are critical for agriculture. The experience in South Asia and Africa tells a very different story pointing to the failed promise of GM crops. So are GM crops really providing widespread benefits to agriculture, regardless of the scale, or can we do better relying on the old-fashioned way of plant and livestock breeding? The Drought Tolerant Maize for Africa project has developed 153 new varieties to improve yields in 13 countries. A comparable GM variety is at least ten years away.[123]

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Would a large-scale switch to less chemical intensive production systems cause a food crisis?

Will organic agriculture feed the world?
Or any other kind of less intensive agriculture for that matter? Many farmers are convinced that heavy applications of artificial pesticides and fertilizers are essential to increase production; farmers practicing organic agriculture in developing countries often adopt chemical inputs if they can afford them. Would a large-scale switch to less chemical intensive systems cause a food crisis? Organically grown food, beverages, supplements, cosmetics, and other household goods are a rapidly growing market in the developed countries and emerging middle classes in the developing world. It is still too early to say whether organic agriculture will remain a niche market or become a major global food source.

What should be done about land grabs?
International land grabs get a lot of attention but wealthy elites appropriating land within their own countries is another, perhaps even bigger issue. Both have important social and political ramifications, displacing communities without compensation and destroying livelihoods. Are these inevitable as the rich countries hedge against future resource scarcities? They are hard to address through legal instruments, and in many cases are carried out through semi-legal or illegal means. Can countries and corporations set an example through their leasing and purchasing decisions?

What is the role of the private sector?
Many of the negative impacts of land use have been ascribed to aspects of modern agriculture, which is driven by an agribusiness model that is heavily subsidized in the sense that all costs to society are not being paid for. Still, many businesses are trying hard to address sustainability, through certification, purchasing policies, and other means. Will the industry be a positive or negative force in addressing land degradation and meeting the Sustainable Development Goals in the future? What kind of economic incentives or taxation measures would tip the scales in favor of sustainability?

What would happen if there were widespread adoption of alternative protein sources?
Some meat substitutes already taste virtually like meat; in a few years they will be indistinguishable and less costly in many ways. They will not involve the inhumane treatment of animals inherent in industrial meat production. The number of vegetarians and vegans is growing rapidly; a new generation of plant-based products that do not sacrifice taste or nutrition could transform large parts of the food system in just a few decades. When combined with lower price points for local, organic, and fair trade products as well as the lower levels of food waste/loss, there is potential to significantly reduce the demand for land resources.

Will emerging technology and innovation take us to scale?
Traditional technologies tend to be cheap and effective but can modern science revolutionize their implementation at greater scales? Warka water towers simply use gravity, condensation, and evaporation to harvest potable water from the atmosphere (i.e., rain, fog, and dew). Innovations like these, owned and operated by communities, can be game changers at the local level. The Vallerani System is based on direct sowing of seeds of shrubs and trees of locally available, indigenous species but it is the mechanization of the traditional "zaï" and semicircular bunds techniques for water harvesting that takes us to scale with each tractor unit able to rehabilitate approximately 1,500-2,500 hectares per year. Similarly, will we be able to restore large swaths of forests using drones? Will precision agriculture reduce yield gaps and at the same time protect water and biodiversity? There are many outstanding questions and it is expected that the second edition of the *Global Land Outlook* will be able to provide some answers.

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Annex One

THE SCIENTIFIC CONCEPTUAL FRAMEWORK FOR LAND DEGRADATION NEUTRALITY

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Annex One

THE SCIENTIFIC CONCEPTUAL FRAMEWORK FOR LDN

Land resources provide food, feed and fibre, and support the often-overlooked regulating and supporting services on which these provisioning services depend, as well as the cultural services delivered by healthy ecosystems. Pressure on the world's finite land resources will grow as the population grows and increases in affluence. Increased competition for land resources is likely to increase social and political instability, exacerbating food insecurity, poverty, conflict and migration. Maintaining the land's ability to deliver ecosystem services will depend on building resilience of the land resource base.

While demands on the global land resources are increasing, the overall health and productivity of land is declining. Thus, it is critical to find effective measures to address land degradation. Avoiding and reversing land degradation will have co-benefits for climate change mitigation and adaptation, and also for biodiversity conservation, in addition to enhancing food security and sustainable development.

Land Degradation Neutrality (LDN) is the new paradigm for managing land degradation, introduced to halt the ongoing loss of healthy land as a result of unsustainable management and land conversion. Defined as "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems,"[1] the goal of LDN is to maintain the land resource base so that it can continue to supply ecosystem services such as provision of food and regulation of water and climate, while enhancing the resilience of the communities that depend on the land.

The target of LDN is a major plank in the global 2030 Agenda for Sustainable Development: LDN will underpin the achievement of multiple Sustainable Development Goals (SDGs) related to food security, poverty reduction, environmental protection and the sustainable use of natural resources.

Overview of the conceptual framework

The Scientific Conceptual Framework for Land Degradation Neutrality[2] provides a scientific foundation for planning, implementing and monitoring LDN. It was developed by a group of experts led by the Science-Policy Interface (SPI) of the United Nations Convention to Combat Desertification (UNCCD), and has been reviewed by technical experts and policy makers. By defining the LDN concept in operational terms, the framework is designed to create a bridge between the vision and its practical implementation. It articulates the scientific basis for the vision and logic of LDN, and, based on this, presents a strategy for achieving LDN, an approach to monitoring LDN status, and guidance on interpreting the results of monitoring.

The objectives of LDN as articulated in the conceptual framework are to:

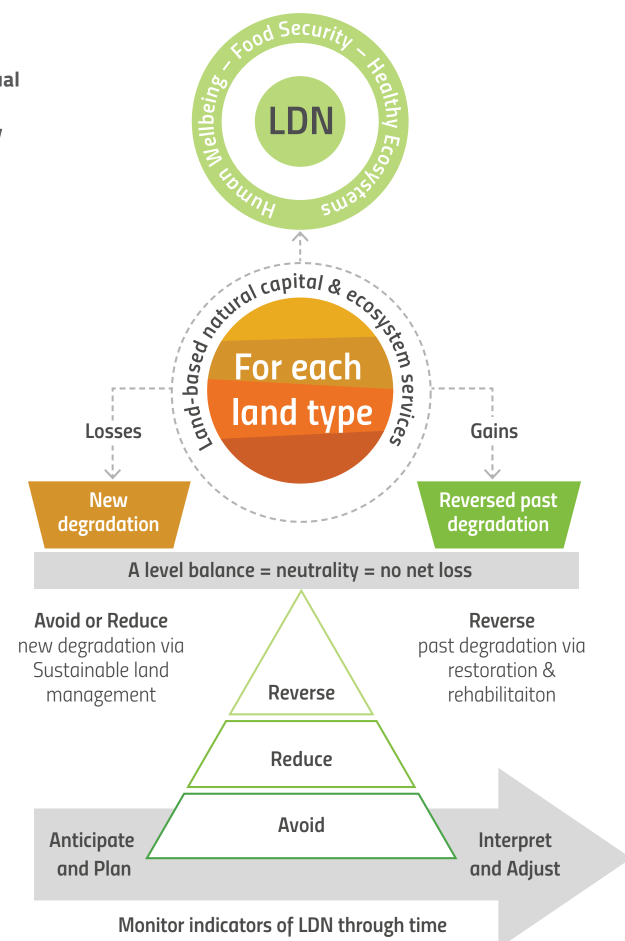
- Maintain or improve ecosystem services;
- Maintain or improve productivity, in order to enhance food security;
- Increase resilience of the land and populations dependent on the land;
- Seek synergies with other environmental objectives;
- Reinforce responsible governance of land tenure.

The framework is structured around five 'modules': the *Vision of LDN*, which articulates the aspirational goal of LDN; the *Frame of Reference*, that explains the LDN baseline against which achievement is measured; the *Mechanism for Neutrality*, that describes the counterbalancing mechanism; *Achieving Neutrality*, that presents the theory of change (logic model) describing the pathway for implementing LDN, including preparatory analysis and enabling policies; and *Monitoring Neutrality*, which presents the indicators for assessing achievement of LDN. The conceptual framework is described in a report that presents the five modules, and focuses on the neutrality aspect of LDN, highlighting the features of LDN that differ from historical approaches to land degradation assessment and management.

The framework presents principles to be followed by all countries that choose to pursue LDN. Principles govern application of the framework and help prevent unintended outcomes during implementation and monitoring of LDN. There is flexibility in the application of many principles but the fundamental structure and approach of the framework are fixed, to ensure consistency and scientific rigour. The conceptual framework is summarised in Figure 1.

In order to achieve the SDG target of a land degradation-neutral world, countries have been invited to commit voluntarily to LDN at the national level. While the scope of the UNCCD is limited to drylands, the LDN conceptual framework is intended to be applicable across all land types, land uses, and ecosystem services, so it can be used by countries according to their individual circumstances. Therefore, the LDN conceptual framework is designed to apply to all land uses (i.e., land managed for production – e.g., agriculture, forestry, for conservation – e.g., protected areas, and also land occupied by human settlements and infrastructure) and all types of land degradation, across the wide variety of countries' circumstances, so that it can be implemented in a harmonized fashion by all countries that choose to pursue LDN.

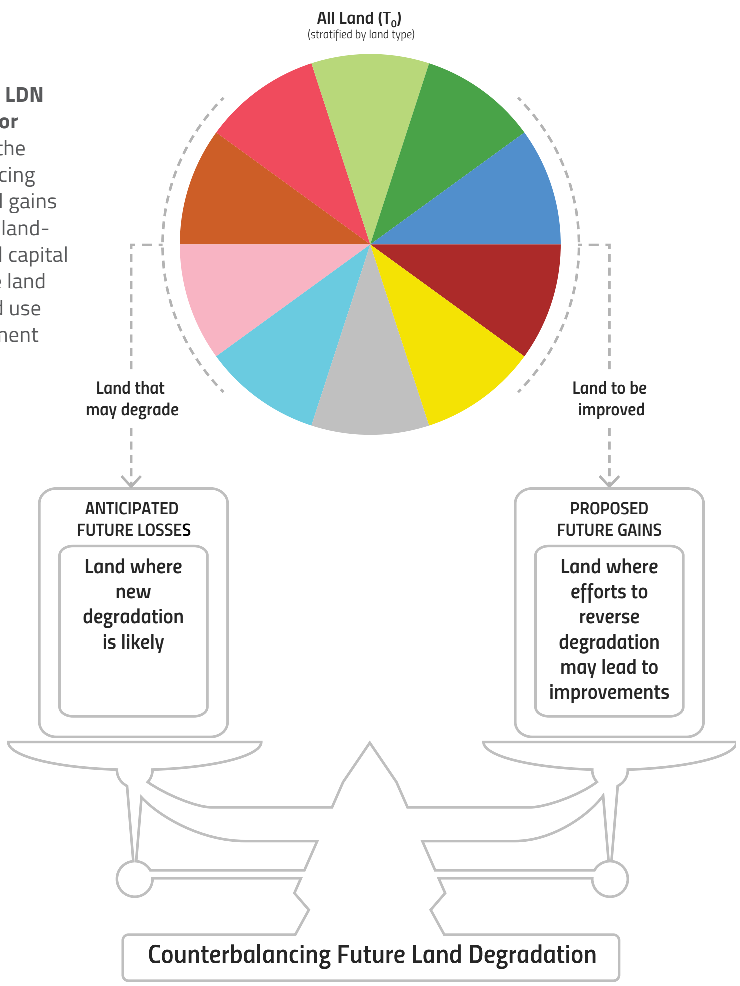
Figure 1: Schematic of the scientific conceptual framework for land degradation neutrality



The elements of the conceptual framework

The Vision and Baseline The aspirational goal of LDN is to maintain or enhance the natural capital of the land and associated land-based ecosystem services. Pursuit of LDN therefore requires effort to avoid further net loss of the land-based natural capital relative to a reference state, or baseline. Therefore, unlike past approaches, LDN creates a target for land degradation management, promoting a dual-pronged approach of measures to avoid or reduce degradation of land, combined with measures to reverse past degradation. The intention is that losses are balanced by gains, in order to achieve a position of no net loss of healthy and productive land.

Figure 2: The LDN mechanism for neutrality is the counterbalancing of anticipated gains and losses in land-based natural capital within unique land types via land use and management decisions.



Integrated land use planning and the counterbalancing mechanism Achieving LDN will require tracking land use changes where degradation is anticipated so that cumulative negative impacts can be estimated, and implementing an optimal mix of interventions designed to avoid, reduce or reverse land degradation, with the intent of achieving neutrality at national scale. Therefore, the conceptual framework introduces a new approach in which land degradation management is coupled with land use planning. Decision-makers are encouraged and guided to consider the cumulative effects on the health and productivity of a nation's land resources caused by the collective impact of their individual decisions that influence management of particular parcels of land. LDN thus promotes integrated land use planning, with a long-term planning horizon including consideration of the likely impacts of climate change. The counterbalancing mechanism requires implementation of interventions that will deliver gains in land-based natural capital equal to or greater than anticipated losses due to degradation elsewhere (see Figure 2).

Achieving neutrality Actions to achieve LDN include sustainable land management approaches that avoid or reduce degradation, coupled with efforts to reverse degradation through restoration or rehabilitation of degraded land. The response hierarchy of Avoid > Reduce > Reverse land degradation (see Figure 3) expresses the priorities in planning LDN interventions: most effort should be applied to avoiding land degradation, on the basis that "prevention is better than cure", because restoring degraded land is time-consuming and expensive. The implementation of LDN is managed at the landscape scale. Counterbalancing anticipated losses with measures to achieve equivalent gains is to be undertaken within each land type. Land types are defined by land potential, which is a reflection of inherent properties such as soil type, topography, hydrology, biological and climatic features.

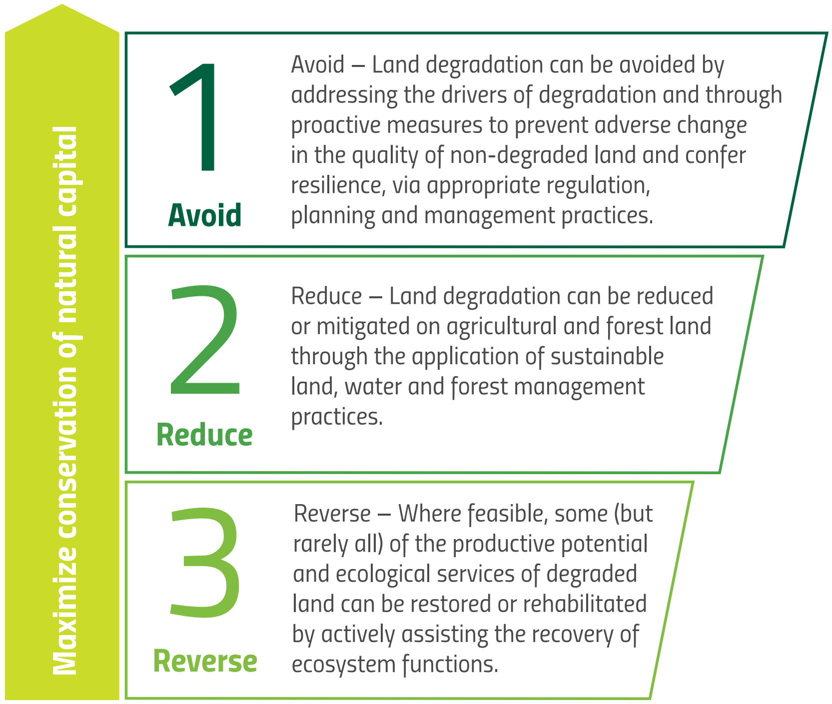
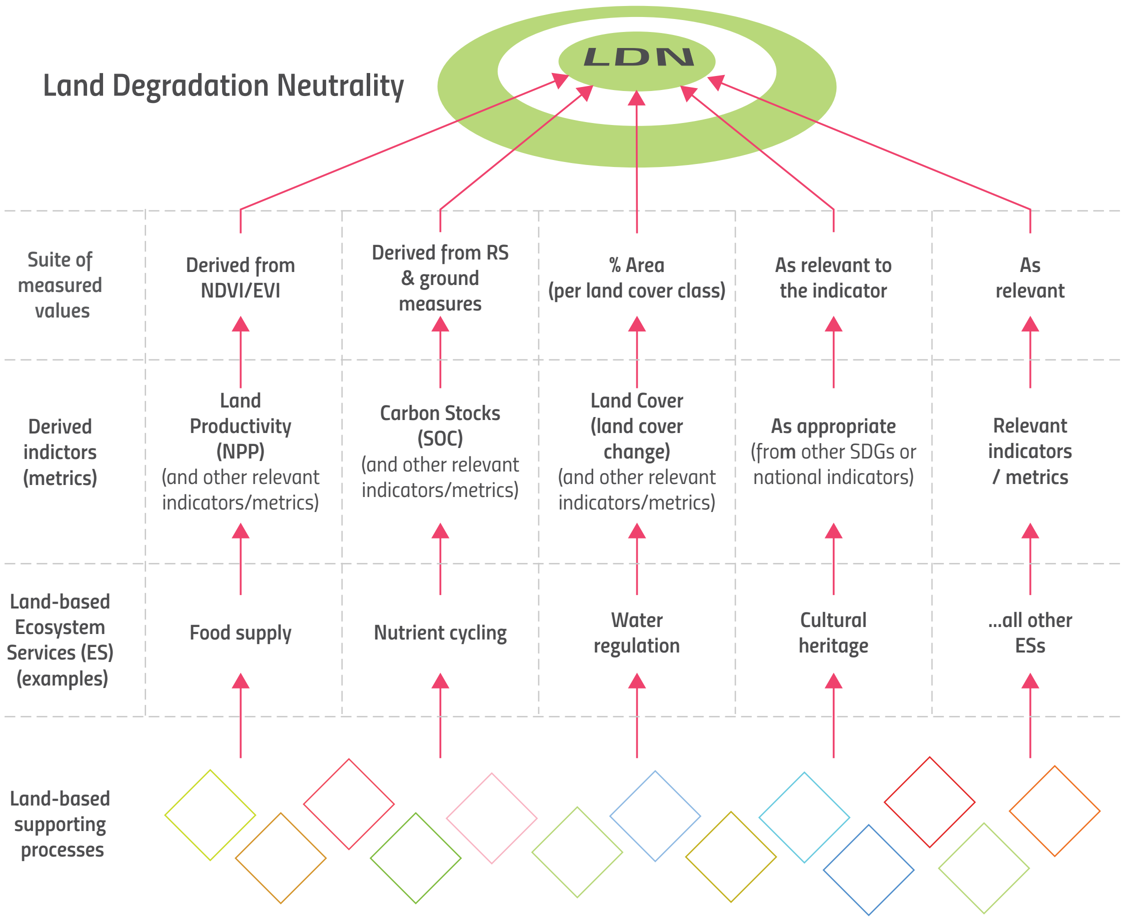


Figure 3: The LDN response hierarchy encourages broad adoption of measures to avoid and reduce land degradation, combined with localised action to reverse degradation, to achieve LDN across each land type.

Land potential influences vegetation community composition and productivity, and determines suitability for uses such as cropping, grazing, forestry, infrastructure or urban development. Counterbalancing will generally not occur between different land types, to ensure "like for like," when assessing and managing the counterbalancing between losses and gains. In other words, a gain in one land type cannot counterbalance a loss in a different land type. Also, the counterbalanced land should have as high or higher natural capital value than that which is anticipated to be lost. Note also that land with the same biophysical characteristics may have different value with respect to human well-being and livelihoods depending on where it is located. Counterbalancing losses in land types managed for conservation with gains in land types managed for production should be avoided.

To achieve the broader development objectives of the UNCCD and the Sustainable Development Goals, LDN activities should seek to deliver 'win-win' outcomes whereby land restoration and rehabilitation contribute to broader environmental goals and more sustainable livelihoods. Planning of LDN measures should therefore consider the full environmental, social and economic implications of alternative options. Resilience of the measures should be assessed, to ensure that restoration activities undertaken will provide counterbalancing of degradation in the longer term.

Figure 4: **Selection of indicators** based on ecosystem services to be monitored



Monitoring LDN Monitoring achievement of neutrality will quantify the balance between the area of gains (significant positive changes in LDN indicators=improvements) and area of losses (significant negative changes in LDN indicators=degradation), within each land type across the landscape. The LDN indicators specify what to measure, while the metrics state how each of the indicators is assessed. Indicators for LDN were selected to reflect the land-based ecosystem services the LDN seeks to support. The relationship between ecosystem services, indicators and metrics is illustrated in Figure 4.

The global LDN indicators (and associated metrics) are land cover (land cover change), land productivity (net primary production) and carbon stocks (soil organic carbon stocks). These indicators are applied in a "one out, all out" approach: where any of the indicators shows significant negative change, it is considered a loss, and conversely, if at least one indicator shows a positive trend and none shows a negative trend, it is considered a gain. Countries are encouraged to supplement the three global indicators with additional indicators for the ecosystem services not covered by the three global indicators, which may include other SDG indicators and/or national indicators that are relevant to their context, such as measures of land contamination or biodiversity impacts. A participatory review of monitoring results will help ensure their accuracy and local relevance, allowing for refinements to account for false positives, such as invasive shrub encroachment.

Governance, stakeholder engagement and learning

Governance of LDN is a critical element. Suitable policies should be enacted to support the implementation of LDN. Safeguards should be introduced to ensure that vulnerable communities are not displaced when lands are targeted for restoration activities. The conceptual framework recommends adoption of the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security (VGGTs), which provide practical guidance on how to protect the rights of local land users, especially those individuals and communities that have no advocate in land use decision-making.

Stakeholders should be involved in the planning and implementation of LDN, and in the verification and interpretation of the results of monitoring.

There are many relevant stakeholder groups, including land users, policymakers and regulators at local, regional and national levels involved in land use planning, resource management; experts in land assessment, restoration, and agricultural extension officers. Where available and effective, stakeholder engagement for LDN should utilise existing local and regional networks.

Learning is a key cross-cutting element of the LDN conceptual framework. Knowledge from monitoring should be verified through stakeholder consultation, and lessons learned should be used for adaptive management, that is, applied to adjust plans for the implementation of LDN, and for future management of land degradation.

Principles to govern LDN

The conceptual framework proposes the following principles to govern the implementation of LDN:

1. Maintain or enhance land-based natural capital.
2. Protect the rights of land users.
3. Respect national sovereignty.
4. For neutrality, the LDN target equals (is the same as) the baseline.
5. Neutrality is the minimum objective: countries may elect to set a more ambitious target.
6. Integrate planning and implementation of LDN into existing land use planning processes.
7. Counterbalance anticipated losses in land-based natural capital with interventions to reverse degradation, to achieve neutrality.
8. Manage counterbalancing at the same scale as land use planning.
9. Counterbalance “like for like” (within the same land type).
10. Balance economic, social and environmental sustainability.
11. Base land use decisions on multi-variable assessments, considering land potential, land condition, resilience, social, cultural and economic factors.
12. Apply the response hierarchy in devising interventions for LDN: Avoid > Reduce > Reverse land degradation.
13. Apply a participatory process: include stakeholders, especially land users, in designing, implementing and monitoring interventions to achieve LDN.
14. Reinforce responsible governance: protect human rights, including tenure rights; develop a review mechanism; and ensure accountability and transparency.
15. Monitor using the three UNCCD land-based global indicators: land cover, land productivity and carbon stocks.
16. Use the “one-out, all-out” approach to interpret the result of these three global indicators.
17. Use additional national and sub-national indicators to aid interpretation and to fill gaps for ecosystem services not covered by the three global indicators.
18. Apply local knowledge and data to validate and interpret monitoring data.
19. Apply a continuous learning approach: anticipate, plan, track, interpret, review, adjust, create the next plan.

CONCLUSION

Land degradation neutrality is a new approach to management of land degradation that is intended to encourage action to avoid or reduce degradation, and also to restore degraded land, in order to achieve the goal of no net loss in healthy, productive land, at national level. The scientific conceptual framework for LDN provides scientifically-based guidance in planning, implementing and monitoring LDN.

To achieve LDN countries will need to assess the cumulative effect of land use decisions, and then undertake measures to restore degraded land, to counterbalance anticipated losses. Linking LDN objectives with existing land use planning mechanisms will facilitate the implementation of LDN. Countries should consider the social and economic as well as environmental outcomes of alternative options when planning LDN measures, and should engage relevant stakeholders.

Counterbalancing anticipated losses with measures designed to achieve gains should occur on a "like for like" basis, and should be managed within each land type.

Three indicators that reflect the land-based ecosystem services have been selected to report on LDN: land cover change, primary productivity and carbon stocks. The conceptual framework provides practical guidance including theoretical examples of how the indicators are assessed. The practical approach presented in the conceptual framework has led to significant country buy-in: in September 2016, the Global Mechanism (GM) of the UNCCD announced that 100 countries – over half of all UNCCD signatories – had embarked on the process of establishing national targets for LDN.

Further information

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Annex Two

MAPPING LAND PRODUCTIVITY DYNAMICS:
detecting critical trajectories of global land transformations

Stefan Sommer,
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and Eva Ivits

Annex Two

MAPPING LAND PRODUCTIVITY DYNAMICS:

detecting critical trajectories of global land transformations

All life on Earth depends on the conversion and fixation of solar energy in the form of organic carbon compounds. On land, this process is driven by the photosynthesis of plants that form the terrestrial vegetation cover and the resulting output is typically referred to as land productivity, which can be quantified in terms of Net Primary Production (NPP). All other organisms (e.g., humans, other species of animal, bacteria, fungi) depend directly and indirectly on this primary production for their health and well-being.

Globally, humans appropriate a constantly increasing proportion of this NPP, affecting the structure and functioning of ecosystems, and which in many cases exceeds their natural variability and dynamics.[1] Hence, land productivity is an essential variable for detecting and monitoring active land transformations typically associated with land degradation processes. It can be expressed as an equivalent of terrestrial NPP per unit of area and time, and reflects the overall capacity of land to support biodiversity and provide ecosystem services. Changes in land productivity are the result of environmental conditions and/or land use and management that impacts the quantity and quality of terrestrial ecosystem services. A persistent decline in land productivity points to the long-term alteration in the health and productive capacity of the land, the basis for economic growth and sustainable livelihoods.

Against this background, trends in land productivity has been adopted by the United Nations Convention to Combat Desertification (UNCCD) as one of three biophysical progress indicators[2] for mandatory reporting and is proposed as a sub-indicator for the global indicator to monitor progress towards achieving Sustainable Development Goal (SDG) target 15.3 on land degradation neutrality (LDN).[3]

Basic principles of monitoring land productivity at the global level

The state of the Earth's vegetative cover and its development over time is a generally accepted representation of land productivity and its dynamics, reflecting integrated ecological conditions and the impact of natural and predominantly anthropogenic environmental change.

The global monitoring of land productivity typically relies on the multi-temporal and thematic evaluation of long-term time series of remotely-sensed vegetation indices, computed from continuous spectral measurements of photosynthetic activity. The provision of the time series of suitable vegetation indices and partly of model-derived gross and net primary production (GPP, NPP) is operationally addressed by existing national and international Earth Observation Systems, closely cooperating within international frameworks such as the intergovernmental Group on Earth Observation (GEO) in implementing Global Earth Observation System of Systems (GEOSS).

A substantial body of peer-reviewed research clearly underpins the use of these indices for studying vegetation dynamics at global, continental and sub-continental scales. There is empirical evidence that these data are highly correlated with biophysically meaningful vegetation characteristics, such as photosynthetic capacity and primary production that are closely related to typical global land surface changes associated with the processes of land degradation and recovery.[4]

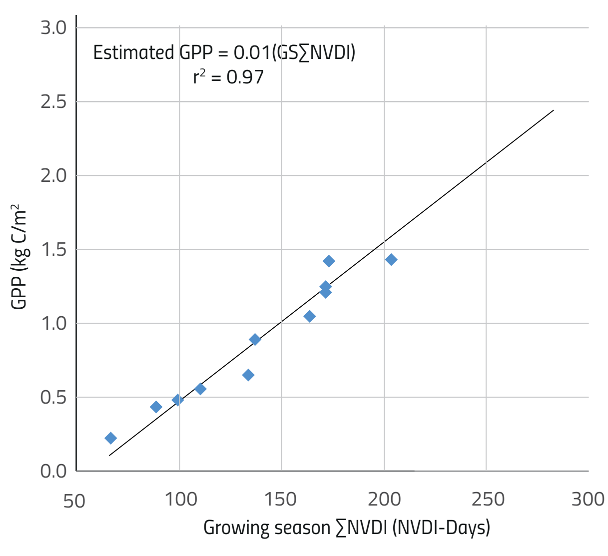

Figure 1: Comparison between integrated gross primary production from 12 flux towers and integrated NDVI from MODIS Terra, for the respective growing seasons where the flux towers were situated. This demonstrates the strong relationship between NDVI and primary production which is directly related to chlorophyll abundance and energy absorption.[10,11]

The use of continuous time series of global vegetation data, primarily in the form of a Normalized Difference Vegetation Index (NDVI), developed rapidly in the early 1990s. Since then, the data processing and techniques for their analyses have improved significantly. Techniques for data quality screening, geometric correction, calibration between sensors, atmospheric and solar zenith corrections, cloud screening, and data compositing have resulted in several databases of global NDVI data of high quality that are freely accessible over the Internet. Currently, the spatial resolution of these datasets range from coarse (8 to 1 km) to medium (250 m) resolution.[5]

Although NDVI is the most commonly used vegetation index, other indices have been proposed and used for global and regional scale studies, such as two variants of the Enhanced Vegetation Index (EVI),[6] the Soil Adjusted Vegetation Index (SAVI),[7] and the model derived FAPAR (Fraction of Absorbed Photosynthetically Active Radiation).[8] Although some of these indices have been reported to perform better than NDVI under some specific vegetation conditions, e.g., SAVI for sparse vegetation cover or FAPAR for sparse and very dense canopies, they require additional adjustment factors or model inputs for their derivation which are not always reliably measured and depend on empirical estimates. An up-to-date review and comparison of the various vegetation indices can be found in Yengoh et. al., 2015.[9]

Despite its well-understood limitations, NDVI is currently considered the most independent and robust option for the global analyses of land productivity, offering the longest consolidated time series and a broad range of operational data sets at different spatial scales. Over the last few decades, extensive research has demonstrated the strong relationship between NDVI and primary productivity as shown in Figure 1.

Thus, the use of NDVI time series is consistent with the demand to use a metric that can provide equivalents of primary productivity. However, in the context of combatting desertification and implementing LDN within the UNCCD and SDG frameworks, approaches to assessing land degradation with global satellite data require the ability to disaggregate information from national scales to sub-national administrative and landscape units (e.g., watersheds) in order to be policy relevant. This is essential as all measures to halt and reverse land degradation have to be addressed at the national or sub-national level fully considering the local context and conditions.

The challenge is how to express land productivity changes directly in physical units of GPP or NPP at the subnational and local levels. Comprehensive, spatially-distributed, direct ground measurements of GPP/NPP are not feasible. Current satellite based products, such as the MODIS NPP[12] or the COPERNICUS DMP (Dry Matter Productivity),[13] though delivered at 1 km sampling, are modelled with very coarse resolution inputs of radiation and climate variables (typically 5 to 10 km) which, when disaggregated to the sub-national level, do not reflect the characteristic vegetation heterogeneity at landscape level.[14] More advanced techniques using chlorophyll fluorescence measurements have only recently started with spatial resolutions of 10 km or more.[15]

Consequently, in terms of maturity and "operational readiness", the estimation of primary productivity state and changes at national and local scales (at resolutions of 250 m to 1 km) with remote sensing inputs, in the form of time integrated vegetation indices as proxies for primary productivity, are the most realistic option for routine use at this time.[16]

Time series processing for land degradation assessments: rationale and strategies

The use of productivity change in land degradation monitoring is aligned in many respects with the principles of ecosystem resilience theory. In this context, a central concept is the system's ability to cope with and recover from disturbance and stress, which can be described and analysed following trajectories of a hysteresis curve as outlined in Figure 2.[17]

This implies that land productivity changes cannot be assessed just on the basis of comparing land productivity values expressed in units of primary production (GPP, NPP) for single reference years or averages of a few years centred around them. To be meaningful, approaches must be based on multi-temporal change and trend analysis which are continuously repeated in defined time steps using an extended time series.

In addition, it should be understood that the analyses of trends and changes in land productivity is a methodology to detect areas with persistent and active declines in primary productivity pointing to on-going land degradation rather than areas which have already undergone degradation processes and have reached a new equilibrium from which they do not further degrade within the observation period in the time series used. This is confirmed by studies which paired and monitored non-degraded and degraded areas in South Africa for 16 growing seasons; while both types of land were exposed to identical rainfall regimes, the degraded areas were not less stable or resilient than non-degraded areas.[18]

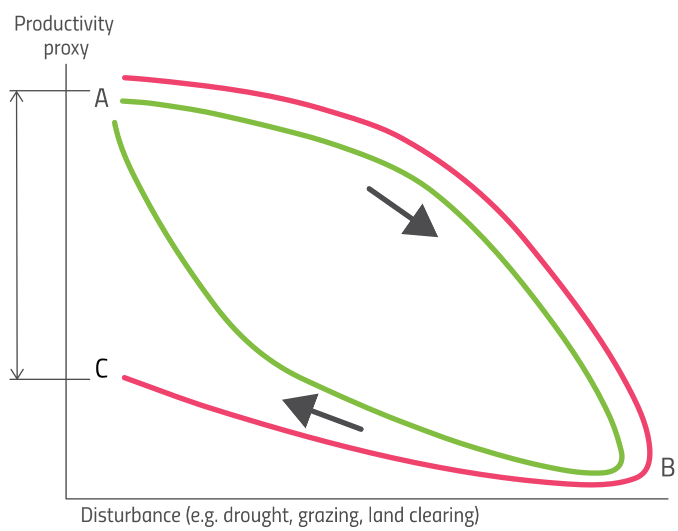

Figure 2: Schematic trajectory of a hysteresis curve. With increasing pressure, productivity declines to reach point B until the stress is reduced. When stress is reduced, productivity increases again. A fully resilient system (green curve) will go back to its original state (A), thus oscillating between stages A and B. If the system has decreased resilience (red curve) it will only return to lower productivity at point C and possibly reach a new equilibrium at a lower productivity level. The resilience of the system (R) is related to the distance between A and C.

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In view of this, the term "land productivity dynamics" (LPD) used in the 3rd edition of the World Atlas of Desertification (WAD)[19] produced by the Joint Research Centre of the European Commission highlights that the primary productivity of a land system, even in stable conditions, is not a steady state but usually highly variable between different years/vegetation growth cycles. This is a function of natural or human-induced (e.g., sustainable land management) adaptation to the considerable natural variability of environmental conditions. Hence a land system's primary productivity assumes a dynamic equilibrium rather than a linear continuum.

The LPD maps used in the 3rd edition of the WAD[19] do not provide a numerical measure of land productivity per se but depict the persistent trajectory of land productivity dynamics during the 15 year observation period of the available remote sensing time series. It provides 5 qualitative classes of persistent land productivity trajectories during the available time window from 1999 to 2013 where classes do not directly correspond to a quantitative measure (e.g., t/ha of NPP or GPP) of lost or gained biomass productivity. The 5 classes, as described in Tables 1 and 2, are rather a qualitative combined measure of the intensity and persistence of negative or positive trends and changes in the photo-synthetically active vegetation cover over the observed period. The main elements of the LPD data set processing chain leading to the 5 classes in the image data are summarised below.

Table 1: Processing steps for land productivity dynamics mapping

Sensor	SPOT-VGT21
Pre-processing	Input: SPOT-VGT daily coverage ▪ geometric correction ▪ spectral and radiometric calibrations to top of atmosphere reflectance (ToA) ▪ pixel masking (land- water-snow delineation, cloud and cloud shadow detection) ▪ atmospheric correction (includes correction for the absorbing and scattering effects of atmospheric gases, in particular ozone, oxygen and water vapour, of the scattering of air molecules, of absorption and scattering due to aerosol particles) and correction of directional effects. ▪ NDVI derivation and extraction of 10 days NDVI composite images (3 per month) i.e., a total of 540 observations in the time series.
Classification	Main steps: ▪ For all 15 years, aggregation of the 36 annual NDVI observations to an annual productivity proxy metric i.e., integral NDVI over the main seasonal growth cycle, in case of pronounced ecosystem seasonality, or integrated yearly NDVI in the absence of pronounced seasonality. (see Figure 3) ▪ Calculation of linear trend of the z-score normalized time series of aggregated NDVI values over the 15 years and parallel calculation of the net change over the same period by applying the Multi Temporal Image Differencing (MTID) method.[20] Combination of the two variables trend and change with 4 variants possible (+trend/+change; +trend/-change; -trend/+change; -trend/-change).[21] (see Figure 4, Step 1) ▪ Iso-data class levelling and differencing of the average productivity in the initial and final 3 years of the time series, resulting in a productivity class change layer. (see Figure 4, Step 2 and Step 3) ▪ Logical matrix combination of the latter two layers to an integrated class layer and conclusive aggregation to the final 5 classes (see Figure 5 Global LPD map), applying weighting functions derived from Local Net Scaling (LNS)[22] (see Figure 4, Step 4) applied to the last 5 years average values of the annual productivity metric within an Ecosystem Functional Units[23,24]
Legend description	The five classes of productivity trends are described as combinations of the above mentioned steps as follows: 1. **Declining trend**: where negative trend, negative MTID change, LNS performance below median 2. **Early/moderate signs of decline**: negative trend, negative MTID change, LNS performance above median 3. **Stable, but stressed**: combinations of contradicting signs of negative trend and positive MTID change, LNS performance below median 4. **Stable, not stressed**: positive trend, positive MTID change + LNS performance below median or positive trend, negative MTID 5. **Increasing trend**: positive trend, positive MTID change, LNS above median

Figure 3: Phenological parameters derived from remote sensing time series for each year 1999 to 2013 from 1 km SPOT VEGETATION data (36 observations/year)

SI: seasonal integral (b+e+g)

CF: cyclic fraction (g)

PF: permanent fraction (d+e+f)

SER: seasonal exceeding residual integral (d+f)

MPI: minimum-minimum permanent integral (a+b+c)

SPI: seasonal permanent integral (b+e)

SRI: seasonal residual integral (e+g)

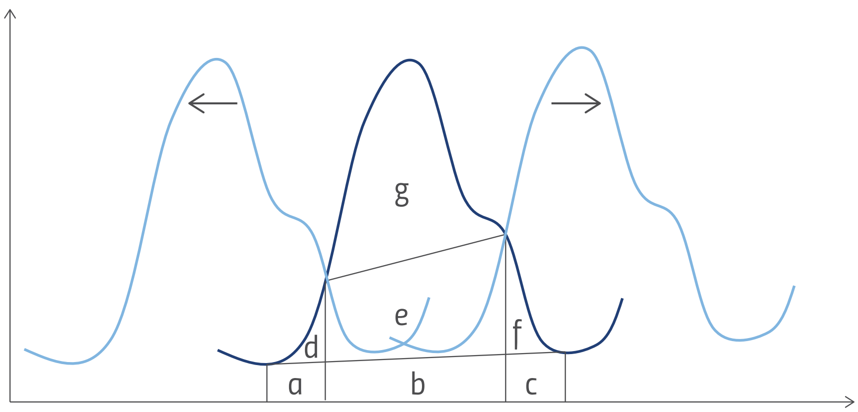
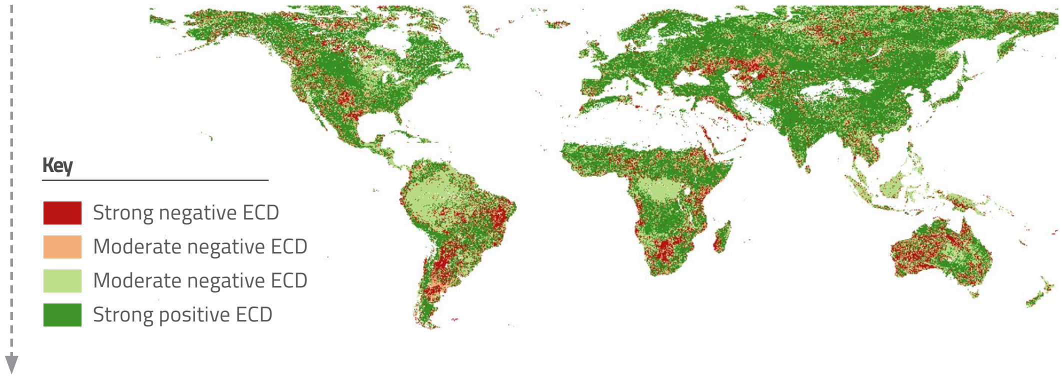
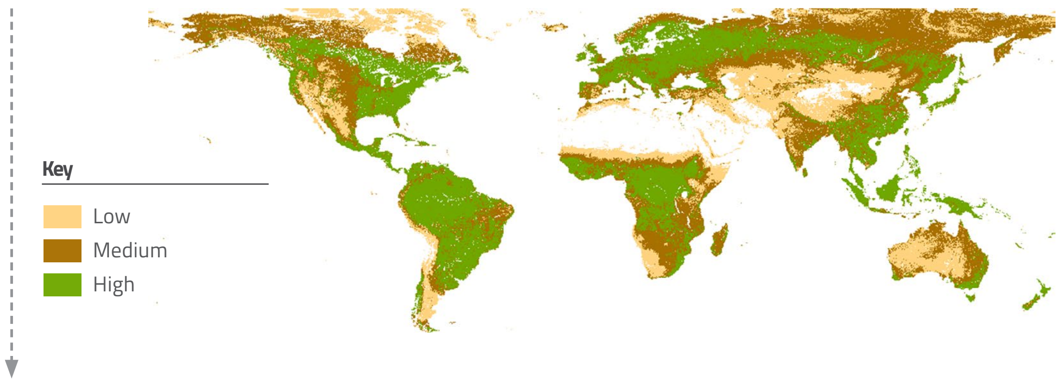


Figure 4: Illustration of the sequence of the 4 main intermediate processing steps as outline in Table 1, applied to full time series of 15 annual phenological aggregates (1999 to 2013), see also Figure 3 and resulting in final LPD map shown in Figure 5.

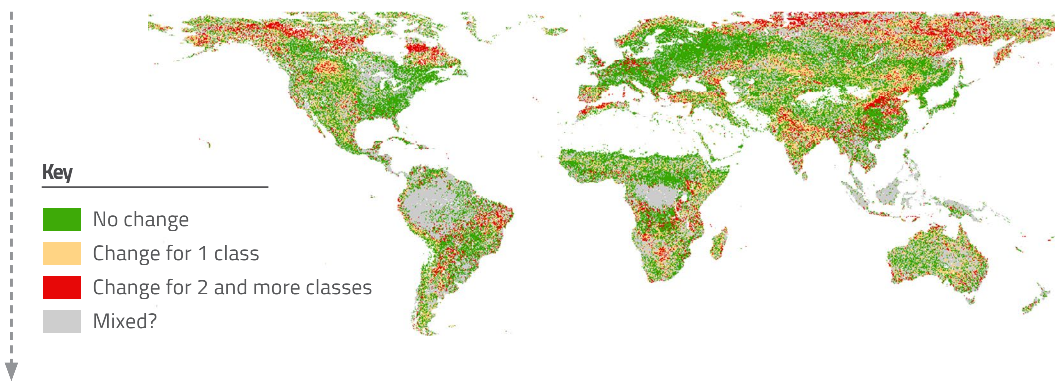
Step 1: Steadiness (1999 - 2013)



Step 2: Initial standing biomass (1999-2001)



Step 3: Standing biomass at change (1999-2001 vs 2011-2013)



Step 4: Local net scaling (performance of last 5 years)

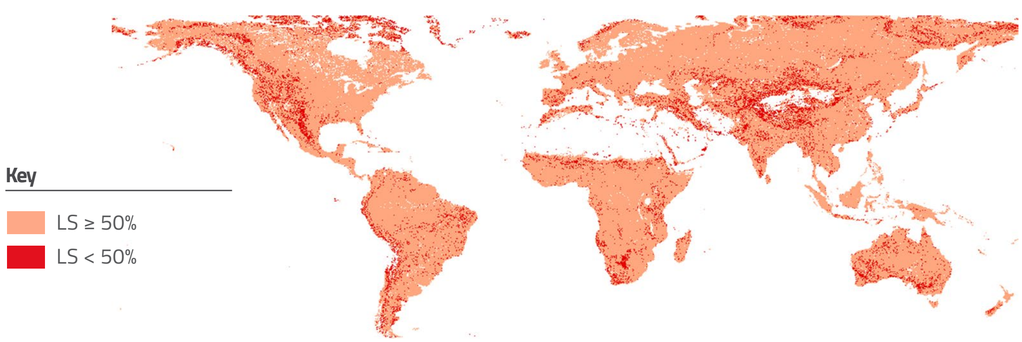


Table 2: Five classes of land productivity dynamics

Class Value	Description
1	Persistent decline in productivity
2	Persistent moderate decline in productivity
3	Stable, but stressed; persistent strong inter-annual productivity variations
4	Stable productivity
5	Persistent increase in productivity

The thematic evaluation of the resulting LPD map (see Figure 5) is further analyzed in light of available information on land cover/land use and as a second step contextualized with environmental change processes that coincide with potential drivers of land degradation following the WAD conceptual "convergence of evidence" framework.

To accommodate the complex interactions and dynamics that trigger land cover/use change, the WAD relies on the concept of convergence of evidence: when multiple sources of evidence are in agreement, strong conclusions can be drawn even when none of the individual sources of evidence is significant on its own. Convergence maps are compiled by combining global datasets on key processes using a reference period of 15-20 years. Combinations are made without prior assumptions in the absence of exact knowledge of land change processes at variable locations. Patterns indicate areas where substantial stress on land resources is to be expected.[25]

The LPD map shows that declining land productivity is a global phenomenon with considerable differences between continents and regions. Even more distinct variations in LPD class distributions are evident at the continental level when they are disaggregated by key land cover/land use types. While excluding land areas with no significant vegetal primary productivity, i.e., hyper-arid, arctic and very-high altitude mountain regions, it is apparent that indications of decreasing land system productive capacity can be observed on all continents.

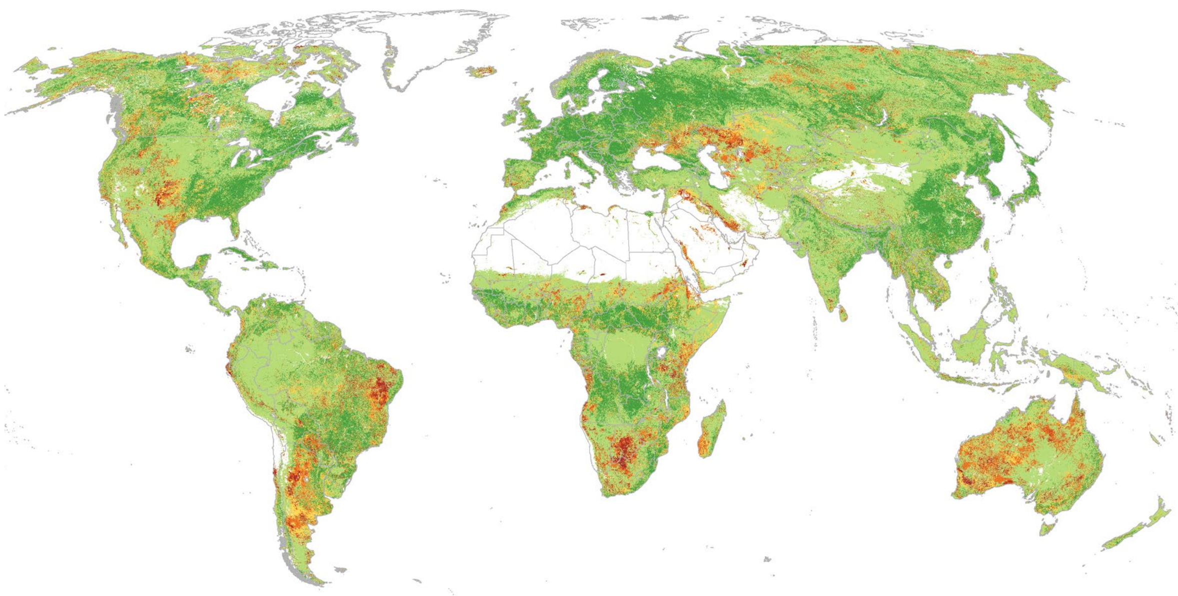


Figure 5: Global Land Productivity Dynamics map 1999 to 2013 showing 5 classes of persistent land productivity trajectories during the observation period. Decreasing productivity trend classes do not per se indicate land degradation or increasing trends recovery. For further evaluation with the aim of identifying critical land degradation zones, an analytical convergence of evidence framework using additional thematic information is required as outlined in the following sections.

Key

- Declining
- Moderate decline
- Stressed
- Stable
- Increasing

Referring to the observation period from 1999 to 2013, approximately 20.4% of the Earth's vegetated land surface shows persistent declining trends in land productivity. However, the level to which the different continents are affected by persistent productivity decline (classes 1 and 2) or a signal of instability or stress in the land's productive capacity (class 3) varies significantly (see Figure 6). Africa, Australia and South America are affected to an extent that is greater than the global average, with declining or stressed areas at approximately 22% for Africa, 37% for Australia and 27% for South America. Asia with 14%, Europe with 12% and Northern America with 18% declining or unstable land productivity dynamics are below the global average. Further differentiation of the extent and significance of land productivity changes become possible by further stratified analyses of LPD class distributions for example as function of land cover/land use information as briefly demonstrated in Chapter 4 of this *Outlook*.

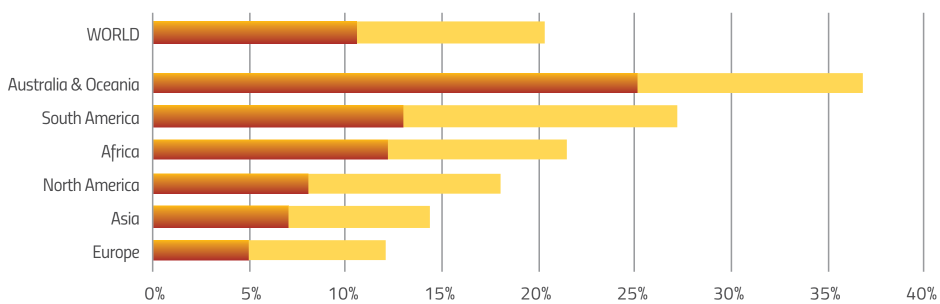
Validation of LPD classes against other data sets

The validation of LPD classes is not a trivial task as typically there is no directly comparable field data on land productivity change. Nevertheless, the validation of LPD classes in terms of plausibility testing against the land cover change detected by the European Space Agency's Climate Change Initiative Land Cover (CCI LC) data set[26] and locally against multi-temporal high resolution data in Google Earth has been performed. A preliminary statistical validation of LPD classes was performed against mapped land cover changes between the CCI LC epochs 2000 and 2010, taking into consideration the full range of mapped CCI LC classes, not only the 6 IPCC land cover/use classes. The area of CCI LC mapped land cover change globally covers approximately 246,067 km^2.

For a number of critical land cover transitions, cross correlation between the expected LPD class distributions in relation to observed changes were investigated and further verification is ongoing. For example, transitions from semi-natural land cover classes with tree cover to bare/sparsely vegetated areas are expected to feature predominantly in LPD classes 1 to 3, but less so in LPD classes 4 and 5. This highlights a somewhat different picture than the overall global LPD class distribution where classes 4 and 5 account for the vast majority accounting for roughly 80% of all pixels.

This example is illustrated in Figure 8 a) and b) where a high level of correspondence between declining land productivity and independently mapped loss of vegetation cover, expressed as land cover class change, provides evidence of the plausibility and relative accuracy of the LPD class distribution. The inverse case is shown with transitions from semi-natural tree covers to irrigated crops (Figure 8 c), one of the limited cases where high input and intensive agriculture may exceed the natural potential of primary productivity. For other land cover transitions, the correlation is less clear at global level (e.g., conversion from evergreen broadleaf forest to cropland) but initial steps towards more refined

Figure 6: Global and continental area percentages affected by persistent declining or unstable land productivity dynamics during the observation period 1999 to 2013.



Key

Declining and moderate decline combined

Stressed

Figure 7: Global distribution of areas with CCI LC mapped land cover change between 2000 and 2010. Area extents are exaggerated in order to be visible at the scale presented.

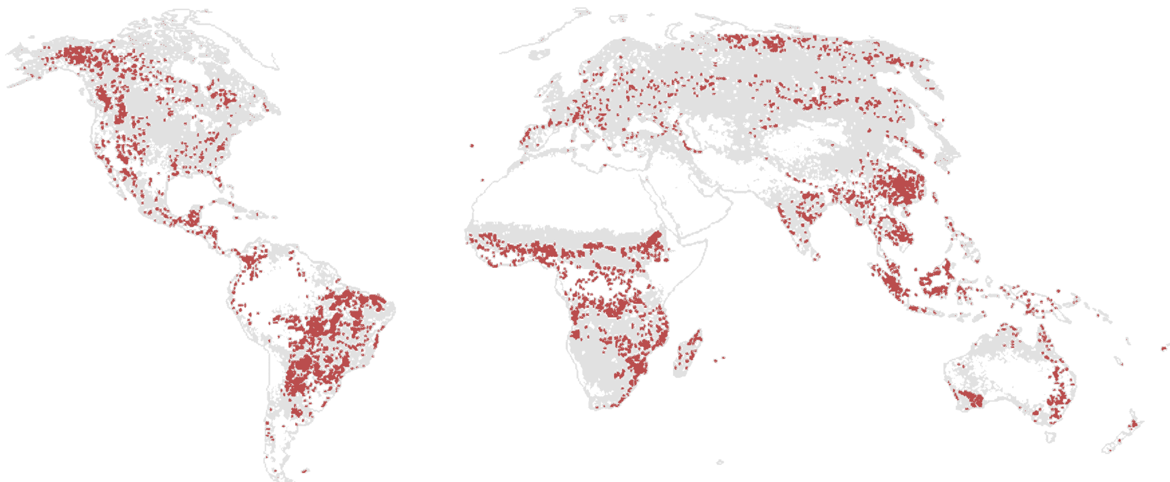
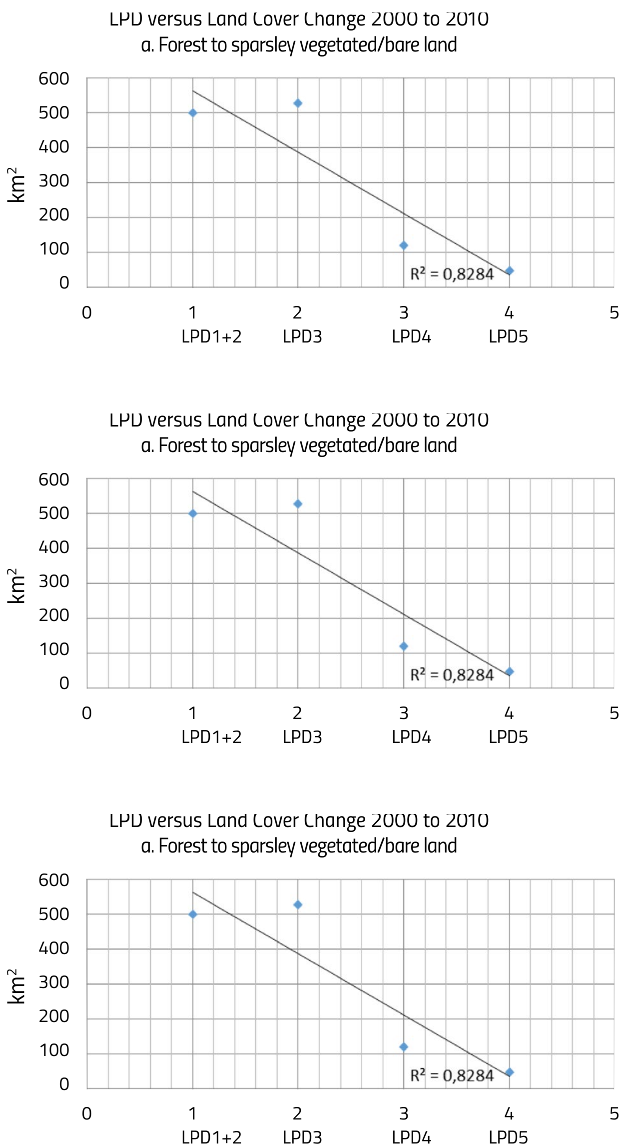


Figure 8: Distribution of LPD classes within areas transitioning from a) forest to bare/sparsely vegetated land, b) forest to shrub land and c) forest to irrigated crop.



and spatially disaggregated verification at regional to national levels indicate clearer and more plausible relationships between LPD classes and transition from semi-natural land cover to cropland. Results of this more refined validation process will be made available and presented in the 3rd edition of the WAD.

The vast majority of LPD classes indicating a clear and persistent change of land productivity fall into areas where no mapped information of land cover change is available. Therefore, local verification using Google Earth multi-temporal high-resolution images is recommended as a quick option for verifying land productivity changes. The LPD geo-tiff class images can be easily downloaded from Google Earth and interactively investigated against changes visible in the underlying high-resolution image data base. During the UNCCD's first LDN pilot phase 2014/2015,[27] it was shown that in many cases declining productivity classes were due to urban and infrastructure expansion (e.g., dam construction, mine openings) which acted as a driver of localized land productivity losses affecting ecosystem functioning in their wider surroundings.

CONCLUSION

The 5 classes of the LPD data set integrate – over a 15 years observation period from 1999 to 2013 – information on the direction, intensity and persistence of trends and changes in above-ground biomass generated by photosynthetically active vegetation cover, widely equivalent to GPP of the global land surface.

Within one pixel (1 km^2), low-resolution imagery may typically assemble a considerable amount of vegetation heterogeneity, and above-ground biomass production is not to be equated with crop production. Consequently, it must be clearly understood and communicated that 'land productivity' in the context of the LPD dataset strictly refers to the overall above-ground vegetation biomass productivity. This is not conceptually the same as, nor necessarily directly related to, agricultural income per area unit or 'land productivity' as used in conventional agricultural terminology.

Furthermore, it has to be understood that the 5 LPD classes provided are not associated to specific levels of above-ground biomass production or specific biomass quantities lost or gained during the observation period. Each class characterizes mainly the overall direction, relative change intensity, and persistence of GPP, independently of the actual level of vegetation abundance or land cover type. This means each LPD class can appear in any type of land cover and at any level of vegetation density. Nevertheless, the quantitative information on biomass productivity levels is contained in the input NDVI time series data and used in the processing chain as outlined in Table1.

Given that the global time series of daily observations of vegetation indices, such as the NDVI (or others), are continuously updated for each subsequent monitoring phase, the extended NDVI time series will be used to produce the LPD classes but with longer time series as input. Thus, LPD class changes between the baseline period and the follow-up monitoring phases will indicate changes in land productivity trajectories. The next LPD release will extend the existing product to the period 1999 to 2016. In parallel it is proposed to address land productivity monitoring with numerical values of change than rather than with 'qualitative classes' of the LPD by providing information on percentage change in land productivity between the baseline and each subsequent monitoring year. A GPP proxy could be expressed as an average of time-integrated NDVI over a 3 to 5 year window centered on the baseline year and the monitoring reference years.

In terms of maturity and "operational readiness," the estimation of GPP at national and sub-national levels (at spatial resolution between 1000 to 250m), the use of remote sensing inputs in the form of vegetation indexes, that reflect green vegetation cover dynamics and spatial heterogeneity at these scales, are currently the most practical for routine use. Extension of the LPD approach to 30m resolution for specific areas using available Landsat archives and new data sources (e.g., Copernicus Sentinel) is only 5 to 10 years away.

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Bold decisions and investments made today will determine the quality of Life on Land tomorrow. This Outlook serves as a timely reminder of the steps we can take to shape a prosperous and more secure future. A future based on rights, rewards and above all respect for our precious land resources.

Land is an essential building block of civilization yet its contribution to our quality of life is perceived and valued in starkly different and often incompatible ways. Conflicts about land use are intensifying in many countries. The world has reached a point where we must reconcile these differences and rethink the way in which we use and manage the land.

The evidence presented in this first edition of the Global Land Outlook demonstrates that informed and responsible decision-making, along with simple changes in our everyday lives, can if widely adopted help to reverse the current worrying trends in the state of our land resources.

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