Humans dominate the planet and their influence extends directly and indirectly to every part of the world. Global population has reached seven billion people and is projected to reach 8.3 billion by 2030.

Exponential increases in human population and changes in patterns of consumption have created unprecedented pressure on the Earth’s natural resource base. Humans and their actions have become the main driver of global environmental change. This section provides snapshots that illustrate the dynamic human footprint on the Earth and its potential impact on the land resource.
This map dramatically illustrates the growing extent of human activity on planet Earth through the detection of lights at night. Covering a 15-year period of night-time satellite observations, it illustrates the phenomenal growth and intensification of human impact, revealing a mosaic of human settlements (e.g. urban clusters), industrial activity, wildfires and human-induced fires lit to clear land.

In the early 1980s the first low-light nighttime images of the Earth’s surface were released from the United States Defense Meteorological Satellite Program (DMSP). These data were originally designed to monitor cloud cover at night for weather forecasting. By the mid-1990s, they were being used to help map human population distribution, estimate built area and impervious surfaces, identify maritime commercial activity (including offshore oil and gas exploration and fishing), map fires and estimate the impacts of human expansion on agricultural land1, 2, 3.

Humans have transformed over half of the Earth’s ice-free terrestrial land surface into cropland and pasture4. Agriculture has evolved to sustain ever-larger populations which, in turn, has led to the more intense use of lands for urban growth, industrialisation and energy extraction. Now, we see a world transformed by these processes. We can observe the phenomenal growth of urban regions by changes in patterns of city lights.

On this map, more established urban centres are shown in white. Other colours show the appearance of lights in different single or combined years (see map caption and legend). The Indian subcontinent and Asia in particular have seen huge urban and industrial growth between 1992 and 2006. Fires, both natural and agricultural in origin, can be seen over vast areas of Africa, South-East Asia, South America and northern Australia. While they span huge areas collectively, individual fires are not as massive as the image suggests because they occurred over the 15-year period of record. Also seen on this image are oil flares where extraction activities are being carried out. Along the coast of South Korea and the Sea of Japan, lights of fishing fleets can be seen plying the waters using their lights to attract squid and other fish.

Night-lights alone under-represent the impact of human activities. Persistent cloud cover obscures urban centres in the Congo and the Amazon, which is why they remain dark in the map. More importantly, many inhabited areas, often in arid areas, have a very thin scattering of lights that suggest low levels of infrastructure.

When combined with maps of population density, the density and brightness of night-light networks can be used to infer the relative level of development and human well-being5.
Nighttime lights increase between 2000 and 2010 (NOAA)

Patterns and trends of night-lights and population densities. In this image, bright lights (yellow) are overlaid on population density (blue). Blue areas represent areas with dense populations but no night-lights. This graphically underscores the lack of infrastructure and corresponding low levels of human well-being in under-served regions. Source: NOAA DMSP-OLS v4; CIESIN GPWv4.

Observing patterns and trends in night-time lights from space is a simple yet powerful way of showing trends in human population presence. This is a colour composite produced from three annual cloud-free composites of night-time lights that appeared in single years: 1992 in blue, 2000 in green and 2006 in red. The colours cyan, yellow and magenta, indicate appearance of night-time lights for combined years. The white colour indicates more established urban centres. The lights detected are from cities and towns, gas flares and fires.

Source: The data were processed by the NOAA National Centers for Environmental Information, DMSP-OLS Night-time Lights Time Series.
Transportation and Accessibility

Infrastructure expansion is a major cause of land degradation\textsuperscript{1, 2}

Logging and transportation roads for forest clearing visible from space in the Amazonian area of Rondonia in Brazil show a classic example of the expanding human impact along corridors. Images show a transition from 1984 to 2016.


Per hectare production costs over economic space, for low-, medium- and high-level production management conditions in Africa.

Source: Chamberlain, J. et al., Food Policy (2014)\textsuperscript{15}.

Average accessibility time per continent.

The imprint of the global road networks reflects a convergence of dynamic processes such as demographic changes, concentration of economies, land cover changes, and land use changes, including intensification of agriculture and urbanisation. All of which affect the status and quality of the land and can exert combined pressures, potentially leading to land degradation (see pages 56, 41 and 142).

The reach and intensity of human impacts extend over the entire planet. This is largely due to the extraordinary mobility of humans, as exemplified by economic globalisation. Local, regional and national economies are closely linked to the movement and transportation of goods and services across borders (see page 41). Although other factors contribute, the geographic “connectedness” of any point on the Earth to all others is a useful indicator of its current economic standing and a predictor of “connectedness” of any point on the Earth to all others is a useful indicator of its current economic standing and a predictor of future economic opportunity.

Access to basic infrastructure that sustains human well-being—such as water, sanitation, energy, schools, hospitals and markets—is one important measure of economic development. Hence, nations worldwide strive to achieve a robust physical infrastructure as a basic and continuing focus of economic development. Hence, nations worldwide strive to achieve a robust physical infrastructure as a basic and continuing focus of economic development. Hence, nations worldwide strive to achieve a robust physical infrastructure as a basic and continuing focus of economic development. Hence, nations worldwide strive to achieve a robust physical infrastructure as a basic and continuing focus of economic development.

However, significant environmental costs accompany the development of physical infrastructure. Over the past century, the construction of roads and railways is one of the most widespread ways the natural landscape has been modified. Among their many impacts, roads lead to the destruction of natural vegetation, fragmentation of habitats, obstruction of animal migratory routes, the spread of exotic species, disruption of flows of rivers, alterations of natural biogeochemical cycles and increased accessibility by humans. All these processes contribute to accumulated stress that affects the functioning of the land and can lead to degradation.

Furthermore, increased human accessibility leads to an expansion of the “agriculture frontier”, especially in developing countries, since the obstacles to (e.g. cost of) marketing commodities grown in remote areas significantly decrease. Accompanying this expansion of agricultural frontiers is the far larger “infrastructure footprint” when immigrants – often enticed by government incentives – settle to take advantage of cheap land and new economic opportunities. The development of Rondonia, Brazil, in the Amazon Basin is a well-known example of the frontier phenomenon.

In contrast to the more dramatic unfolding of agricultural frontiers, many parts of the less-developed world – such as arid and semi-arid lands – are already occupied by smallholder agriculturalists and pastoralists, but at low population densities. People there are often hugely dependent on the land and forced to overexploit the available resources (see page 65). In such areas, the extension of infrastructure, especially roads, may lead to improvements in basic services to local populations and potentially enable access to local, regional and even international markets. Given the limitations of and challenges to maintaining livelihoods in remote arid and semi-arid regions, roads can also facilitate migration to urban areas where people seek employment, education and healthcare, etc. While urbanisation generally serves national interests and there are incentives to promote it, migration to urban areas in some locations, such as sub-Saharan Africa, is often less than anticipated due to socio-economic and socio-cultural situations. Rural areas might see an increase in population but a delay in infrastructure development.

This may be related to inevitable disparities between urban and rural education opportunities as well as difficulties in returning expected remittances from urban to rural areas. However, as the economic power of globalisation increases, the pressure will likely grow to “relocate” some land uses (e.g. crop and animal agriculture) from areas with high production and environmental costs (e.g. Europe) to areas that have a comparative advantage (i.e. developing countries) (see page 41).
Population Distribution, Trends and Projections

Increasing population impacts on the global environment

Human Population on Earth

The Population Division of the United Nations estimated that in mid-2015 the world population was 7.3 billion. This is almost triple the 1950 value of 2.6 billion. As of 2015, both China and India have over 1 billion people. Combined, this represents nearly 40% of the total world population and, together with the rest of Asia, over 60% of the global population (4.4 billion) live in this region of the world. The remaining people are distributed across the rest of the world, with 16% in Africa (1.2 billion), 10% in Europe (738 million), 9% in Latin America and the Caribbean (634 million) and the remaining 5% in Northern America (358 million) and Oceania (39 million).

In 2015, the ten most populated countries in the world were located in Africa (Nigeria), Asia (Bangladesh, China, India, Indonesia and Pakistan), Latin America (Brazil and Mexico), Northern America (United States of America) and Europe (Russian Federation). By 2050, six of these countries are expected to exceed 300 million: China, India, Indonesia, Nigeria, Pakistan and the United States of America.

Projected Population Growth

According to UN estimates, the human population on Earth is projected to increase by 50% by 2100, stabilising at about 11.2 billion. Recent analysis of these data, however, suggest that a stabilisation of the world population this century is highly unlikely. It is estimated that there is an 80% probability that the range of increase will in fact lie between 9.6 billion and 12.3 billion by 2100. Regardless of the actual figure, it is clear that Earth’s population is growing to unprecedented levels.

Regional Variation

One of the striking features of the UN’s projected growth is its uneven distribution across the globe. Between 2015 and 2050, it is estimated that the global population will increase by 2.4 billion. Of this, an overwhelming 50% will be concentrated in Africa (1.3 billion) and 38% (or 0.9 billion) in Asia. The remaining will be distributed across Latin America (6%), North America (3%) and Oceania (1%). In contrast, Europe will experience a 14% drop in its population in 2050 as compared to 2015. Over the period covering 2015 to 2050, half of the world’s population growth will be concentrated in India, Nigeria, Pakistan, Democratic Republic of the Congo, Ethiopia, Tanzania, United States of America, Indonesia and Uganda (listed in order of the size of each country’s contribution to total growth).


Population Distribution, Trends and Projections in mid-2015 the world population was 7.3 billion across the rest of the world, with 16% in Africa (1.2 billion), 10% in Europe (738 million), 9% in Latin America and the Caribbean (634 million) and the remaining 5% in Northern America (358 million) and Oceania (39 million).

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Human population is taking its toll on the planet

The human imprint on the planet has a major impact on the functioning of the Earth system. The concept of the Anthropocene is commonly used to capture this shift in the relationship between humans and the global environment (see page 112). Because the impact on the environment is closely intertwined with population dynamics, it is important to monitor and include these in the land degradation evaluation. Further to distribution, density and migration, population dynamics impact the planet in various ways (Source: Bongaarts, J., 2016).

1. Economic stagnation. In poor societies, populations often double in size in two or three decades. Food production, industries, offices, housing, schools, health clinics and infrastructure must be built at least at the same rate. Many communities are unable to keep up — as is evident from high unemployment rates, explosive growth of slum populations, overcrowded schools and health facilities and dilapidated public infrastructure (such as roads, sewage systems and power grids). Furthermore, in rapidly growing regions, about half of the population is aged under 20. The low ratio of workers to dependents depresses living standards and makes it more difficult to invest in the human and environmental capital needed. The size of the formal labour force is also limited when women remain at home to care for large families.

2. Political unrest. Youth unemployment becomes widespread when economies are unable to provide jobs. Vigorous competition for few jobs leads to low wages, which in turn contribute to poverty. Large numbers of unemployed and frustrated young people fuel socio-economic tensions, high crime rates and political instability and hamper environmental awareness and concern.

3. Environmental degradation. Unprecedented global threats such as climate change and decreasing biodiversity have been building and will become more severe as populations, economies and consumption grow. Crucial local environmental problems — including shortages of fresh water and arable land, mounting waste and air, water and soil pollution — adversely affect health and threaten the expansion of food production required to feed more people a better diet. These local environmental impacts, linked to increased food, fibre and fuel production, affect global biogeochemical cycles.

By the end of the century, in 2100:
- There will likely be more than four times as many people in sub-Saharan Africa
- The populations of West Asia and North Africa will double in size
- Both Europe and East Asia will see declines in their total population

Globally, it is estimated that 450 million people will migrate from rural to urban areas by 2050. In recent years, there has been a growing acceptance that “environmental refugees” – populations forced to migrate due to the impacts of climate change – are a growing problem. Although there is great uncertainty, some estimate that between 100 and 250 million people (or higher) will be displaced before 2050.

Other factors also drive migration, e.g. land degradation, natural disasters and conflicts. Migration per se is a complex issue and for any given region various drivers can be involved, including economic, political, social, demographic and environmental conditions, all of which are linked in complex ways depending upon local conditions.

Migration will be a significant factor on the African continent, which is rapidly changing. As throughout the rest of the world, Africa is experiencing rapid urbanisation: in fact, six of 10 counties with the highest rates of urbanisation in the world are in Africa. To help cities cope with the challenges posed by such an influx (including disrupting local employment, provision of services and cultural impacts) rural development programmes are being developed in an attempt to make rural regions more attractive to youth.

A recent, detailed analysis of UN migration data from 2005 to 2010 depicts some remarkable features of the global migration system. Four major trends emerged:

1. Migrants from sub-Saharan Africa (the vast majority of African migrants) moved predominantly within the continent. An estimated 665,000 migrants moved within Eastern Africa and 1 million people moved within Western Africa;
2. Migrants from South Asia and South-East Asia tend to move to Western Asia, North America and (to a lesser degree) Europe. Migrants from Latin America move almost exclusively to North America and Southern Europe;
3. Migration to and from Europe is characterised by a much more diverse set of flows to and from almost all other regions in the world; and
4. Although the largest flows occurred within or to neighbouring regions, numerous flows go through the centre of the circle, which indicates that long-distance flows are applicable to understanding the redistribution of populations to countries with higher income levels, whereas the return flows are negligible.
PART II – GLOBAL PATTERNS OF HUMAN DOMINATION

Flow estimates* by region 2005

- 250,000
- 500,000
- 1,000,000
- 2,000,000
- 5,000,000

Migration within region (line widths as above)

For clarity, only flows over 200,000 are shown.

A refugee from Sudan sorts and cleans millet by getting rid of the dust and herbs. Farchana camp in Chad host more than 22,000 refugees. Source: European Commission DG ECHO. Flickr.com

Internally Displaced Persons (IDPs) use sticks and scraps of plastic to construct makeshift shelters at Intifada transit camp near Nyala in South Darfur. These shelters are characteristic of many IDP settlements in Darfur. Source: Mark Knobil. Flickr.com

Irish Naval personnel from the LÉ Eithne (P31) rescuing migrants as part of Operation Triton. Source: Irish Defence Forces. Flickr.com
The Urban Planet

Productive land is lost to urbanisation

The Earth viewed from space – with 70% of its surface covered with water – is called the Blue Planet. The remaining 30% of terrestrial land surface is home to a human population of 7.6 billion and, in the age of the Anthropocene, it may be more appropriate to refer to it as the Urban Planet: More than half of the world’s population now reside in urban areas, despite these covering only around 3% of the land surface (excluding Antarctica).

In 1900, only 10% of the global population were urban dwellers. By 2014, this number rose to 54% of the world’s population. This is a harbinger of a trend that is expected to continue. By 2050, the world’s population will be about one-third rural and two-thirds urban, roughly the reverse of the rural-urban mix of the mid-twentieth century.

It is generally accepted that the long-term consequences of urbanisation are complex and uncertain. On the positive side, urbanisation can lead to increased energy efficiencies, higher productivity and enormous economic benefits. The latter is especially true in emerging markets, which have enjoyed rising incomes. This has shifted the global economic balance toward the east and south. On the negative side, there is no doubt that urban sprawl displaces species, alters water cycles, consumes irrereplaceable wetlands and farmlands and is reshaping the global landscape. The land area needed to provide food, energy and materials to a city is often 200 times greater than the area of the city itself. As hubs of production, consumption and congestion, cities account for 70% of the world’s carbon emissions, which contribute to global warming.

Cities are also a major source of aerosols (the “haze plumes”), which alter regional precipitation patterns. In addition, the growth of cities alters land cover and land surface temperatures (one case study in South East China found that mean surface temperatures increased 0.05°C per decade). Cities alter the environment via the widespread use of paved roads and roofs, which prevents water from infiltrating into the soil and thus promotes flooding and polluted runoff that damage aquatic ecosystems. Cities are major sources of crime, noise, water and air pollution, “heat island” effects, artificial light and disease.

These combined problems tend to be exacerbated in developing countries where currently about 0.9 billion city dwellers live in urban slums under dire social disparities. It is perhaps ominous that the overwhelming majority of new urban dwellers by 2050 will be in developing countries.

China’s Urbanisation

China’s urbanisation rate has been described by the World Bank as “unprecedented in scale”. Over the past several decades, rapid urbanisation has profoundly changed the entire country’s social, economic and environmental core. The National Development and Reform Commission of China reported that the percentage of its population living in urban areas surpassed 55% in 2016 and the government is targeting a value of 60% by 2020. By 2050, it is projected that nearly 80% of all Chinese residents will reside in cities.

Although urbanisation has been extremely beneficial for social and economic development, the long-term consequences for the environment are serious and challenging. Problems include land degradation, loss of arable land, depletion of natural resources, the pollution of soil, air and water, fragmentation of natural landscapes and decline in basic ecosystem services (e.g. water resources, crop pollination, carbon sequestration, food production).

Perhaps one of the most pressing issues is the conversion of agricultural areas, such as rich farmland in the eastern coastal provinces, into urban centres. Arable land lost to development and contamination is frequently replaced by marginal and lower-quality alternatives. The National Land Resource Survey of China reported that the amount of available land in China has peaked yet rural land conversion rates continue unabated and have actually accelerated (based on 2008–2012 data). About 3 million hectares of high-quality arable land (plus an additional 1 million hectares of paddies) have been lost to urban use in the past 10 years. Hence, pressure on China’s farmland resources will inevitably continue, threatening its food security.

A significant driver of the loss of arable land is the central government’s transfer of fiscal responsibilities of land management to local governments. This has created a “ perverse incentive to maximize urban sprawl” since many local governments greatly benefit financially by shifting farmland to nonagricultural use and selling building rights (in some instances accounting for 40% or more of a city’s entire budget). Although the issues are complex and multidimensional, novel ways must be found to protect and better manage existing farmland and to reduce the loss of arable land. The remaining high-quality arable land is being overused, which leads to reduced fertility, soil erosion, acidification and heavy metal contamination. Increasing efforts are being made to reclaim and restore degraded lands. Overall, agricultural production has only slightly decreased in recent years but the continued loss of arable land, coupled with other forms of land degradation, will compromise the future of China’s food production systems.

Simulation results suggest that for each 1% increase in China’s urbanisation rate, there is a decline in 0.065% of cultivated area and a 0.087% decline in its agricultural production potential.

China’s Urbanisation Rate

In 1900, only 10% of the global population were urban dwellers. By 2014, this number rose to 54% of the world’s population. By 2050, the world’s population will be about one-third rural and two-thirds urban, roughly the reverse of the rural-urban mix of the mid-twentieth century. This is a harbinger of a trend that is expected to continue.
Among 233 countries or areas:

- Just 15% had levels of urbanisation greater than 60%, i.e. more than 60% of the population living in urban areas.
- Only 6% had more than 80% of the population living in urban areas.

Estimates indicate that in 2014, around half of all countries or areas had more than 60% of their population living in urban areas and in 25% of countries or areas the urban population exceeded 80% of the total country population.

- Northern America and Latin America and the Caribbean are the most urbanised regions, with 80% or more of their populations residing in urban settlements.
- Europe, with 73% of its population living in urban areas in 2014, is expected to be more than 80% urban by 2050.

Projections indicate that by 2050 in nearly 70% of all countries or areas in the world the urban population will be more than 60% and 38% of all countries or areas will have more than 80% of their population living in urban areas.

- Of the 2.5 billion new urban dwellers anticipated by 2050, 90% will live in Africa and Asia. Nevertheless, they are expected to remain the two least urbanised regions of the world.
- India, China and Nigeria – together are expected to account for more than one-third of global urban population growth.

Urban Clusters

Urban populations grow detached from their remote impact on the environment

According to the Atlas of the Human Planet 2016\(^1\), about 85% of global inhabitants (6.2 billion) live in cities (including towns, suburbs and large urban areas). This figure shows the distribution by climate types (see page 72) of the planet’s total urban area and urban population. More than 30% of the urban area and 34% of the urban population are located in dryland regions (including dry subhumid, semi-arid, arid and hyper-arid climates), increasing stress on surrounding water resources.

<table>
<thead>
<tr>
<th>Climate Types</th>
<th>Distribution in Drylands</th>
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<tbody>
<tr>
<td>Humid</td>
<td>Dry Subhumid</td>
</tr>
<tr>
<td>Semi-arid</td>
<td>Arid</td>
</tr>
<tr>
<td>Hyper-arid</td>
<td></td>
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</tbody>
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Spurred by the increasing dominance of global urbanisation (see Urban Planet), there have been initiatives to map urban areas in detail at the global scale:

- The recently published Atlas of the Human Planet 2016\(^1\), offers a comprehensive view of urbanisation dynamics, spatial maps, and summaries quantifying the growth of the global urbanised population over the past 40 years, covering the period from 1975 to 2015. It is based on the Global Human Settlement Layer (GHSL)\(^2,3\), a collection of maps of the human presence and built-up areas, from villages to mega-cities, derived from satellite data with a 38m detail.
- Focusing on the current status of settlements, the “Global Urban Footprint” (GUF)\(^6\) provides detailed worldwide mapping of built-up settlements with a spatial resolution of around 12m – examples are shown throughout this atlas.
PART II – GLOBAL PATTERNS OF HUMAN DOMINATION

Some extraordinary changes have occurred across the globe over the past 40 years with regard to human habitation; the Atlas of the Human Planet 2016 illustrates the following findings:

- Globally, built-up areas increased by approximately 250%, while population increased by a factor of 1.8;
- There is significant geographical variation in population growth and built-up areas. The largest population growth was observed in low-income countries where, for example, the population of Africa tripled and its built-up area quadrupled. In contrast, the population of Europe was stable but its built-up area doubled;
- Urban Centres: Most of the world’s population live in agglomerations with densities greater than 1,500 people per km² and more than 50,000 total inhabitants. As of 2015, 13,000 individual Urban Centres existed on the planet;
- Urban Clusters: Clusters of agglomerations with more than 300 people per km² and at least 5,000 inhabitants per km², were used to capture both the dense Urban Centres and the surrounding suburbs and towns. In the past 40 years, the number of these Urban Clusters have doubled. Urban Clusters constituted 4% of the terrestrial land mass in 1975. By 2015, this figure rose to 7.6%, which is approximately half the size of the European Union; and
- About 85% of the planet’s inhabitants live in cities, either in Urban Clusters and Urban Centres.

The impacts of urbanisation on the environment are immediate and profound (see The Urban Planet, page 30). As urban clusters expand, productive land and soil is sealed, and natural ecosystems (e.g. pastures, forests) are replaced to varying degrees by land use to support urban centres. This includes agricultural fields, pens and pastures for animals, housing for workers and the inevitable complex network of pathways, roads and railways that connects it all. The ebb and flow of commodities, services and people into and out of urban/non-urban regions (such as ecosystem services (water, food), the physical transport of materials (mining of raw materials to construct the built environment), people (migration, tourism and lifestyle mobility), money (remittances) and so forth) affect the populations, economies and status, development and management of distant lands far-removed from any particular urban environment.
Extents of Global Agriculture

**NORTH AMERICA – CALIFORNIA**

Agriculture in the world’s drylands has obvious local value, but often has outsized regional or national economic importance. For example, California has only 2.0% of harvested cropland in the United States but its production, largely of specialty crops, represents 10.7% (US$42.6B) of total agricultural sales nationally (https://www.agcensus.usda.gov/). There is understandable resistance to policies that would affect production in these economically important regions.

**SOUTH AMERICA – BOLIVIA**

Some of the crops that evolved in drylands have a persistent, widespread and important economic specialty role in the world’s agricultural economy. The date palm (Phoenix dactylifera) has been an important crop for millennia. It is tolerant of high temperatures, drought and saline conditions. It has come to be cultivated in and around lands worldwide, ranging from Pakistan to California. Other crops from the drylands, such as grain amaranth quinoa (Chenopodium quinoa) and the date palm (Phoenix dactylifera), have been an important crop for millennia. It is tolerant of high temperatures, drought and saline conditions. It has recently experienced an unexpectedly rapid growth in global popularity. Such sudden increases in demand may cause economic booms which can lead to social problems that accompany rapid growth and environmental threats when production is expanded into marginal areas.

More than 40% of the world’s cropland is in drylands. By continent, they comprise as little as 16% (South America), to more than 70% (Australia and Oceania).

Agriculture provides food, fibre and other products that sustain human life. It is one of the most pervasive drivers of environmental change on Earth through both direct and indirect impacts on climate, biodiversity, land degradation and freshwater. Its extent reflects the growth and migration of the human population to every part of the planet.

In 1700, over 2.65 million km² of land were devoted to cropland worldwide; in 2014, the total area of croplands was estimated to be 20.59 million km², which represents an eight-fold expansion. Croplands occupy about 14% of the total ice-free land area on the planet, while pastures occupy about 26%.

Nearly half of the world’s agricultural land (44%) is located in drylands (see page 72), mainly in Africa and Asia, and supplies about 60% of the world’s food production. Most of this production has been achieved through the Green Revolution – improved seeds, chemical fertilisers, enhanced technologies and irrigation. Food production in drylands is threatened by water shortages, climate change, land degradation and persistent poverty. Climate change may have a major impact on drylands as temperatures become more extreme (hot and cold), rainfall declines, groundwater tables drop and climate zones shift. Although climate change will likely increase aridity, the actual risk to agriculture is difficult to quantify. In addition, economic uncertainties and social unrest can lead to “debilitating levels of outmigration and instability” in drylands, which, besides the direct toll on human presence, may lead to lower agricultural productivity and further stagnation and marginalisation of local economies.

Agricultural production must continue to meet the needs of a rapidly growing global population. One estimate is that over 1 billion hectares of “wild” land will have to be converted to agriculture to feed the global population by 2050. However, not all land is suitable for agriculture and there is intense and increasing competition for land due to urbanisation, bioenergy farming, forest plantations and protected areas.

An alternative is found in ‘sustainable intensification’, which includes ceasing agricultural expansion, closing ‘yield gaps’ (the difference between observed yields versus maximum potential yields) on underperforming lands, increasing efficiencies (management, technologies), reducing overuse of water and fertilisers, shifting diets from meat to plants, and reducing waste. Regardless of the pathways taken, maintaining dryland production will be a challenge in the future.
Agriculture and land degradation

Increased agricultural production is essential to feed a growing population. However, the expansion of agriculture into “new” lands often threatens local and regional ecosystems. Intensification of production on existing agricultural lands to fill “yield gaps” is also a threat to the environment through the potential overuse of water, fertilisers and pesticides that affect local and regional water resources and ecosystems. The drylands will play a major role both in providing lands for “new” agricultural production and opportunities to intensify existing production. Charting an “optimum” path among these options that meets desired needs and minimises environmental damage is the challenge of this century.

PART II – GLOBAL PATTERNS OF HUMAN DOMINATION | World Atlas of Desertification

10 thousand years ago, the world’s drylands were also centres of agricultural development. Not only did they give rise to irrigation but, more importantly, many were centres for agricultural plant domestication. The “Fertile Crescent” stretching from the Tigris and Euphrates Rivers to the Mediterranean Levant was especially important. Critical food crops were developed here, including barley (Hordeum vulgare), wheat (Tritium sp.), lentils (Lens culinaris), peas (Pisum sativum), chickpeas (Cicer arietinum) and broadbeans (Vicia faba).

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Impacts on Global Forests

Forest change can contribute to land degradation

“Forests play a fundamental role in combating rural poverty, ensuring food security and providing decent livelihoods, they offer promising mid-term green growth opportunities; and they deliver vital long-term ecosystem services, such as clean air and water, conservation of biodiversity and mitigation of climate change”

FAO Director General

The 2015 Global Forest Resources Assessment of the Food and Agriculture Organization reported that the total area of global forests has declined by 3% over the previous 25 years. However, there has been some glimmer of hope. Between 1990 and 2000, the annual rate of net global forest loss was 3.9 Mha per year but was halved to 3.3 Mha per year between 2010 and 2015. These figures are encouraging but must be examined in the context of natural versus plantation forests and by the rapidly changing rates of deforestation and afforestation. For example, the global area of natural forest area decreased by 6% between 1990 and 2015. The replacement of natural tropical forest with intensively managed plantations of exotic tree species will undoubtedly increase overall timber production potential but will reduce its natural biodiversity, habitat value and supply of ecosystem services.

The dynamics of national- to global-scale economic opportunities, combined with public policies, drive forest change. In addition to the economic consumption of forest products (i.e. timber, fuelwood), there is also the demand for land for agricultural expansion and the construction of roads and other infrastructure, all of which lead to deforestation, land degradation, biodiversity loss and habitat fragmentation. For example, the recent surge in deforestation in the Brazilian Amazon is due to economic instability, monetary exchange rates, political support for agribusiness and reduced government expenditure on the enforcement of existing environmental laws. The differential importance of these sets of drivers lead to regionally distinct patterns of forest decline.

Forests are the most biologically diverse ecosystems and critical for sustaining local and global livelihoods. They produce oxygen, equilibrate freshwater flows and cycle nutrients in addition to providing important provisioning services. Over 25% of all global forests are managed specifically for soil and water protection. Reforestation and forest regeneration can be a major global carbon sink, but the current rate of forest degradation and subsequent release of greenhouse gases is contributing to climate change.

Carbon stocks in forests have decreased by almost 11 gigatonnes (Gt) in the past 25 years. Although CO₂ emissions from net forest conversion decreased from an average 4 Gt CO₂ yr⁻¹ (2001-2010) to 2.9 Gt CO₂ yr⁻¹ (2011-2015), suggesting a smaller than expected contribution to anthropogenic forcing due to forest loss, the emissions from forest degradation increased significantly from 0.4 Gt CO₂ yr⁻¹ in the 1990s to 1.0 Gt CO₂ yr⁻¹ during the period 2011-2015.

Deforestation can be considered a type of land degradation when forest ecosystems, with all of their important cultural, regulating and provisioning services, are exchanged for another land use, such as crop agriculture, with a narrow provisioning service focus. Some of the damages sustained by the land resource are the immediate reduction or loss of biomass productivity with a linked loss in habitat, biodiversity, and carbon stock. Clearance of natural forests accelerates soil erosion and the alteration of soil functioning. This can provoke a reduction in carbon, nutrient...
and water storage and cycling capacities that seriously affect land productivity or the long-term productive capacity of the land system. These effects can be partly offset when previously forested land is managed under adaptive and sustainable practices. In many cases, introduced agriculture, including pasture and crops, does not focus enough on protecting the newly exposed land area, and the trade-off of forest for alternative land uses leaves a permanent deficit in ecosystem services. Resilience of forests is highly variable, but due to the feedback process of land degradation, disturbance may lead to a downward spiral in the ability of the land to provide the ecosystem goods and services that characterised the original state. Participatory forest planning and management is one approach that can lead to the development and dissemination of adaptive practices that increase the quality of natural capital factors through reduction in loss of biodiversity, reduced forest fragmentation and reduced vulnerability to soil erosion and landslides.

At regional scale, North and Central America, Europe and Asia report increases forest carbon stock while South America and Africa report strong decreases and Oceania reports stable forest carbon stocks. The annual rate of decrease of forest carbon stock weakened between 1990 and 2015. Source: H. Eva

Forest Area Change in Asia
While for all of Asia an increase in total forest area is reported for the period 1990 - 2015, mainly due to forest plantations in China, there is still substantial forest loss in tropical areas. Source: FAO FRA, 2015

New estimates of dryland forest cover reveal a larger than expected area covered with trees, adding around 9% to the global total forest cover. An estimated 1.327 Mha of dryland area with tree canopy cover of more than 10% - a surface similar to the area of tropical moist forest cover - underline the importance of dryland forest in general and its potential role in the global carbon cycle. Source: J.F. Bastin et al., 2017

Tree canopy cover >10% (Mha) in Drylands

Human Appropriation of Land’s Biological Production

A Human Footprint on Earth

Humans appropriate a large proportion of the biological production of all land ecosystems.

Life on Earth depends on the conversion of solar energy into organic carbon compounds. Within the ocean and water bodies algae (seaweed, algae diatoms) are the main mechanism for converting sunlight to carbon, whilst on land this process is driven by the photosynthesis of all the plants that comprise terrestrial vegetation cover. The output of this global process is referred to as Net Primary Production (NPP). All organisms (e.g. all species of animals including humans, bacteria, fungi) depend directly and indirectly on the primary production of plants as an essential foundation of their lifestyle.

Globally, humans use a disproportionate and growing component of NPP. Some is used directly for food, as inputs to animal husbandry and animal products, for energy, or for industrial purposes. Simply put, NPP is the primary source upon which humans rely to feed themselves and their domesticated animals and as a raw material for products based on plant fibre, pulp and wood and, increasingly, as a source of energy. The diversion of products of these biological processes to sustain human populations can have profound impacts on the structure and functioning of global ecosystems. This may result in ecosystem perturbations that can exceed their natural variability and dynamics and result in persistent weakening of ecosystem function and finally a transformation of existing ecosystems into something quite different. These transformations or state changes may result in decreased economic and ecological value. Increasing amounts of NPP claimed by humans also means that less biomass remains for sustaining other species and maintaining ecosystems now and into the future.

The proportion of terrestrial NPP consumed directly and indirectly through human land use has come to be known as Human Appropriation of Net Primary Productivity (HANPP). It can be mapped and quantified.

A map of HANPP represents a characterisation of the extent to which anthropogenic land conversion and biomass harvest of all types (i.e. not only agricultural crops) alter the natural capacity of primary biomass production (NPP) of "undisturbed" terrestrial ecosystems under current environmental conditions (i.e. climate and soil). It has become an important and powerful measure of the impact of human land use on the natural potential to provide NPP.

The adjacent graphical scheme illustrates the basic components considered in the calculation of HANPP. The teal bar on the left represents natural undisturbed potential NPP. The right bar displays actual ‘NPP actual’ under current land use, which is the sum of harvested NPP, and the remaining NPP, after human harvest. Under most land uses ‘NPP actual’ is smaller than potential NPP. The difference between NPP and ‘NPP actual’ denotes the loss of NPP caused by the conversion of land from natural conditions to anthropogenic land use.

Finally, HANPP consists of the harvest and loss due to land development of land use, land cover and biomass harvest in different land uses. These data are now increasingly available from national to global scales, making it possible to provide global and regional maps on HANPP. The impact of human land use and the resulting appropriation of biomass or HANPP is evident in virtually all ecosystems on Earth (excluding largely unoccupied parts of the arctic, hyper-arid zones and tropical rain forests).

Basic NPP components considered in HANPP calculations. Source: Haberl et al., 2007, 2013.
The total global biomass production appropriated by humans (HANPP) amounted to 15.6 GtC/yr around the year 2000, which corresponds to 23.8% of the global potential NPP. Of this, only 6.07 GtC/yr or 38.9% of total HANPP are really used for human requirements, while the remaining biomass included in the HANPP is lost or destroyed during harvest or as a consequence of land conversion. Land conversion alone reduced global potential NPP by an estimated 9.6% or 6.29 GtC/yr.

When examining global HANPP numbers for different world regions and land use categories, a clearer picture of critical areas and issues appears: global croplands show the highest HANPP levels with an average of 83.5% of potential NPP followed by areas with high levels of built-up areas/infrastructure, with an average HANPP of 73%. Eastern and southern Asia, western Europe and parts of North America are characterised both by intense agriculture and by high population and infrastructure density. By most measures – and particularly HANPP – they are the most intensely used regions in the world (shown in red).

Significant increases in future biomass demand are expected. Projected growth of world population, together with changes in human diets towards animal-product consumption, are expected to drive further increases in the amount of biomass required as food and feed. Moreover, many energy scenarios also envisage increases in the amount of biomass used for energy.

Land degradation

Land degradation refers to reduction of land productivity as a result of overuse or over-appropriation by humans. Therefore, the ratio between harvested NPP and NPP lost due to land conversion could be used to identify critical areas of land degradation. Not all conversions provoke NPP losses as this depends on the land use. A more detailed discussion of analysing the HANPP components in view of potential land degradation risk can be found on page 112.

The concept of HANPP first appeared in the early 1970s. Research on HANPP increasingly attracted attention with initial global estimates in the mid-1980s. The most recent approach to comprehensive assessments of global HANPP is based on a combination of vegetation modelling, agricultural and forestry statistics and global geographical information system (GIS) data derived from satellite imagery.

When putting land in economic use, humans usually replace original vegetation with human-dominated systems such as agro-ecosystems, managed forests or tree plantations, or, in extreme cases, total replacement of natural vegetation with built-up or urban land. As indicated in the graphical representation of the basic NPP components considered in HANPP calculations (see diagram on the opposite page), the notion of potential vegetation refers to the vegetation that would prevail in a defined area under current soil and climate conditions in the absence of human intervention. Land use results in a deviation from previously existing natural vegetation (potential), to another type of vegetation (actual) that is dependent on human management to adapt to changing demands and environmental conditions.

The NPP of actual and natural vegetation types are sometimes dramatically different, but usually occur in fairly restricted geographical areas. For example, if natural vegetation is totally replaced by houses and streets (urbanisation), the actual NPP is significantly reduced compared to the natural potential and HANPP becomes very high. Conversely, actual NPP may be dramatically increased and exceed the natural potential NPP in and areas through the introduction of irrigation and fertilisation.

Humans appropriate 20 to 25% of the Earth’s annual land net primary production (NPP), while they represent less than 1% of the mass of organisms.
Global Telecoupling: consumption is increasingly coupled to distant production areas

Nearly one third of global arable land use is connected to international trade.

Physical transformation of “natural” landscapes to other productive uses, including intensively managed agricultural fields, is dramatic as are the changes imposed on local habitat, hydrology and biodiversity. Images of these changes—particularly those acquired from space—have helped to engage the attention of a global audience and mobilise efforts to understand and address the problems that accompany them. Images from satellites have also provided data at a global scale that allows for a comprehensive understanding of both the spatial and temporal dimensions of change.

Collectively, physical consequences that result from land use change have significant global environmental impacts, particularly with respect to carbon emissions. For example, in response to increased global demand for agricultural production, conversion of Brazilian rainforest to soybean fields releases carbon contained in the soil and forest biomass into the atmosphere. Even though these increases have been partially offset by reforestation efforts in production areas and in consumption areas increased forest cover has been facilitated on retired agricultural lands, the net result with respect to carbon emissions is still negative. The need for a more comprehensive and transparent assessment of how countries account for economic growth that includes displaced natural resources used—including land use change and carbon emissions—is an emerging challenge.

Physical environmental changes are relatively easy to map, measure and document, but beyond economic and environmental considerations, the social and institutional feedbacks that shape and are shaped by land transformations are more difficult to map and understand.

Once it is accepted that these telecouplings exist, the first-order impacts within affected areas are, on the surface, straightforward: there are losers and winners with respect to immediate economic and environmental outcomes. However, because we are dealing with human and natural systems that are inextricably linked, the web of impact typically extends into many economic and social webs of interaction at a variety of local, regional and global scales.

Resource governance, or the lines of control that govern land use, may not be in force, fully understood, or systematically circumvented in areas into which land uses are transferred. The effectiveness of local resource governance may determine which specific areas and populations are directly affected.

Within areas of consumption, the increasing free-flow of information may influence attitudes toward economic fairness and environmental sustainability and impact both production and consumption. The complexity of economic, environmental and social factors that influence and are affected by global telecouplings is a vibrant area of multidisciplinary research and is reshaping the ways in which we look at global markets, particularly within a framework of climate change.

In the future, it seems unlikely that large new areas of agriculture will be brought into production, particularly in the drylands, unless there is a transformative development in our ability to produce freshwater from other sources. Thus, as pointed out elsewhere (see page 50) it is more likely that agriculture will be brought into production, particularly in the drylands unless there is a transformative development in our ability to produce freshwater from other sources.
A global economic web of production and consumption drives environmental change.

Under growing globalisation, country-based economic changes will have greater than ever impacts on other economies around the globe. The use of arable land is intrinsically linked to global food supply chains that themselves are increasingly driven by globalised telecoupled demand and supply mechanisms. Consumption of goods imposes pressures not only on the domestic arable land resources but increasingly on arable land outside the country.

The map shows the land used for export production (in Mha) and highlights total land use (cropland, grazing land and forest land) that gets displaced through export production. The thickness of the arrows and numbers next to the arrows represent the amount of land used as inputs for the production of imported and exported goods.

Source: Data from Yu et al, 2013.

telecoupling:

“Telecoupling is a way to express one of the often-overwhelming consequences of globalisation — the way an event or phenomenon in one corner of the world can have an impact far away. In effect, systems couple — connecting across space and time.”

Jack Liu, professor, Michigan State University, USA

A global economic web of production and consumption drives environmental change.
Environmental Globalisation

Virtual Water

The world is facing serious problems of water scarcity. Currently, two-thirds of the global population (over 4 billion people) suffer from severe water scarcity at least one month of the year. This is due to inadequate supplies, poor sanitation and pollution, mismanagement, overuse and waste. In addition, climate change is altering precipitation patterns around the world, causing shortages in some areas and flooding in others. It is clear that humans are changing the water system of the globe in significant ways – thereby jeopardising the very environmental systems upon which humankind relies for freshwater – without adequate knowledge of the system and how it will respond to change. To understand the impacts humans are having on water, every component of the water cycle must be carefully scrutinised, including virtual water.

Virtual water is the total amount of water required to produce a commodity (e.g., food and clothing). Hence, the trade of commodities, whether regional, national or international, represents the transport of virtual water from one area to another. The study of virtual water is important in terms of water scarcity and its impact on global food security and the role of food trade in compensating for water deficits. The number of trade connections and the total volume of virtual water trade has more than doubled over the past two decades. Understanding flows of virtual water was one of the first steps towards understanding “telecoupling” or the increasingly dispersed geographic nature of the multiple components of a global economy (see Global Telecoupling, page 40) that creates impacts on the environment far from the consumption areas. Consumers remain largely unaware of the distant impacts, including land degradation, of their consumption.

At the global scale, understanding virtual water is essential to understanding the largely “hidden” movement and considerable economic value of water in international trade. Because of limited water resources, the world’s drylands are increasingly dependent on the trade of virtual water. In a very practical sense, if food is imported, so is the water that it took to produce. Globalisation has contributed to the ease by which developed countries are increasingly importing water that is embodied in goods from the rest of the world, which effectively alleviates pressure on domestic water resources. For example, consumers in the United States routinely purchase clothing made from cotton grown in Pakistan, a country with severe water shortages. But this is not restricted only to developed countries. China, which faces severe water shortages, especially in the north and north-western regions, has attempted to incorporate a virtual-water strategy to deal with regional water management and food-trade policies. However, while China’s virtual water exports account for 21% of its renewable water resources and 86% of its virtual water use, it is the world’s largest importer of virtual water, accounting for 31% of the total virtual water transported.

Globally, the volume of virtual water trade is vast: roughly 27 trillion m³ of virtual water was traded worldwide in 2010. In 1986, 68% of the world’s population lived in water-exporting countries; by 2010, 60% of the global population lived in water-importing countries. Globally, there is a net transfer of virtual water from areas with a water surplus to areas with a water deficit. This is dynamic due to land-use changes, e.g. the recent development of new croplands concentrated in the water-rich tropics, particularly in South America, while croplands in some of the semi-arid/subhumid lands of central Asia have been abandoned (see Agricultural Expansion, page 50).

The magnitude and role of virtual water in the future will be shaped by many factors, including population growth, economics and availability. Increasingly, it will be influenced by the changing climate, especially in drylands (see Urbanisation, page 30) and changing land-use. Without the discovery or development of new water resources (see Water Resources, pages 88 and 92), a contraction in the trade of virtual water will put water-importing nations in an increasingly perilous position. As the market for virtual water becomes more constrained, some nations and communities will be favoured over others due to inequalities in political and economic influence. Moreover, because virtual water is embedded in global trade, there are private interests that could have outsized influence on trading patterns and partners.

The importance of virtual water in global trade suggests the need for a close examination of its role in the functioning and health of the planet and the global economy. Along with ensuring that the world’s population has access to food via trade of virtual water, will come the challenge of balancing a number of trade-offs associated with other issues, such as “virtual greenhouse gasses” that are similarly embedded in food and other products that are traded internationally.

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If food and goods are imported, so is the water that it took to produce it.©
Virtual water is the amount of water required to produce a commodity. International trade of commodities signifies flows of virtual water over large distances.

The increase in virtual water trade and the percentage of the total virtual water flux in the network corresponding to plants, animals, luxury and other commodities. Source: Carr, J.A. et al., 2013.

Irrigation alongside an overseas shipping container in Angola. Source: Roeder, A.
“Humans have fundamentally altered global patterns of biodiversity and ecosystem processes. Surprisingly, existing systems for representing these global patterns, including biome classifications, either ignore humans altogether or simplify human influence...”

E.C. Ellis and N. Ramankutty

For over a century, researchers have been exploring global-scale relationships between climate and terrestrial ecosystems. Many simple but effective models have been developed to understand and map vegetation as conditioned by climate and other environmental factors. One of the most successful schemes is the Holdridge Life Zone system (see figure below), where biomes are classified based on broad correlations between precipitation, temperature and elevation. Originally published in 1947, variants of the Holdridge Life Zone system continue to play a key role in global studies of the interactions of climate and natural resources: recent examples include studies on the conservation of dry forests, the effects of climate change on terrestrial aridity, and the mapping of land degradation risk.

However, there is a compelling argument that “It is no longer possible to understand, predict, or successfully manage ecological pattern, process, or change without understanding why and how humans reshape these over the long term.” Hence, the concept of anthromes or “anthropogenic biomes”) was introduced to acknowledge that the majority of the terrestrial biosphere of the Earth has been altered by human activity. We are now living in the Anthropocene where, both intentionally and unintentionally, humans are global-scale ecosystem engineers. Anthromes are global ecological patterns created by the sustained interactions between humans and ecosystems. As illustrated in the previous pages of this atlas, human domination of the planet is extensive and is the main driver of global environmental change. The concept of anthromes and their global mapping encourages a rethinking of the biosphere since it “puts people in the map,” which reveals the geographical extent and functional depth of human impacts. The current distribution and types of anthromes represents an integration of the long period of time it took to develop and expand agriculture (over the past 10,000 years) with human population growth and dispersion across the globe.

Human impacts – and their disruption of ecosystem structure, processes and services – include both high- and low-intensive disturbances. Examples include urbanisation, infrastructure (roads, boreholes, pipelines, sewage systems, electricity lines, etc.), extraction (e.g. mining, fracking, logging, dredging, groundwater loss), agriculture (e.g. cultivation, irrigation, landless livestock systems, land clearing, salinisation), various types of pollution (oil spills, heavy-metal contamination, pesticides, medical waste, etc.), garbage spills, and livestock grazing. The direct and indirect consequences of any disturbance at any point on the Earth will vary, depending on the complex interactions of three factors: (a) biophysical conditions (soil, fertility, elevation, biome type, climate, water availability, infrastructure, etc.), (b) social characteristics (cultural traditions and practices, population density, gender equality, political stability, etc.), and (c) economic state (proximity and access to markets, regulatory constraints, degree of wealth, dependency on state institutions, diversification of market products, etc.). Elucidating the specific consequences of these disturbances at tens of thousands of locales across the planet is key to ultimately understanding the complex diversity of relationships between humans and ecosystems.

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Human use has affected most of the Earth’s biomes.