LIVING PLANET REPORT 2016

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BIODIVERSITY

The Living Planet Index, which measures biodiversity abundance levels based on 14,152 monitored populations of 3,706 vertebrate species, shows a persistent downward trend.

RISKS

Our use of natural resources has grown dramatically, particularly since the mid-20th century, so that we are endangering the key environmental systems that we rely upon.



ANTHROPOCENE

Scientists propose that, as a result of human activity, we have transitioned from the Holocene into a new geological epoch: the “Anthropocene”.

RESILIENCE

The 21st century presents humanity with a dual challenge to maintain nature in all of its many forms and functions and to create an equitable home for people on a finite planet.

WWF

Why we are here
To stop the degradation of the planet’s natural environment and to build a future in which humans live in harmony with nature.

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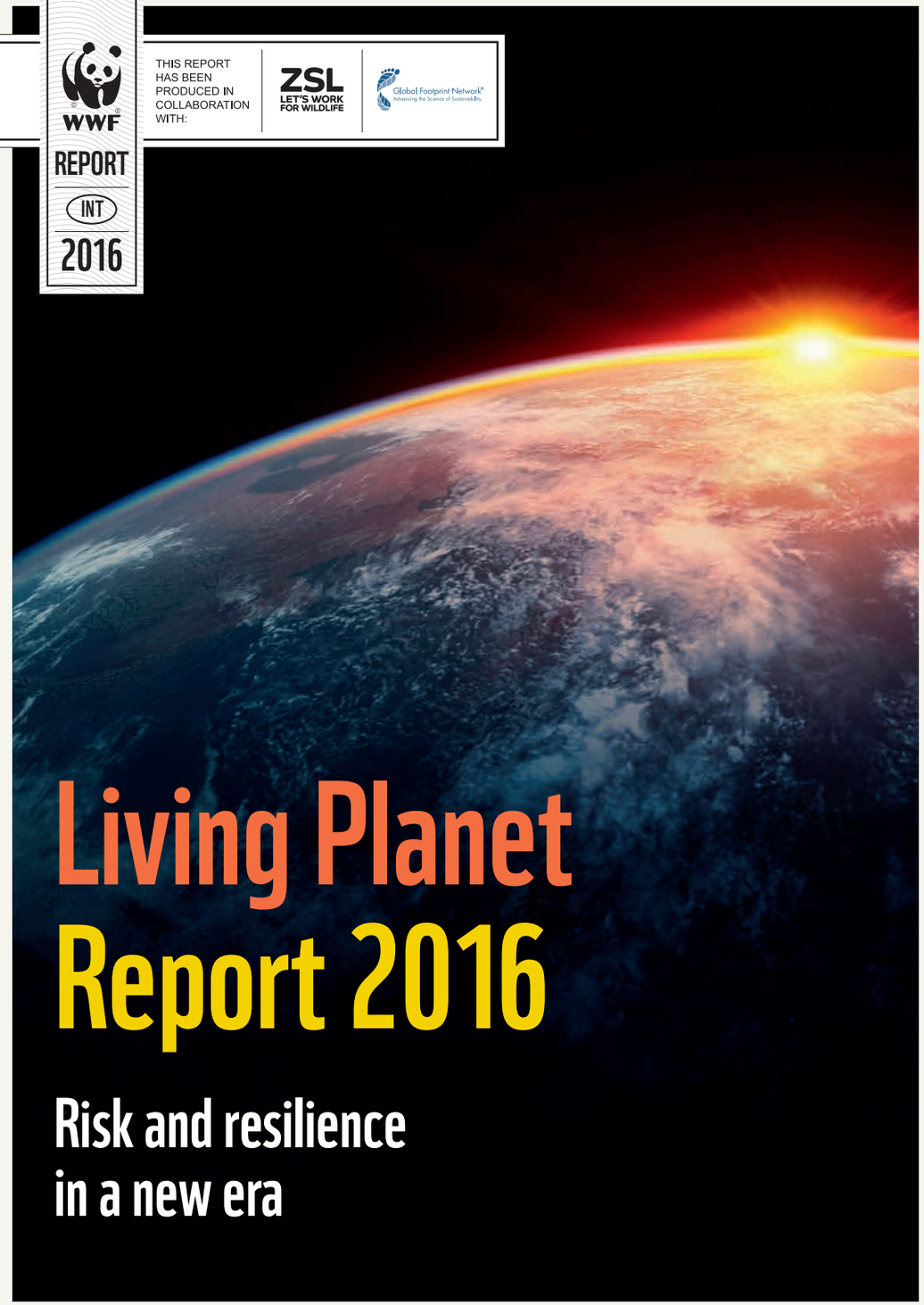
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Global Footprint Network® Advancing the Science of Sustainability



Living Planet Report 2016

Risk and resilience in a new era

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WWF
WWF is one of the world's largest and most experienced independent conservation organizations, with over 5 million supporters and a global network active in more than 100 countries. WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature, by conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable, and promoting the reduction of pollution and wasteful consumption.

Zoological Society of London
Founded in 1826, the Zoological Society of London (ZSL) is an international scientific, conservation and educational organization. Its mission is to achieve and promote the worldwide conservation of animals and their habitats. ZSL runs ZSL London Zoo and ZSL Whipsnade Zoo; carries out scientific research in the Institute of Zoology; and is actively involved in field conservation worldwide. ZSL manages the *Living Planet Index*® in a collaborative partnership with WWF.

Stockholm Resilience Centre
Stockholm Resilience Centre conducts independent research and is part of Stockholm University. Founded in 2007, the Stockholm Resilience Centre advances research on the governance of social-ecological systems with a focus on resilience - the ability to deal with change and continue to develop - for global sustainability.

Global Footprint Network
Global Footprint Network is an international research organization that is measuring how the world manages its natural resources and responds to climate change. Since 2003 Global Footprint Network has engaged with more than 50 nations, 30 cities, and 70 global partners to deliver scientific insights that have driven high-impact policy and investment decisions. Together with its partners, Global Footprint Network is creating a future where all of us can thrive within our planet's limits.

Stockholm Environment Institute
SEI is an independent, international research institute. It has been engaged in environment and development issues at local, national, regional and global policy levels for more than a quarter of a century. SEI supports decision making for sustainable development by bridging science and policy.

Metabolic
Metabolic specializes in using systems thinking to define pathways towards a sustainable future. Working with an international network of partners, Metabolic develops strategies, tools, and new organizations to achieve scalable impact for addressing humanity's most pressing challenges.

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Living Planet Report 2016

Risk and resilience in a new era

A RESILIENT EARTH FOR FUTURE GENERATIONS


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It is rare that a scientific idea fundamentally alters our worldview. Copernicus's realization that the Earth orbits the sun is one such example. Darwin's theory of evolution is another. The Anthropocene – the defining concept in WWF's *Living Planet Report 2016* – is another.

Copernicus kick-started the scientific revolution. His realization and those that followed in his wake – from Kepler, Galileo, Newton – have allowed us to navigate our planet and solar system, and helped create the world we now live in. And Darwin's insights forced us to re-evaluate our place on Earth. Thanks to these insights nothing will be the same again.

In a similar way the Anthropocene shifts our world on its axis. This single word encapsulates the fact that human activity now affects Earth's life support system. It conveys the notions of deep time – the past and future – and the uniqueness of today. Beyond geology and Earth system science, it captures the profound responsibility we now must shoulder. It provides a new lens to see our human footprint and it communicates the urgency with which we must now act. The dominant worldview of infinite natural resources, of externalities and exponential growth, is at an end. We are no longer a small world on a big planet. We are now a big world on a small planet, where we have reached a saturation point. Unsustainability at all scales, from localized deforestation to air pollution from cars, hits the planetary ceiling, putting our future at risk. Fifty years of exponential growth has accumulated to such an extent that we have reached Planetary Boundaries – and crashed through them.

This WWF *Living Planet Report* comes at a critical juncture following the remarkable successes in 2015 of the Paris Agreement on climate change and the agreement on the Sustainable Development Goals for people and planet. The 2016 report is an essential assessment of the state of the planet and it is a shock to read. It synthesizes the mountain of evidence showing the Earth system is under increasing threat: climate, biodiversity, ocean health, deforestation, the water cycle, the nitrogen cycle, the carbon cycle.

The conclusion is stark: the planetary stability our species has enjoyed for 11,700 years, that has allowed civilization to flourish, can no longer be relied upon.

Yet, I am optimistic for our future. In the 20th century we solved some of the biggest challenges in our history. Many diseases have been eradicated. Child and maternal health is improving. Poverty is decreasing. And the ozone hole is beginning to stabilize. However, to make greater progress will necessitate brave new innovations and shifts in thinking to enable collective action across the world. In short, we need an urgent transition to a world that works within Earth's safe operating space. What the Anthropocene teaches us, and which is articulated in detail in the following pages, is the need for a grand transformation. *The Living Planet Report* provides the necessary thought leadership and vision to put the world on a sustainable trajectory based on systems thinking – and starting with the food and energy systems. I am confident this will contribute to the momentum to move from talk to action to ensure a resilient Earth for future generations.

Johan Rockström,

Executive Director
Stockholm Resilience Centre

LIVING ON THE EDGE



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The evidence has never been stronger and our understanding never been clearer. Not only are we able to track the exponential increase in human pressure over the last 60 years—the so-called "Great Acceleration" and the consequent degradation of natural systems, but we also now better understand the interdependencies of Earth's life support systems and the limits that our planet can cope with.

Take biodiversity. The richness and diversity of life on Earth is fundamental to the complex life systems that underpin it. Life supports life itself. We are part of the same equation. Lose biodiversity and the natural world and the life support systems, as we know them today, will collapse. We completely depend on nature, for the quality of the air we breathe, water we drink, climate stability, the food and materials we use and the economy we rely on, and not least, for our health, inspiration and happiness.

For decades scientists have been warning that human actions are pushing life on our shared planet toward a sixth mass extinction. Evidence in this year's *Living Planet Report* supports this. Wildlife populations have already shown a concerning decline, on average by 58 per cent since 1970 and are likely to reach 67 per cent by the end of the decade.

Yet there is also evidence that things are beginning to change. First, there is no hiding, the science is definitive. Second, we are feeling the impact of a sick planet—from social, economic and climate stability to energy, food and water security—all increasingly suffering from environmental degradation.

Third, we are beginning to increasingly understand that a diverse, healthy, resilient and productive natural environment is the foundation for a prosperous, just and safe future for humanity. This will be crucial if we are to win the many other human development battles such as combatting poverty, improving health and building economies. So, while environmental degradation continues, there are also unprecedented signs that we are beginning to embrace a "Great Transition" toward an ecologically sustainable future.

Despite 2016 set to be another hottest year on record, global CO_2 emissions have stabilized over the last two years, with some arguing they may even have peaked, and it looks like China's huge coal burning may have finally peaked too. Economists say this is likely a permanent trend. Rampant poaching and wildlife trafficking is devastating ecosystems, but the U.S. and more notably China have recently committed to a historic ban of domestic ivory trade.

Perhaps more importantly, the interdependence between the social, economic and environmental agendas is being recognized at the highest levels through the truly revolutionary approach adopted in defining the new set of the world's Sustainable Development Goals. We must translate this awareness and commitment into action and change.

We are entering a new era in Earth's history: the Anthropocene. An era in which humans rather than natural forces are the primary drivers of planetary change. But we can also redefine our relationship with our planet, from a wasteful, unsustainable and predatory one, to one where people and nature can coexist in harmony.

We need to transition to an approach that decouples human and economic development from environmental degradation—perhaps the deepest cultural and behavioural shifts ever experienced by any civilization.

The speed and scale of this transition is essential. As outlined in this edition of the *Living Planet Report*, we have the tools to fix this problem and we need to start using them immediately.

There's never been a more opportune time for the environmental movement and our society as a whole. These changes are indeed upon us, and if we are awed by the scale of the challenges that this generation is facing, we should be equally motivated by the unprecedented opportunity to build a future in harmony with the planet.

Marco Lambertini,

Director General
WWF International

THE STORY OF SOY

1. the Cerrado is one of the richest savannah formations on Earth

Located between the Amazon, Atlantic Forest and Pantanal, the Cerrado is the largest savannah region in South America, covering more than 20 per cent of Brazil. The Cerrado is one of the world's richest savannah formations in terms of living beings: it shelters 5 per cent of all the living species on Earth and one in every ten Brazilian species. There are over 10,000 species of plants, almost half of which are found nowhere else in the world. The Cerrado is also one of the most threatened and over-exploited regions in the world. These wooded grasslands once covered an area half the size of Europe: now, its native habitats and rich biodiversity are being destroyed much faster than the neighbouring rainforest. Unsustainable agricultural activities, particularly soy production and cattle ranching, as well as burning of vegetation for charcoal, continue to pose a major threat to the Cerrado's biodiversity.

(source: WWF-Brazil; WWF, 2014)



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RISK AND RESILIENCE IN A NEW ERA

SETTING THE SCENE

Earth's ecosystems have evolved for millions of years. This process has resulted in diverse and complex biological communities, living in balance with their environment. These diverse ecosystems also provide people with food, fresh water, clean air, energy, medicine and recreation. Over the past 100 years, however, nature and the services it provides to humanity have come under increasing risk.

The size and scale of the human enterprise have grown exponentially since the mid-20th century. As a result, the environmental conditions that fostered this extraordinary growth are beginning to shift. To symbolize this emerging environmental condition, Nobel Prize winner Paul Crutzen (2002) and others have proposed that we have transitioned from the Holocene into a new geological epoch, calling it the "Anthropocene" (e.g. Waters et al., 2016). During the Anthropocene, our climate has changed more rapidly, oceans are acidifying and entire biomes are disappearing – all at a rate measurable during a single human lifetime. This trajectory constitutes a risk that the Earth will become much less hospitable to our modern globalized society (Richardson et al., 2011). Scientists are now trying to discern which human-induced changes represent the greatest threat to our planet's resilience (Rockström et al., 2009a).

Such is the magnitude of our impact on the planet that the Anthropocene might be characterized by the world's sixth mass extinction event. In the past such extinction events took place over hundreds of thousands to millions of years. What makes the Anthropocene so remarkable is that these changes are occurring within an extremely condensed period of time. Furthermore, the driving force behind the transition is exceptional. This is the first time a new geological epoch may be marked by what a single species (*Homo sapiens*) has consciously done to the planet – as opposed to what the planet has imposed on resident species.

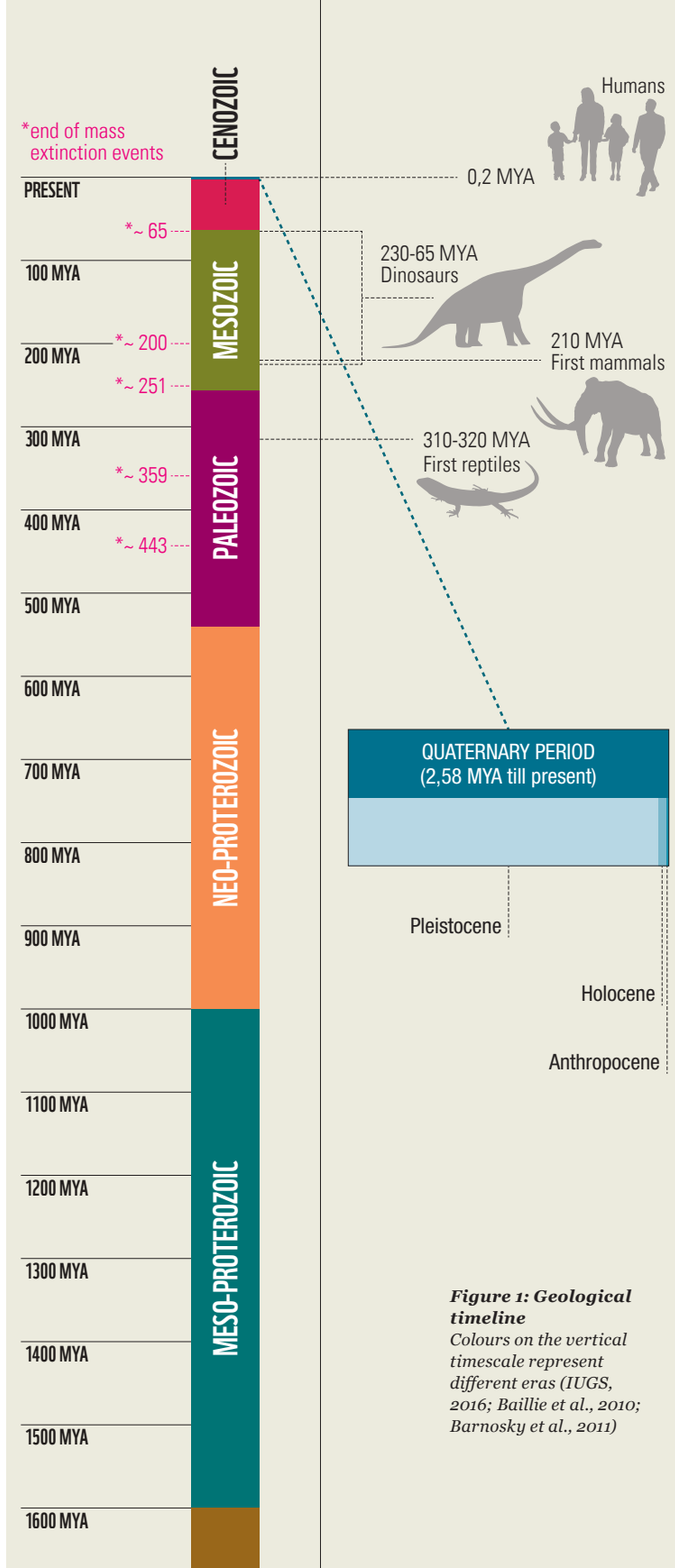


Figure 1: Geological timeline
Colours on the vertical timescale represent different eras (IUGS, 2016; Baillie et al., 2010; Barnosky et al., 2011)

Determining epochs: a geologist's perspective

Recent human development has taken place within the relatively stable climatic conditions of the Holocene epoch (Figure 1). The concept of a new epoch – the Anthropocene – is attracting the attention of more and more scientists with a wide range of interests and expertise.

Geologists interpret the Earth's environmental phases, including the history of climate, atmosphere and biodiversity, by studying what is recorded in the rock record. Eons, eras, periods and epochs are based on progressively smaller but nested units of geologic time. They are defined through global events that leave a trace within rock strata. For instance, there might be evidence of changes in rock chemistry or of the emergence or disappearance of particular species identified through their fossilized remains. Until recently all of these phase or time changes resulted from naturally occurring events such as meteorite impacts, tectonic movements, massive volcanic activity and changes in atmospheric conditions. Sometimes the effects of these changes on contemporary species were so profound as to cause widespread mass extinctions. To date, five mass extinctions have been identified in the rock record, including at the end of the Permian period when over 90 per cent of marine and around 70 per cent of terrestrial species were lost (e.g. Erwin, 1994).

How might a future geologist identify the Anthropocene epoch in the rock record? There are many features that might bear witness to human influence. For example, remains of some megacities may become complex fossil structures. Urbanization itself may be regarded as an alteration in sedimentation processes via the construction of manmade rock strata. Scientists suggest a range of potential markers will be detected, from pesticides to nitrogen and phosphorus, and radionuclides (Waters et al., 2016). The accumulation of particulate plastics in marine sediments (Zalasiewicz et al., 2016) might be found in many of the rocks. Finally, it is likely that a future geologist will notice the rapid decline in the number of species based on clues in the fossil record (Ceballos et al., 2015): we are already losing species at a rate consistent with a sixth mass extinction event. The current evidence regarding these types of changes indicates that the Anthropocene may have commenced in the mid-20th Century (Waters et al., 2016).

EXECUTIVE SUMMARY

CHARTING OUR COURSE TOWARD A RESILIENT PLANET

Under the current trajectory, the future of many living organisms in the Anthropocene is uncertain; in fact several indicators give cause for alarm. The Living Planet Index, which measures biodiversity abundance levels based on 14,152 monitored populations of 3,706 vertebrate species, shows a persistent downward trend. On average, monitored species population abundance declined by 58 per cent between 1970 and 2012. Monitored species are increasingly affected by pressures from unsustainable agriculture, fisheries, mining and other human activities that contribute to habitat loss and degradation, overexploitation, climate change and pollution. In a business-as-usual scenario, this downward trend in species populations continues into the future. United Nations targets that aim to halt the loss of biodiversity are designed to be achieved by 2020; but by then species populations may have declined on average by 67 per cent over the last half-century.

ON AVERAGE, POPULATIONS OF VERTEBRATE SPECIES DECLINED BY 58 PER CENT BETWEEN 1970 AND 2012

Not only wild plants and animals are affected: increasingly people are victims too of the deteriorating state of nature. Living systems keep the air breathable and water drinkable, and provide nutritious food. To continue to perform these vital services they need to retain their complexity, diversity and resilience.

INCREASINGLY PEOPLE ARE VICTIMS TOO OF THE DETERIORATING STATE OF NATURE

The way we appropriate natural resources has had a tremendous impact on the Earth's environmental systems, impacting both people and nature. This, in turn, affects the state of biodiversity and climate. An understanding of Planetary Boundaries can help us grasp the complexity of human impacts on the planet (Rockström et al., 2009b; Steffen et al., 2015a). Pushing the boundaries of nine Earth system processes may lead to dangerous levels of instability in the Earth system and increasing risk for humans. Researchers suggest that humans have already driven at least four of these global processes beyond their safe boundaries. There is scientific uncertainty about the biophysical and societal effects of crossing these boundaries, but attributable global impacts are already evident for climate change, biosphere integrity, biogeochemical flows and land-system change (Steffen et al., 2015a).

AN UNDERSTANDING OF PLANETARY BOUNDARIES CAN HELP US GRASP THE COMPLEXITY OF HUMAN IMPACTS ON THE PLANET

Another way to look at the relationships between our behaviour and the Earth's carrying capacity is through Ecological Footprint calculations. The Ecological Footprint represents the human demand on the planet's ability to provide renewable resources and ecological services. Humanity currently needs the regenerative capacity of 1.6 Earths to provide the goods and services we use each year. Furthermore, the per capita Ecological Footprint of high-income nations dwarfs that of low- and middle-income countries (Global Footprint Network, 2016). Consumption patterns in high-income countries result in disproportional demands on Earth's renewable resources, often at the expense of people and nature elsewhere in the world.

IF CURRENT TRENDS CONTINUE, UNSUSTAINABLE CONSUMPTION AND PRODUCTION PATTERNS WILL LIKELY EXPAND ALONG WITH HUMAN POPULATION AND ECONOMIC GROWTH

If current trends continue, unsustainable consumption and production patterns will likely expand along with human population and economic growth. The growth of the Ecological Footprint, the violation of Planetary Boundaries and increasing pressure on biodiversity are rooted in systemic failures inherent to the current systems of production, consumption, finance and governance. The behaviours that lead to these patterns are largely determined by the way consumerist societies are organized, and fixed in place through the underlying rules and structures such as values, social norms, laws and policies that govern everyday choices (e.g. Steinberg, 2015).

Structural elements of these systems such as the use of gross domestic product (GDP) as a measure of well-being, the pursuit of infinite economic growth on a finite planet, the prevalence of short-term gain over long-term continuity in many business and political models, and the externalization of ecological and social costs in the current economic system encourage unsustainable choices by individuals, businesses and governments. The impacts of these choices are often felt well beyond the national and regional borders in which the choices originate. This is why the links between drivers, deeper causes and global phenomena like biodiversity loss can often be difficult to grasp. Throughout this report, the interconnectedness between impacts in one part of the globe and consumer choices thousands of kilometres away are illustrated by the story of soy.

THERE IS A CLEAR CHALLENGE FOR HUMANITY TO ALTER OUR COURSE SO THAT WE OPERATE WITHIN THE ENVIRONMENTAL LIMITS OF OUR PLANET AND MAINTAIN OR RESTORE RESILIENCE OF ECOSYSTEMS

Given our current trajectory toward unacceptable conditions that are predicted for the Anthropocene era, there is a clear challenge for humanity to alter our course so that we operate within the environmental limits of our planet and maintain or restore resilience of ecosystems. Our central role as driving force into the Anthropocene also gives reason for hope. Not only do we recognize the changes that are taking place and the risks they are generating for nature and society, we also understand their causes.

These are the first steps to identifying solutions for restoring the ecosystems we depend upon and creating resilient and hospitable places for wildlife and people. Acting upon this knowledge will enable us to navigate our way through the Anthropocene. Several inspiring cases of successful transitions are highlighted throughout the report.

We need to design responses that match the size of the challenge of actually shifting to sustainable and resilient modes of production and consumption. This challenge is also outlined in the UN 2030 Agenda for Sustainable Development. Protecting the Earth's natural capital and its attendant ecosystem services is in the interest of both people and nature. Developing a just and prosperous future, and defeating poverty and improving health, is much less likely to happen in a weakened or destroyed natural environment.

TRANSITIONING TOWARD A RESILIENT PLANET ENTAILS A TRANSFORMATION IN WHICH HUMAN DEVELOPMENT IS DECOUPLED FROM ENVIRONMENTAL DEGRADATION AND SOCIAL EXCLUSION

Transitioning toward a resilient planet entails a transformation in which human development is decoupled from environmental degradation and social exclusion. A number of significant changes would need to happen within the global economic system in order to promote the perspective that our planet has finite resources. Examples are changing the way we measure success, managing natural resources sustainably, and taking future generations and the value of nature into account in decision-making.

This transition requires fundamental changes in two global systems: energy and food. For the energy system, a rapid development of sustainable renewable energy sources and shifting demand toward renewable energy are key. For the food system, a dietary shift in high-income countries – through consuming less animal protein – and reducing waste along the food chain could contribute significantly to producing enough food within the boundaries of one planet. Furthermore, optimizing agricultural productivity within ecosystem boundaries, replacing chemical and fossil inputs by mimicking natural processes, and stimulating beneficial interactions between different agricultural systems, are key to strengthening the resilience of landscapes, natural systems and biodiversity – and the livelihoods of those who depend on them.

THE SPEED AT WHICH WE CHART OUR COURSE THROUGH THE ANTHROPOCENE WILL BE THE KEY FACTOR DETERMINING OUR FUTURE

The speed at which we chart our course through the Anthropocene will be the key factor determining our future. Allowing and fostering important innovations, and enabling them to be rapidly adopted by governments, businesses and citizens, will accelerate a sustainable trajectory. So too will understanding the value and needs of our increasingly fragile Earth.

AT A GLANCE

What is going on?

CHAPTER 1

STATE OF THE NATURAL PLANET

- The Living Planet Index shows a decline of 58 per cent between 1970 and 2012 with greatest losses in freshwater environments.
- If current trends continue to 2020 vertebrate populations may decline by an average of 67 per cent compared to 1970.
- Increased human pressure threatens the natural resources that humanity depends upon, increasing the risk of water and food insecurity and competition over natural resources

What is our role?

CHAPTER 2

HUMAN IMPACTS ON THE PLANET

- Human activities and resource uses have grown so dramatically, particularly since the mid-20th century, that we are endangering a number of key environmental systems.
- These systems interact with each other, so we need to maintain them all to underpin human well-being.
- Global impacts and associated risks to humans are already evident for climate change, biosphere integrity, biogeo-chemical flows and land-system change.
- By 2012, the equivalent of 1.6 Earths was needed to provide the natural resources and services humanity consumed in one year.

What can we do?

CHAPTER 4

A RESILIENT PLANET FOR NATURE AND PEOPLE

- The 21st century presents humanity with a dual challenge to maintain nature in all of its many forms and functions and to create an equitable home for people on a finite planet.
- The WWF One Planet Perspective outlines better choices for governing, using and sharing natural resources within the Earth's ecological boundaries.
- Redirecting our path toward sustainability requires immediate fundamental changes in two important systems: energy and food.
- The speed at which we transition to a sustainable society is a key factor for determining our future.

What are underlying reasons?

CHAPTER 3

EXPLORING ROOT CAUSES

- A prerequisite for reducing human pressures and drivers is to understand the nature of the decision-making that results in environmental, social and ecological degradation.
- Systems thinking can help to define root causes of human behaviour that lead to unsustainable consumption patterns, destructive production patterns, malfunctioning governance structures and short-term focused economic planning.
- When applied to the food system, root causes include the poverty trap, concentration of power, and lock-ins to trade, agricultural research and technology.

THE STORY OF SOY

2. around half of the Cerrado is lost

Around half the native savannah and forest of the Cerrado has been converted to agriculture since the late 1950s. As these ecosystems are lost, so are the wildlife they support and the vital ecological services they provide, like clean water, carbon sequestration and healthy soils. Species that are threatened include the jaguar, maned wolf and giant anteater, but also many other plants and animals that are unique to the Cerrado. Not only fragile ecosystems and species are feeling the strain. Habitat destruction also threatens the way of life of many indigenous people and other communities who rely on forests, natural grasslands and savannahs for their livelihoods.

(source: WWF-Brazil; WWF, 2014)



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CHAPTER 1: STATE OF THE NATURAL PLANET

MONITORING GLOBAL BIODIVERSITY

Biodiversity encompasses the genetic variation within species, the variety and population abundance of species in an ecosystem, and the habitats across a landscape. Monitoring of all these different aspects is imperative as it provides insight into trends in biodiversity and ecosystem health to make informed decisions on resource use and protection. Because biodiversity is so multifaceted, a variety of metrics are necessary; the use of any one in particular would depend upon the biodiversity component of interest and the ultimate use of the information. Contemporary examples of indices now in use include the Living Planet Index (LPI), the IUCN Red List of Threatened Species, and indicators that show us the state of specific habitats – such as forests – or the state of natural capital (Tittensor et al., 2014).

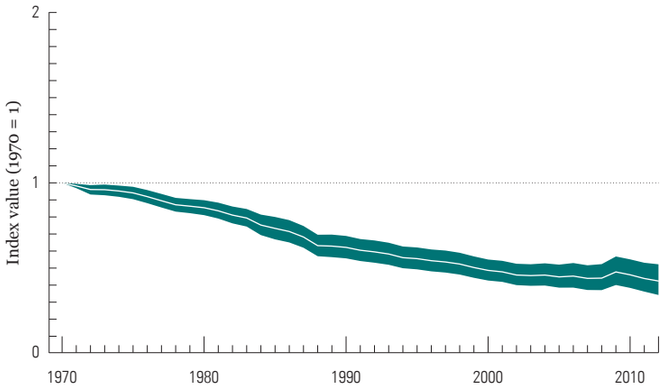
The Global Living Planet Index

The LPI measures biodiversity by gathering population data of various vertebrate species and calculating an average change in abundance over time. The LPI can be compared to the stock market index, except that, instead of monitoring the global economy, the LPI is an important indicator of the planet's ecological condition (Collen et al., 2009). The global LPI is based on scientific data from 14,152 monitored populations of 3,706 vertebrate species (mammals, birds, fishes, amphibians, reptiles) from around the world.

From 1970 to 2012 the LPI shows a 58 per cent overall decline in vertebrate population abundance (Figure 2). Population sizes of vertebrate species have, on average, dropped by more than half in little more than 40 years. The data shows an average annual decline of 2 per cent and there is no sign yet that this rate will decrease. The *Living Planet Report 2014* reported a 52 per cent decline from 1970 to 2010; although the marine and terrestrial datasets have been augmented with new data, it is the stronger decline in freshwater species that has had more influence on the global decline in this report.

FROM 1970 TO 2012 THE LPI SHOWS A 58 PER CENT OVERALL DECLINE IN VERTEBRATE POPULATION ABUNDANCE

Figure 2: The Global Living Planet Index shows a decline of 58 per cent (range: -48 to -66 per cent) between 1970 and 2012
Trend in population abundance for 14,152 populations of 3,706 species monitored across the globe between 1970 and 2012. The white line shows the index values and the shaded areas represent the 95 per cent confidence limits surrounding the trend (WWF/ZSL, 2016).



OVER 3,000 DATA SOURCES ARE COMPILED WITHIN THE LPI DATABASE

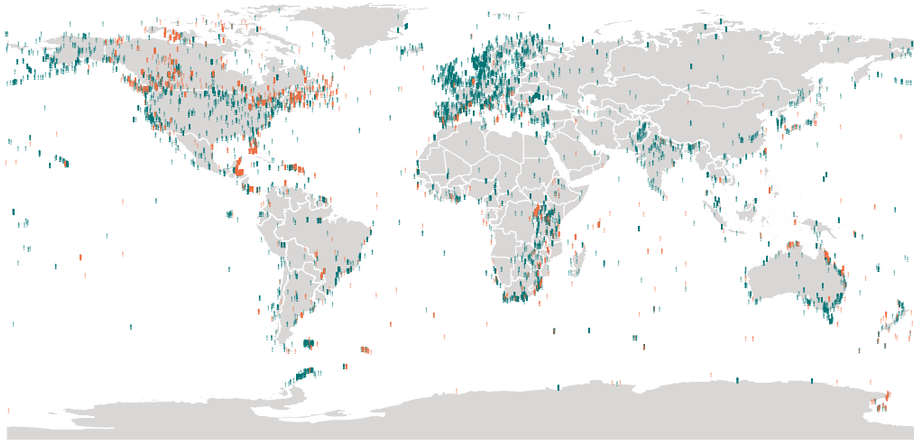
Monitoring species

Over 3,000 data sources are compiled within the LPI database. One requirement for including a data source is that the population in question has been consistently monitored using the same method over the entire length of the study time period. Some sources are long-term monitoring studies such as the breeding bird surveys in Europe (EBCC/RSPB/BirdLife/Statistics Netherlands, 2016) and North America (Sauer et al., 2014). Others are short-term projects that addressed a particular research question. The majority of these sources are derived from articles found in peer-reviewed scientific journals.

Combined into one dataset, the species census data provides an important tool for monitoring the state of nature. However, the distribution of locations represented by the data is uneven, lacking ideal coverage for all species groups and regions (Figure 3). By targeting data searches toward identified gaps in the dataset, researchers are trying to solve this problem. The LPI database is continually evolving and for each *Living Planet Report* a larger dataset is available to use for the analysis. As such, the percentages reported for LPIs often change from year to year as the dataset increases (see page 40-41 for more details). The new percentages stay within the same range (as measured by the confidence intervals) as previous results so there are similar overall trends even if the final percentage value is often different.

Since the last *Living Planet Report*, 668 species and 3,772 different populations have been added (Figure 3). Representation of marine species data, particularly fish, has increased in the latest LPI dataset. However, there are still major geographic gaps in the data, largely in Central, West and North Africa, Asia and South America. Furthermore, the dataset is currently limited to populations of vertebrate species. Methods to incorporate invertebrates and plants are now in development.

Figure 3: The distribution of locations providing data for the Living Planet Index
Map showing the location of the monitored populations in the LPI. New populations added since the last report are highlighted in orange (WWF/ZSL, 2016).



Maps used are for general illustration only and are not intended to be used for reference. The representation of political boundaries does not reflect the position of the Government of India.

A closer look at threats

Whether or not populations are in trouble depends on species resilience, location, and the nature of the threats (Collen et al., 2011; Pearson et al., 2014). Threat information is available for about one third of populations in the LPI (3,776 populations). Over half of the populations (1,981) for which threat information is available are declining. The most common threat to declining populations is the loss and degradation of habitat. Other studies confirm that this is the main threat to vertebrate species (e.g. Baillie et al., 2010; Böhm et al., 2013; IUCN, 2015). The principal causes of habitat loss appear to be unsustainable agriculture and logging, and changes to freshwater systems (Baillie et al., 2010). Threats often interact, which can exacerbate the effects on species: for example, habitat destruction and overexploitation might compromise a species' ability to respond to changes in climate (Dirzo et al., 2014).

When population information is entered in the LPI database, any associated threat information is included. This information allows for a better understanding of the patterns behind population decline on regional or global levels. The database recognizes five categories of threats. Figure 4 shows how these threats affect species – either directly or indirectly.

Figure 4: Different threat types in the Living Planet Index database
Categories and descriptions of the different threat types referred to in the Living Planet Index database (based on Salafsky et al., 2008).

THREATS

Habitat loss and degradation



This refers to the modification of the environment where a species lives, by either complete removal, fragmentation or reduction in quality of key habitat characteristics. Common causes are unsustainable agriculture, logging, transportation, residential or commercial development, energy production and mining. For freshwater habitats, fragmentation of rivers and streams and abstraction of water are common threats.

Species overexploitation



There are both direct and indirect forms of overexploitation. Direct overexploitation refers to unsustainable hunting and poaching or harvesting, whether for subsistence or for trade. Indirect overexploitation occurs when non-target species are killed unintentionally, for example as bycatch in fisheries.

Pollution



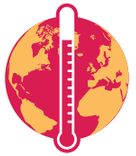
Pollution can directly affect a species by making the environment unsuitable for its survival (this is what happens, for example, in the case of an oil spill). It can also affect a species indirectly, by affecting food availability or reproductive performance, thus reducing population numbers over time.

Invasive species and disease



Invasive species can compete with native species for space, food and other resources, can turn out to be a predator for native species, or spread diseases that were not previously present in the environment. Humans also transport new diseases from one area of the globe to another.

Climate change



As temperatures change, some species will need to adapt by shifting their range to track suitable climate. The effects of climate change on species are often indirect. Changes in temperature can confound the signals that trigger seasonal events such as migration and reproduction, causing these events to happen at the wrong time (for example misaligning reproduction and the period of greater food availability in a specific habitat).

Terrestrial Living Planet Index

The terrestrial system includes many habitats (such as forests, savannahs and deserts) as well as manmade environments (such as cities or agricultural fields). It is the best monitored of the three systems, primarily because this is where people live and also because research in this system presents fewer logistical challenges than research in freshwater and marine systems. For this reason, the dataset behind the terrestrial LPI is the most comprehensive. It is based on data for 4,658 monitored populations of 1,678 terrestrial species or 45 per cent of the species in the entire LPI database.

THE MAJORITY OF EARTH'S LAND AREA IS NOW MODIFIED BY HUMANS

Over the past centuries, the terrestrial system has been transformed: the majority of Earth's land area is now modified by humans (Ellis et al., 2010). This has had a large impact on biodiversity (Newbold et al., 2015). The terrestrial LPI confirms this. It shows that populations have declined by 38 per cent overall since 1970 (Figure 5), with an average annual decline of 1.1 per cent.

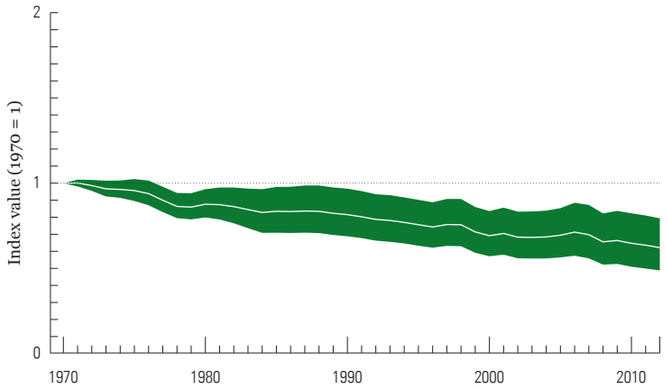


Figure 5: The terrestrial LPI shows a decline of 38 per cent (range: -21 to -51 per cent) between 1970 and 2012
Trend in population abundance for 4,658 populations of 1,678 terrestrial species monitored across the globe between 1970 and 2012 (WWF/ZSL, 2016).

Key

- Terrestrial Living Planet Index
- Confidence limits

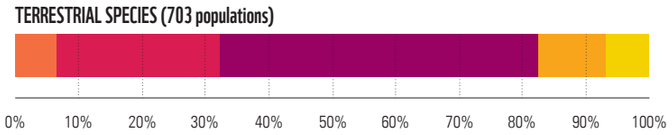
Since 1970, despite widespread modification by humans, the terrestrial system has experienced a less steep decline in population abundance than marine and freshwater systems. Designated protected areas cover 15.4 per cent of the Earth's land surface (including inland water) (Juffe-Bignoli et al., 2014). This is likely to have contributed to the conservation and recovery of some species, thereby putting brakes on the fall of the terrestrial vertebrate index.

Figure 6: Threat type frequency for 703 declining terrestrial populations in the LPI database showing 1,281 recorded threats
Each population has up to three threats recorded, so the total number of recorded threats exceeds the number of populations (WWF/ZSL, 2016).

Key

- Climate change
- Overexploitation
- Habitat loss / degradation
- Invasive species and disease
- Pollution

The LPI database contains threat information for 33 per cent of its declining terrestrial populations (n=703). Habitat loss and degradation are the most common threats to terrestrial populations in the LPI (Figure 6), followed by overexploitation. Other threats vary in importance according to taxonomic group (Figure 7).

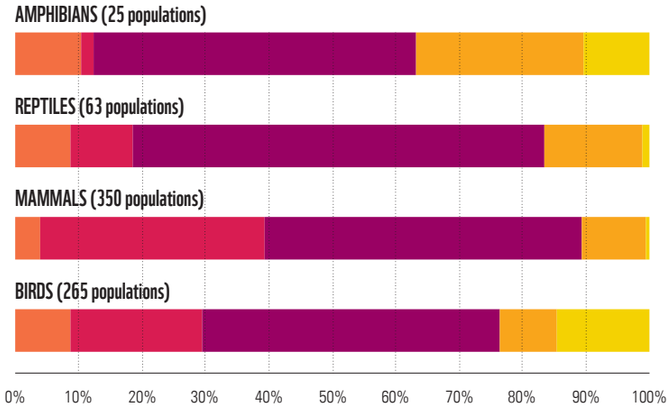


Next to habitat loss and degradation, invasive species and disease are the most common threats to amphibians and reptiles. Either through predation or competition, the negative effects of exotic species on native reptiles has been well documented in several areas of the globe. The introduction of non-native rats, cats and mongooses, together with non-native reptiles, has had an enormous impact on native reptiles, especially on islands (Whitfield Gibbons et al., 2000).

Figure 7: Taxonomic differences in threat frequency for 703 declining terrestrial populations in the LPI database
(WWF/ZSL, 2016).

Key

- Climate change
- Overexploitation
- Habitat loss / degradation
- Invasive species and disease
- Pollution



African elephants: threatened by overexploitation

Sixty per cent of the declining terrestrial mammal populations in the LPI are threatened by overexploitation. African elephant (*Loxodonta africana*) populations are among them, though they also suffer from habitat loss and fragmentation. Over the past two centuries, there has been a reduction in the range of African elephants, as well as large-scale population declines (Barnes, 1999). Poaching for ivory appears to be the primary cause of the decline in elephant numbers (Wittemyer, 2014).

CITES (the Convention on International Trade in Endangered Species of Wild Flora and Fauna) set up a system to evaluate relative poaching levels. The Proportion of Illegally Killed Elephants (PIKE) is the number of illegally killed elephants divided by the total number of elephant carcasses encountered. Figure 8 shows the trend in PIKE for the 54 sample sites across Africa. The levels of illegal killing of elephants have increased since 2005 and peaked in 2011. Despite the slight decline since 2011, over half of the elephants found dead are deemed to have been illegally killed which is above the PIKE level considered to be a cause for concern (indicated by the red line in the graph).

A region of particular concern is Selous-Mikumi in Tanzania where PIKE is still calculated to be higher than 0.7. Elephant population in this area declined from 44,806 estimated individuals in 2009 to 15,217 in 2014, a decline of 66 per cent over a five year period (Tanzania Wildlife Research Institute, 2015). The area encompasses the Selous Game Reserve, one of the largest faunal reserves in the world. Since 1982, the reserve has been a World Heritage Site, but in 2014 it was placed on the List of World Heritage in Danger because of widespread poaching (UNESCO, 2014). The international community – and especially ivory source, transit and destination countries – have been called upon to support Tanzania in its effort to protect the reserve's wildlife and unique habitats.

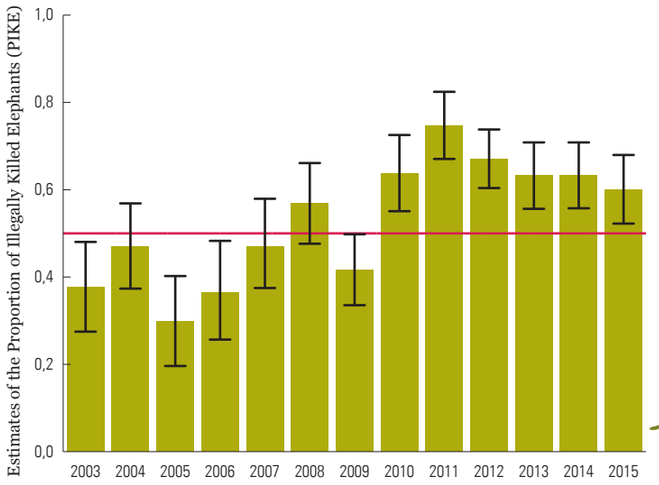


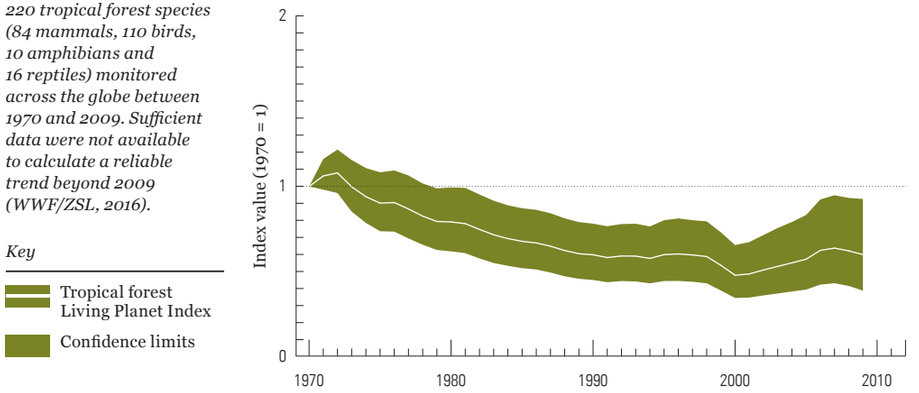
Figure 8: Estimates of the Proportion of Illegally Killed Elephants (PIKE) *between 2003 and 2015 (bars) with 95 per cent confidence limits (error bars) and the threshold value of 0.5 above which proportion of illegally killed elephants is a cause for concern (red line). Based on the analyses of 14,606 elephant carcasses (CITES, 2016).*



A closer look at tropical forests

In terms of species diversity, tropical forests are among the richest ecosystems on Earth. They also have suffered the greatest loss of area (Hansen et al., 2013). By 2000, 48.5 per cent of the tropical/subtropical dry broadleaf forest habitat had been converted for human use (Hoekstra et al., 2005). Such an extensive modification is likely to affect those species that live in and depend upon that habitat. The LPI confirms this, showing a 41 per cent overall decline in tropical forest species between 1970 and 2009 (Figure 9). This translates to an average annual decline of 1.3 per cent. The index is based on 369 populations of 220 species. The specific reason for the temporary increase observed from the year 2000 has not been documented but it is seen in the trend for both mammals and birds, the two groups for which most data is available in this index.

Figure 9: The tropical forest species LPI shows a decline of 41 per cent (range: -7 to -62 per cent) between 1970 and 2009
Trend in population abundance for 369 populations of 220 tropical forest species (84 mammals, 110 birds, 10 amphibians and 16 reptiles) monitored across the globe between 1970 and 2009. Sufficient data were not available to calculate a reliable trend beyond 2009 (WWF/ZSL, 2016).





A closer look at grasslands

Grasslands are terrestrial ecosystems dominated by herbaceous and shrub vegetation and maintained by fire, grazing, drought and/or freezing temperatures (White et al., 2000). Grasslands have come under a high degree of pressure from humans, particularly because these ecosystems are usually suitable for agriculture. As of 2000, 45.8 per cent of temperate grassland area had been converted and is now predominantly used for human activities (Hoekstra et al., 2005). Similarly, more than 40 per cent of the Brazilian Cerrado has been converted to agricultural crops (Sano et al., 2010).

THE EFFECT OF CONVERSION ON GRASSLAND SPECIES IS APPARENT IN MANY SYSTEMS ACROSS THE GLOBE

The effect of conversion on grassland species is apparent in many systems across the globe. In North America, grassland bird species declined consistently between 1966 and 2011 (Sauer et al., 2013) as a consequence of agricultural intensification (Reif, 2013). In recent years, rapid declines in small mammal populations have been recorded in Australia's savannah (Woinarski et al., 2010). The grasslands LPI clearly illustrates the effects of conversion (Figure 10). The index is based on 372 populations of 126 species that occur only in grasslands (classified under the grassland, savannahs or shrubland habitats by the IUCN Red List). It shows an overall 18 per cent decline, with an average annual decline of 0.5 per cent. The trend starts to stabilize after 2000 and there is a slight increase from 2004. Conservation efforts have helped stem the decline of some mammal species in Africa and it is these species driving the trend after 2004, whereas the bird populations continue to decline until 2012.

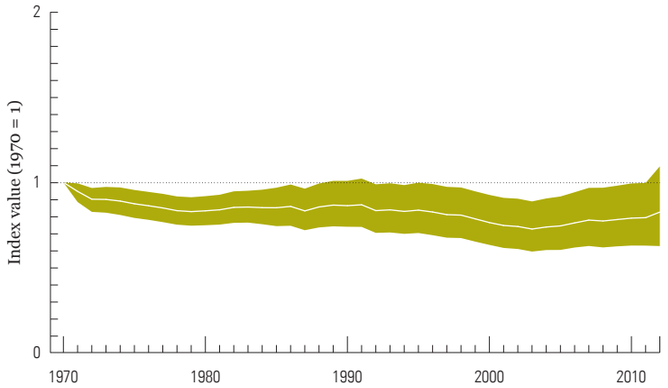


Figure 10: The grassland species LPI shows a decline of 18 per cent (range: +10 to -38 per cent) between 1970 and 2012
Trend in population abundance for 372 populations of 126 grassland species (55 mammals, 58 birds and 13 reptiles) monitored across the globe between 1970 and 2012 (WWF/ZSL, 2016).

Key

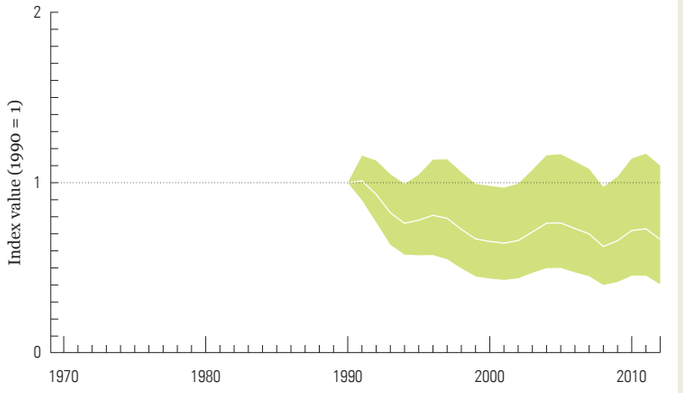
- Grassland Living Planet Index
- Confidence limits

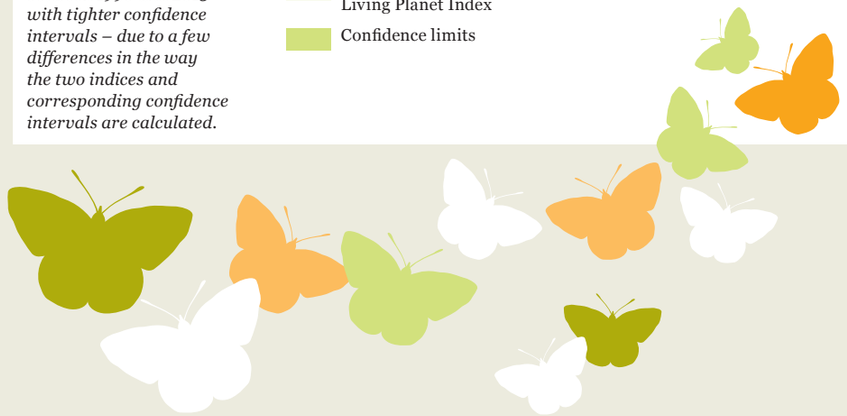
Grassland butterflies

The LPI database does not yet include information for invertebrate species. However, information from other monitoring efforts can help bridge the gap. Since 2005, monitoring data for several European butterfly species has been collected and harmonized for use in the European Grassland Butterfly Indicator for the European Environment Agency (Van Swaay and Van Strien, 2005; Van Swaay et al. 2015).

The LPI methodology is applied to this data, which includes 17 grassland butterfly species monitored in 12 countries. Results show a 33 per cent overall decline over 22 years (Figure 11). Confidence intervals reveal a wide variation in trends as some species are on the increase while others are in decline. However, there is an overall decline which suggests that human modification of habitat is having an impact on grassland species. Furthermore, in many countries in Europe, butterfly numbers declined precipitously before 1990 (Van Swaay et al., 2015); therefore abundance was already historically low at the baseline.

Figure 11: The grassland butterflies LPI shows a decline of 33 per cent (range: +10 to -59 per cent) between 1990 and 2012
Trend in population abundance for 203 populations of 17 grassland butterflies species monitored across 12 EU countries between 1990 and 2012 (WWF/ZSL, 2016). The index differs from the official European Grassland Butterfly Indicator (Van Swaay et al., 2015) – which estimates a decline of 30 per cent between 1990 and 2013 with tighter confidence intervals – due to a few differences in the way the two indices and corresponding confidence intervals are calculated.





COMEBACK OF LARGE CARNIVORES IN EUROPE

Over the 19th and 20th centuries, Europe's large carnivore populations saw their numbers and distribution decline dramatically, mainly due to human intervention, such as hunting pressure and habitat loss. This trend, however, was reversed in the last few decades, primarily thanks to the European Union's Birds and Habitats Directives, forming the backbone of nature conservation in Europe. The Nature Directives protect a range of species and habitats across the 28 member states of the European Union, including bears, lynx, wolverines and wolves.

As a result of improved legal protection, large carnivores have returned to many European regions from which they had been absent for decades, and reinforced their presence where they already occurred. Currently, many populations of large carnivores are further increasing or at least stable. For example, the Eurasian lynx experienced a contraction in range during the 19th and first half of the 20th century due to hunting pressure and deforestation. Due to legal protection, reintroductions, translocations and natural recolonization, populations have more than quadrupled in abundance over the past 50 years. The European population (excluding Russia, Belarus and Ukraine) was recently estimated at 9,000-10,000 individuals, 18 per cent of the global population (Deinet et al., 2013). The comeback of large carnivores shows that with political will supported by a forward-looking legal framework and a wide range of committed stakeholders, nature can recover.

In some places where large carnivores such as lynx previously disappeared, loss of knowledge can create challenges, especially for certain land-user groups like hunters or farmers. However, there are also numerous positive examples of successful coexistence between humans and large carnivores across Europe. Translating the positive examples and subsequent management approaches into the specific contexts of each region will pave the way further for these charismatic animals. Furthermore, cooperation across Europe will be vital as large carnivores do not respect national borders.



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Freshwater Living Planet index

Freshwater habitats – such as lakes, rivers and wetlands – carry immense importance for life on Earth. Freshwater accounts for only 0.01 per cent of the world's water and covers approximately 0.8 per cent of the Earth's surface (Dudgeon et al., 2006) but provides a habitat for almost 10 per cent of the world's known species (Balian et al., 2008). Because humans and almost every living being require water, these habitats command high economic, cultural, aesthetic, recreational and educational value.

Freshwater habitats are challenging to conserve as they are strongly affected by the modification of their river basins as well as by direct impacts from dams, pollution, invasive aquatic species and unsustainable water extractions. Further, they often cross administrative and political boundaries so they require extra effort for collaborative forms of protection. Several studies have found that species living in freshwater habitats are faring worse than terrestrial species (Collen, et al., 2014; Cumberlidge et al., 2009). The freshwater LPI substantiates this finding, showing that on average the abundance of populations monitored in the freshwater system has declined overall by 81 per cent between 1970 and 2012 (Figure 12), with an average annual decline of 3.9 per cent. These figures are based on data for 3,324 monitored populations of 881 freshwater species.

FRESHWATER HABITATS ARE CHALLENGING TO CONSERVE AS THEY ARE STRONGLY AFFECTED BY THE MODIFICATION OF THEIR RIVER BASINS AS WELL AS BY DIRECT IMPACTS FROM DAMS, POLLUTION, INVASIVE AQUATIC SPECIES AND UNSUSTAINABLE WATER EXTRACTIONS

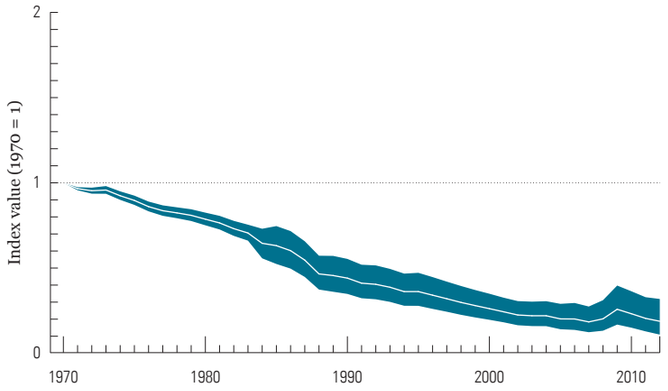


Figure 12: The freshwater LPI shows a decline of 81 per cent (range: -68 to -89 per cent) between 1970 and 2012
Trend in population abundance for 3,324 populations of 881 freshwater species monitored across the globe between 1970 and 2012 (WWF/ZSL, 2016).

Key

- Freshwater Living Planet Index
- Confidence limits

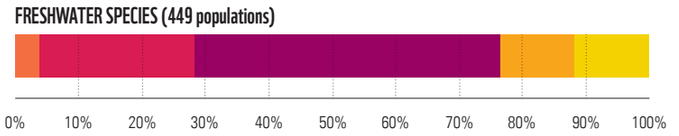
THE MOST COMMON THREAT TO DECLINING FRESHWATER POPULATIONS IS HABITAT LOSS AND DEGRADATION

The LPI database contains threat information for 31 per cent of its declining freshwater populations (n=449). Based on this information, the most common threat to declining populations is habitat loss and degradation. This is mentioned in 48 per cent of threatened species cases (Figure 13). Freshwater habitat loss because of humans can occur through direct intervention, for example through excavation of river sand or interruption of a river's flow. But habitat loss and degradation can also occur through indirect effects. For example, deforestation can increase river sediment load, leading to more erosion of the river's bank (Dudgeon et al., 2006) with subsequent changes in the water quality and flow. Direct overexploitation – through unsustainable fishing or collection for subsistence or commercial purposes – is the second most frequent threat to freshwater populations (24 per cent), followed by invasive species and disease (12 per cent), pollution (12 per cent) and climate change (4 per cent).

Figure 13: Threat type frequency for 449 declining freshwater populations in the LPI database showing 781 recorded threats
Each population has up to three threats recorded, so the total number of recorded threats exceeds the number of populations (WWF/ZSL, 2016).

Key

- Climate change
- Overexploitation
- Habitat loss / degradation
- Invasive species and disease
- Pollution





The frequency with which different threats are mentioned in the database varies according to taxonomic group (Figure 14). For amphibians, invasive species and disease represents the second most prevalent threat after habitat loss. It is cited as a threat in 25 per cent of cases, potentially reflecting the impact of *Batrachochytrium dendrobatidis*, a species of fungus responsible for chytridiomycosis, a disease of amphibians. This pathogen is implicated in the steep decline or extinction of more than 200 species of amphibians (Wake and Vredenburg, 2008) and threatens many more (Rödder et al., 2009). Furthermore, the rapid global spread of the disease has been linked to climate change (Pounds et al., 2006). The amphibian trade is likely to have contributed to the original spread of the pathogen (Weldon et al., 2004) and can still facilitate introduction into new regions (Schloegel et al., 2009).

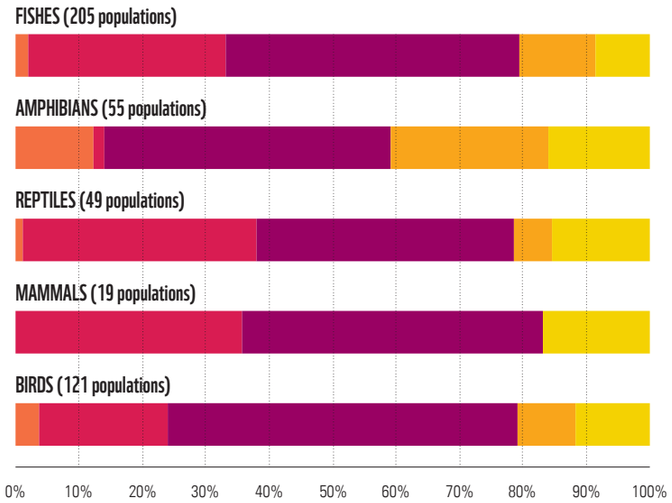


Figure 14: Taxonomic differences in threat frequency for 449 declining freshwater populations in the LPI database *(WWF/ZSL, 2016).*

Key

- Climate change
- Overexploitation
- Habitat loss / degradation
- Invasive species and disease
- Pollution

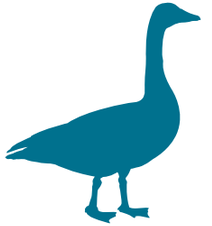
For freshwater bird, mammal, fish and reptile populations, habitat loss is the most frequently recorded threat, followed by overexploitation. Among mammals, river dolphins are declining rapidly due to unintentional overexploitation. Entanglement in gillnets is a frequent cause of death for Irrawady dolphins (Minton et al., 2013; Hines et al., 2015), while unsustainable levels of bycatch in local fisheries is one of the causes of the probable extinction of the Yangtze river dolphin (Turvey et al., 2007). Overexploitation has been mentioned among the causes for population declines in several reptiles (Whitfield Gibbons et al., 2000), especially freshwater turtles collected for food or for the pet trade.

A closer look at wetlands

Wetlands are found all over the world from the equatorial tropics to the frozen plains of Siberia. Both inland wetlands and coastal wetlands are now in decline. A recent global review found that as much as 87 per cent of wetland area may have been lost over the last 300 years (Davidson, 2014). Wetland loss – mainly caused by land reclamation for agricultural use (Junk et al., 2013) – continues, but at a much faster rate than before. The Natural WET index – an indicator of change in area of all natural wetlands (Dixon et al., 2016) – shows a 30 per cent decline over the past 40 years alone. This includes a 27 per cent decline in the extent of inland wetlands and a 38 per cent decline in coastal wetlands.

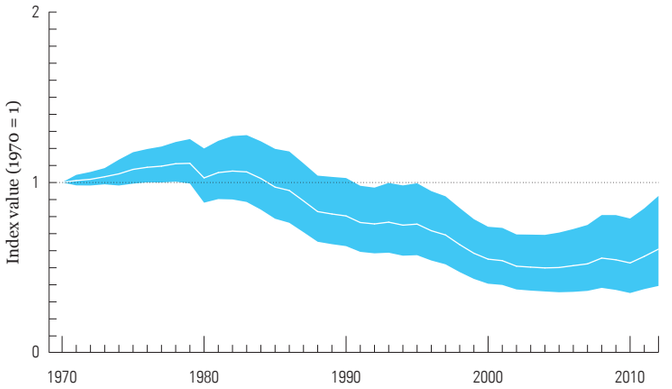
87 PER CENT OF WETLAND AREA MAY HAVE BEEN LOST OVER THE LAST 300 YEARS

The reduction of wetland area directly affects wetland-dependent species since they will face reduced habitat availability and increased competition for food and other resources. Within the LPI, wetland-dependent species – as defined by IUCN Red List habitat categories – suffered an overall 39 per cent reduction in abundance between 1970 and 2012 (Figure 15), with an average annual decline of 1.2 per cent. The index is based on 706 populations of 308 freshwater species occurring exclusively within inland wetlands.



From 2005 onwards the index is slightly increasing. Several bird species show increasing trends at this point in time. Some species of water birds – geese in particular – have benefitted from improved foraging opportunities resulting from changes in agricultural practices in staging and wintering areas along their migration routes in North America and Europe (Fox et al. 2005; Van Eerden et al. 2005). As data for bird populations from these areas represents a big proportion of the LPI dataset, this is likely to have an effect on the trends in years when little data is available, as is often the case in more recent years.

Figure 15: The wetland-dependent species LPI shows a decline of 39 per cent (range: -8 to -60 per cent) between 1970 and 2012
Trend in population abundance for 706 inland wetlands populations of 308 freshwater species (4 mammals, 48 birds, 224 fish, 4 amphibians and 28 reptiles) monitored across the globe between 1970 and 2012 (WWF/ZSL, 2016).



Key

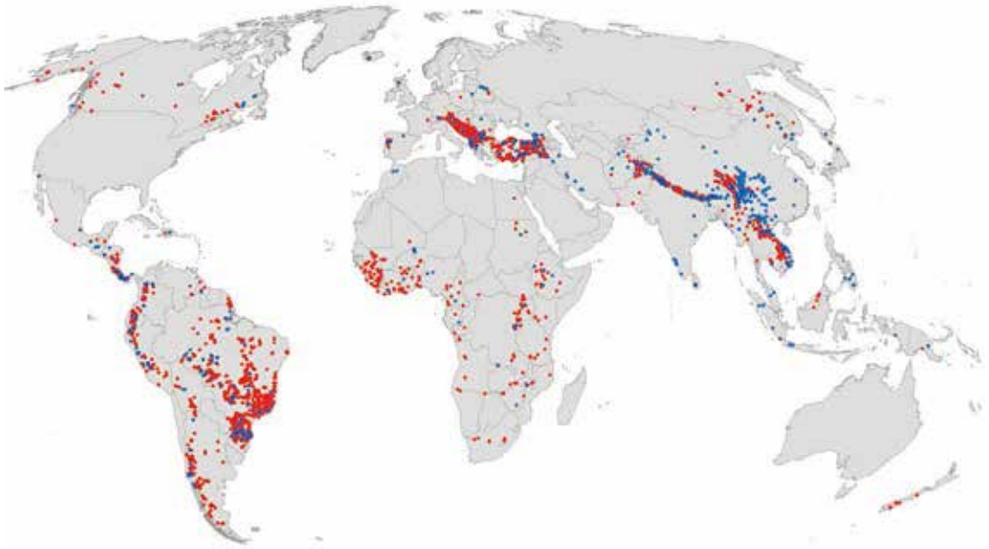
- Wetland Living Planet Index
- Confidence limits

THE REDUCTION OF WETLAND AREA DIRECTLY AFFECTS WETLAND-DEPENDENT SPECIES SINCE THEY WILL FACE REDUCED HABITAT AVAILABILITY AND INCREASED COMPETITION FOR FOOD AND OTHER RESOURCES

A closer look at rivers

While change in size is an appropriate measure when monitoring the health of wetlands, volume and timing of flow and connectivity are more appropriate for monitoring the state and functionality of rivers. Historically, rivers have been extensively altered for urban development, transportation, flood protection, water supplies or energy generation. At least 3,700 major dams are either planned or under construction for hydropower and for irrigation, primarily in countries with emerging economies (Zarfl et al., 2015) (Figure 16). Almost half (48 per cent) of global river volume is already altered by flow regulation, fragmentation, or both. Completion of all dams planned or under construction would mean that natural hydrologic flows would be lost for 93 per cent of all river volume (Grill et al., 2015).

ALMOST HALF OF GLOBAL RIVER VOLUME IS ALREADY ALTERED BY FLOW REGULATION, FRAGMENTATION, OR BOTH



Maps used are for general illustration only and are not intended to be used for reference. The representation of political boundaries does not reflect the position of the Government of India.

Figure 16: Global distribution of future hydropower dams either planned (red dots, 83 per cent) or under construction (blue dots, 17 per cent) *(Zarfl et al., 2015).*

Key

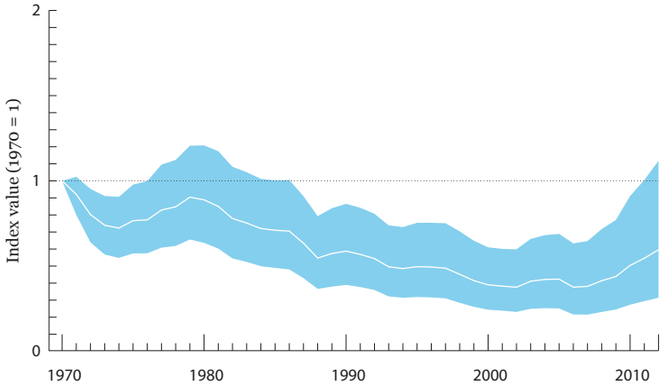
- Dams under construction
- Dams planned



Dams alter flow, temperature and sediment transport of rivers (Reidy Liermann et al., 2012). Furthermore, dams inhibit migration, affecting the regular movement and distribution of species (Hall et al., 2011). The global analysis of fish population trends shows that on average, the abundance of fish species that migrate within freshwater habitat (potamodromous species) or between freshwater and marine habitats (anadromous, catadromous and amphidromous species) declined by 41 per cent overall between 1970 and 2012 (Figure 17), with an average annual decline of 1.2 per cent. The index is based on 162 species and 735 populations.

Although threat information for many of the populations was unavailable, of the 226 populations for which threat data is available, nearly 70 per cent are threatened by alteration of their habitat. This is likely to explain the overall picture of decline. The increase seen after 2006 occurs in a number of migratory fish species: this could indicate the benefits that have been seen in some regions, for example in Europe, of improvements in water quality (EEA, 2015) and the introduction of fish passes in rivers to allow migration where there are manmade barriers.

Figure 17: The migratory fish LPI shows a decline of 41 per cent (range: +12 to -69 per cent) between 1970 and 2012
Trend in population abundance for 735 populations of 162 migratory fish species monitored worldwide between 1970 and 2012 (WWF/ ZSL, 2016). The species included in this index are classified as either catadromous, anadromous, potamodromous or amphidromous by GROMS (Global Register of Migratory Species).



Key

- Migratory fish Living Planet Index
- Confidence limits

DAM REMOVAL FOR RIVER RESTORATION: THE ELWHA RIVER

Free-flowing rivers are the freshwater equivalent of wilderness areas. The natural flow variations of these rivers shape and form diverse riverine habitats, within and next to the river. In many places, connected, free-flowing rivers are crucial for carrying sediment downstream, bringing nutrients to floodplain soils, maintaining floodplains and deltas that protect against extreme weather events, and providing recreational opportunities or spiritual fulfilment. Almost everywhere that free-flowing rivers remain, they are home to vulnerable freshwater biodiversity. Dams and other infrastructure threaten these free-flowing rivers as they create barriers, causing fragmentation and alteration to flow regimes. Dams also affect long-distance migratory fishes by obstructing their migratory pathways, making it difficult or impossible to complete their life cycles.

The Elwha River in the Pacific Northwest of the United States provides a striking example. Two hydroelectric dams – the Elwha Dam constructed in 1914 and the Glines Canyon Dam completed in 1927 – blocked passage for migratory salmon. Local people reported a huge decline in adult salmon returning to the river after the Elwha Dam was constructed. This heavily affected the Lower Elwha Klallam Tribe, who relied on the river's salmon and other associated species in the watershed for physical, spiritual and cultural reasons. Salmon are a keystone species in that they bring nutrients from the coast inland, nourishing both terrestrial and aquatic species that benefit from this supply of nutrients.

In the mid-1980s the Elwha Klallam Tribe and environmental groups started to push for the removal of the Elwha and Glines Canyon dams. Eventually the Elwha River Ecosystem and Fisheries Restoration Act of 1992 was put in place, mandating the "full restoration of the fisheries and ecosystem". After 20 years of planning, work to remove the Elwha Dam began in 2011, the largest dam removal in US history. The removal of the Glines Canyon Dam was completed in August 2014. Fish populations are expected to make a return to the river. Some chinook salmon already did in 2012, just after the Elwha dam came down.



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Marine Living Planet Index

Oceans and seas cover over 70 per cent of the Earth's surface. They play a critical role in regulating Earth's climate, and they also provide us with a wealth of benefits including food, livelihoods and cultural uses. Maintaining the health of the marine environment, including its biodiversity, is vital to humanity's survival.

The marine LPI shows a 36 per cent overall decline between 1970 and 2012 (Figure 18) with an average annual decline of 1 per cent. This index is based on data for 6,170 monitored populations of 1,353 marine species (birds, mammals, reptiles and fish). Most of these species are fish and they drive the trend shown. The majority of the decline in the marine LPI occurred between 1970 and the late 1980s, after which the trend stabilizes. This reflects the trend in fish catch globally, which stabilizes at much lower population levels after 1988 (FAO, 2016a). This is at the time when the concept of maximum sustainable yields was introduced to control the extent to which fish stocks are harvested.

Although the overall marine index is stable from 1988, and some fisheries are now showing recovery because of stronger management measures, the majority of the stocks that contribute most to global fish catch are now either fully fished or overfished (FAO, 2016a).

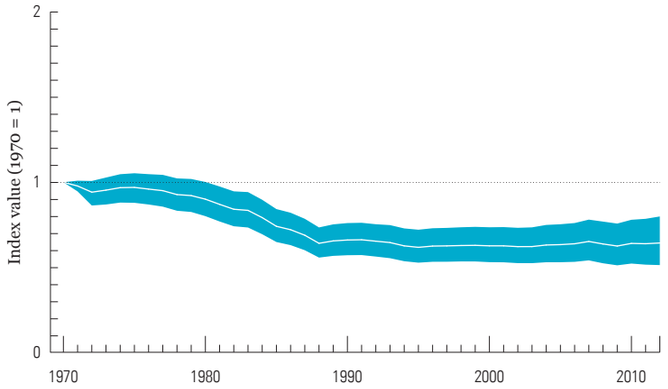


Figure 18: The marine LPI shows a decline of 36 per cent (range: -20 to -48 per cent) between 1970 and 2012
Trend in population abundance for 6,170 populations of 1,353 marine species monitored across the globe between 1970 and 2012 (WWF/ZSL, 2016).

Key

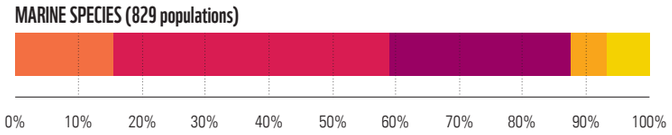
- Marine Living Planet Index
- Confidence limits

Threat information is available for 29 per cent of declining populations (n=829). Data indicates that the most common threat for marine species is overexploitation, followed by loss and degradation of marine habitats (Figure 19).

Figure 19: Threat type frequency for 829 declining marine populations in the LPI database showing 1,155 recorded threats
Each population has up to three threats recorded, so the total number of recorded threats exceeds the number of populations (WWF/ZSL, 2016).

Key

- Climate change
- Overexploitation
- Habitat loss / degradation
- Invasive species and disease
- Pollution

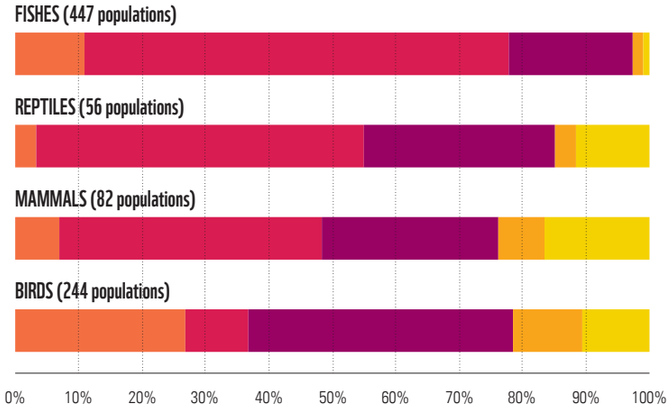


Overexploitation through overfishing is the most common threat attributed to declining fish populations (Figure 20). Recent statistics suggest that 31 per cent of global fish stocks are overfished (FAO, 2016a). Without effective management, unsustainable levels of fishing could lead to commercial extinction. Currently, the Northern Pacific bluefin tuna (Collette et al., 2011) is at risk for this reason. Also, a third of sharks, rays and skates are estimated to be threatened with extinction primarily because of overfishing (Dulvy et al., 2014).

Figure 20: Taxonomic differences in threat frequency for 829 declining marine populations in the LPI database
(WWF/ZSL, 2016).

Key

- Climate change
- Overexploitation
- Habitat loss / degradation
- Invasive species and disease
- Pollution



For sea birds, marine mammals and reptiles, overexploitation mostly refers to incidental killing, bycatch or targeted trade. Individuals are considered bycatch when their capture or death is unintentional. It also refers to accidental mortalities occurring from boat strikes.

Changes in habitat are the second most common threat associated with declining marine populations (Kovacs et al., 2012). Deterioration of coastal ecosystems affect feeding, breeding and nursery grounds for many marine mammals, such as seals, sea lions and walrus, marine turtles and seabirds. For seals and sea lions, habitat degradation also includes the loss of prey as humans are outcompeting them for fish and other food resources (Kovacs et al., 2012). Coastal habitat change is the most frequently reported threat for birds, as development affects nesting habitat. Other threats for seabirds include pollution and bycatch (Croxall et al., 2012).

How the LPI database evolves

Improving the coverage of the datasets behind the LPI is an ongoing effort with many data gaps needing to be filled around the world (Figure 3), not least for the marine LPI (see box). The LPI shows a trend analysis on the basis of the data available. One of the objectives of ZSL and WWF is to keep the LPI database up to date and seek data for species where we have no or limited information. Since there is no central repository for this data, or for its coordinated release, ongoing searches are conducted to find and add data from relevant studies and reports as they become public.

The Living Planet Index draws upon known data available on the size of populations of different species at the time of publication, and tracks changes to these over time. Each species has one or more populations and the data for these populations comes from many sources (see the LPR supplement for more information on the calculation of the LPI). Importantly, the overall indices can change if data on new species are added - which adds one or more new populations to the database - and also if new populations of existing species already in the LPI are added.

As an example, since the publication of the Living Blue Planet Report in 2015, both data on populations of species new to the LPI and on new populations of existing LPI species have been added to the marine dataset. In this case, these new data are responsible for the difference in the marine LPIs reported in 2015 and 2016.

To explore the impact of the addition of new data on the marine LPI, a recalculation shows what happens when the marine LPI uses the same set of species as used in 2015 but adds new populations for these species (from the 2016 dataset). The result is a 44 per cent decline between 1970 and 2012, eight percentage points lower than the marine LPI for 2016 (-36%). Consequently, newly added populations of those species which are already included within the index account for a difference of five percentage points between the results in 2015 (-49%) and this recalculation (-44%).

THE LIVING PLANET INDEX DRAWS UPON KNOWN DATA AVAILABLE ON THE SIZE OF POPULATIONS OF DIFFERENT SPECIES AT THE TIME OF PUBLICATION, AND TRACKS CHANGES TO THESE OVER TIME

The remaining eight percentage points difference between 2015 and 2016 is explained by the inclusion of populations of new species. These new species comprise three birds, one mammal and 115 fish. New fish species data covered all marine realms except the Arctic. Whilst variations in trend occur with the addition of new data, these are within the confidence limits of the previous results and the general trend still shows substantially lower population sizes over time than the start of the LPI in 1970.

Challenges in monitoring of marine species globally

One of the central challenges in understanding the impact of humans on marine species populations is that official statistics appear to be significantly underestimating the amount of wild fish caught. A recent study revealed that between 1950 and 2010, actual global catches of fish were likely to have been 50% higher than reported to the United Nations (Pauly and Zeller, 2016).

The data behind the marine LPI is mostly comprised of fish populations and of these, a large proportion are commercial fish stocks from areas where they are subject to more effective fisheries management including catch monitoring. The marine LPI currently has limited data from artisanal, subsistence and recreational fishing, illegal, unreported and unregulated (IUU) fishing and bycatch. This is due to the challenges of monitoring the impact of these activities, or in some cases, the data are collected but not reported. IUU fishing is a major problem in the high seas outside of areas of national jurisdiction, but it can also occur in many coastal areas (FAO, 2016).

It is widely acknowledged that the catches from artisanal and subsistence fisheries comprise a major part of world fisheries and are crucial for food security in developing countries. As such, it is vital to understand how these populations are responding to fishing pressure to avoid overexploitation.

If many key species and regions are not being monitored yet, or if monitoring is inadequate, this poses a serious challenge in understanding the impact of humans on marine species populations and developing appropriate policies to counter negative effects. Gathering further data on fish stocks and other marine species across a range of habitats is a priority for future estimates of overall marine population trends. As the marine LPI largely relies on official statistics, it is not possible yet to fully reflect the non-commercial, subsistence components of fisheries. It is therefore likely that fish populations are declining at much greater levels that the marine LPI is currently able to show.

A closer look at coral reefs

Coral reefs are highly biodiverse habitats located in shallow parts of the ocean. Thousands of species take advantage of the food, protection and nursery habitat provided by reefs (Burke et al., 2011). While reefs cover less than 0.1 per cent of the total area of the world's ocean, they support over 25 per cent of all marine fish species (Spalding et al., 2001).

Three-quarters of the world's coral reefs are now threatened (Burke et al., 2011) and the species they support are subject to high and increasing pressure.

Scientists warn that strong action is needed to reduce the concentration of greenhouse gases in the atmosphere, including CO_2. Otherwise coral reefs could face large-scale extinction by mid-century, due to widespread and regular mass coral bleaching events and acidification (Hoegh-Guldberg, 2015) (see box). Coral reefs also face other serious threats, including overfishing and destructive fishing (such as the use of explosives and cyanide); sediment, nutrient and pesticide pollution; and coastal development.

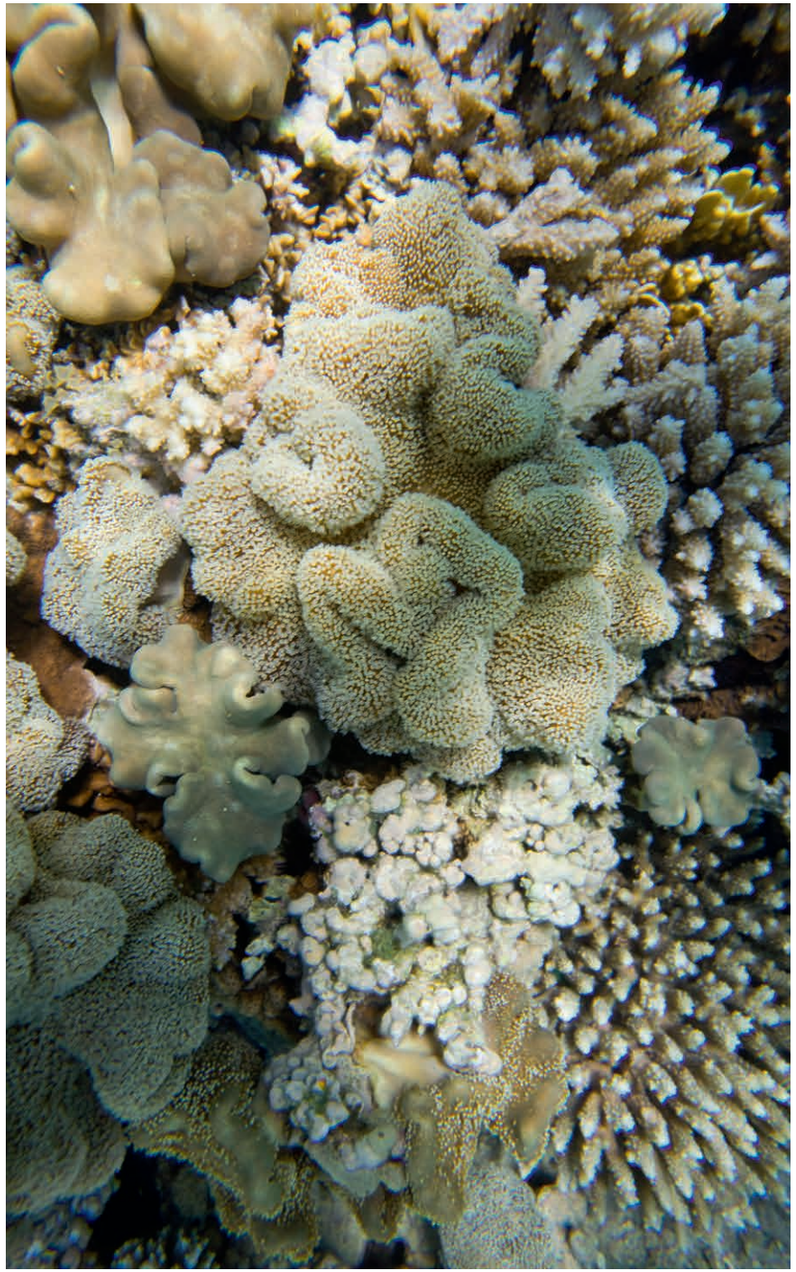


THREE-QUARTERS OF THE WORLD'S CORAL REEFS ARE NOW THREATENED

Warming waters bring coral bleaching and mortality across the globe

Bleaching occurs when corals are stressed by unusual conditions such as high water temperatures. If the water gets too warm, corals expel the tiny algae living in their tissues, causing the coral to turn completely white. Heat stress can kill corals directly or indirectly via starvation and disease (Hoegh-Guldberg, 1999). In a severe bleaching event, large swathes of reef-building corals die.

The 2015-2016 global mass coral bleaching event – the third ever recorded – may be the longest and most intense in history, impacting reefs from Hawaii to the Great Barrier Reef, and those of South East Asia and Africa (NOAA, 2016). Scientists expect that climate change will cause these bleaching events to occur more regularly, compromising the ability of corals to recover between each episode (Hoegh-Guldberg, 1999, Donner et al., 2005; Frieler et al., 2013).



© Global Warming Images - WWF

Coral reef off Dahab in the Red Sea in Egypt showing signs of coral bleaching. Like many areas of coral around the world, reefs in the Red Sea are increasingly threatened by global warming-induced coral bleaching. Bleaching is caused when the water temperature rises to a point that the zooxanthellae – the symbiotic algae that live on corals – cannot tolerate. They can recover if the water temperature drops, but prolonged heat will eventually kill the coral.

THE LIVING PLANET INDEX IN PERSPECTIVE

In 2010, the Convention on Biological Diversity's (CBD) 196 signatory countries agreed to 20 ambitious biodiversity targets for 2020. They require nations to take effective and urgent action to halt the loss of biodiversity and ensure that ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being and poverty eradication (CBD, 2014a). The LPI is one of a suite of global indicators used to monitor whether the targets are being met (Tittensor et al., 2014).

Different indicators shed light on particular aspects of biodiversity, and provide a way of understanding the magnitude and mechanisms of threats and pressures. The LPI monitors trends in population abundance through the changing sizes of wildlife populations. The Red List Index (RLI) differs by monitoring how the global extinction risk of a species is changing. Another measure is how many species there are in a given local area (local richness).

BY 2020 VERTEBRATE POPULATIONS MAY HAVE DECLINED BY AN AVERAGE OF 67 PER CENT SINCE 1970

Projecting the Living Planet Index

The Global Biodiversity Outlook 4 (CBD, 2014a) compares the current status of indicators and their projected trends up to 2020 with the UN biodiversity targets. Figure 21 shows what will happen if current trends continue to 2020; by this time vertebrate populations may have declined by an average of 67 per cent since 1970.

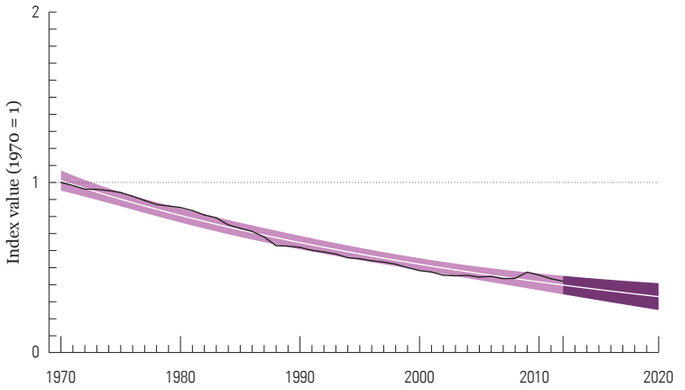


Figure 21: The Living Planet Index extrapolated to 2020 under a business as usual scenario
The Living Planet Index (solid black line) with model fit and extrapolation to 2020 (white line, shaded area) under a business as usual scenario, shaded band shows 95 per cent confidence limits of the model fit. Using method from Tittensor et al., 2014.

Key

- Global Living Planet Index
- Confidence limits
- Global Living Planet Index - extrapolated
- Confidence limits

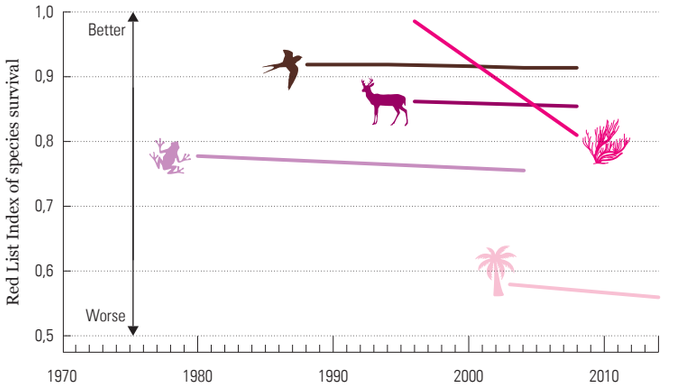
The Red List Index

By tracking the number of threatened species, the RLI quantifies overall risk of extinction and how it is changing over time. The RLI is based on IUCN Red List assessments that classify species into one of seven categories (Extinct, Critically Endangered, Endangered, Vulnerable, Near Threatened, Least Concern or Data Deficient). This classification relies on a wide range of criteria including range size, population size and threats. As species can be reassessed over time, the number of species that are threatened with extinction and the severity of that threat can change. Declines in the RLI indicate either that more species are threatened with extinction or some species are increasingly threatened with extinction. The RLI is now calculated for five groups – birds, mammals, amphibians, corals and cycads (a class of seed plants found in the tropics) (Figure 22).

Figure 22: Red List Index of species survival for birds, mammals, amphibians, corals and cycads
(IUCN and Birdlife International, 2016).

Key

- Birds
- Mammals
- Corals
- Amphibians
- Cycads



The position of each line shows how the level of extinction risk varies between species groups. In this graph, cycads have the lowest index value in 2003 and 2014 and so these species are at greater risk of extinction compared to birds, mammals, corals and amphibians. The slope of each line corresponds to the speed that extinction risk of a group is changing: a steeper slope equals more change per unit time. Corals exhibit faster change than the other groups; between 1996 and 2008, their survival status dropped considerably. Analysing how patterns of extinction risk vary and have changed up to now helps us understand the potential for future extinctions and whether or not we are experiencing unusual levels of extinction (see box on the sixth mass extinction).

Entering the sixth mass extinction?

Palaeontologists characterize mass extinctions as biological or biotic crises defined by the loss of a vast amount of species in a relatively short geological time period. A mass extinction has occurred only five times in the past ~ 540 million years (Barnosky et al., 2011; Jablonski, 1994; Raup and Sepkoski, 1982).

Mass extinctions have occurred in response to changes in key environmental systems, for example in response to changes in climate or atmospheric composition, the availability of land at different latitudes or sea at different depths, or combinations of these (Barnosky et al., 2011; Erwin, 1994). But in the last few centuries the Earth has experienced exceptionally high and increasing rates of species loss (eg. Ceballos et al., 2015; Régnier et al., 2015).

Recent studies suggest probable extinction rates at present are up to 100-1,000 extinctions per 10,000 species per 100 years, which is much higher than the long-term rate of extinction (excluding the episodes of crisis in Earth's history) – the background extinction rate (Ceballos et al., 2015; Steffen et al., 2015a). This suggests that we are on the edge of a sixth mass extinction.

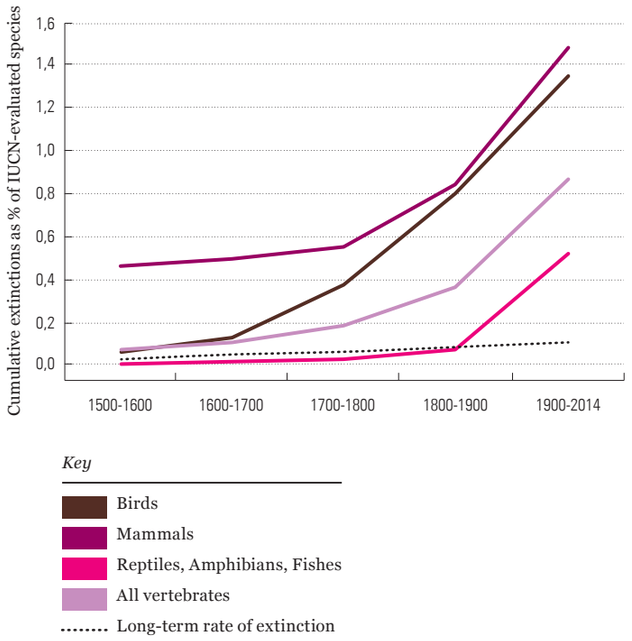


Figure 23: Cumulative vertebrate extinctions as a percentage of researched species (IUCN, 2014)
Graph shows the percentage of the number of species evaluated among mammals (5513; 100 per cent of those described), birds (10,425; 100 per cent), reptiles (4414; 44 per cent), amphibians (6414; 88 per cent), fishes (12,457; 38 per cent), and all vertebrates combined (39,223; 59 per cent). Dashed black curve represents the number of extinctions expected under a constant standard background rate of 2 E/MSY (Ceballos et al., 2015).

Projecting biodiversity trends: the Local Biodiversity Intactness Index

The Local Biodiversity Intactness Index (LBII) forecasts how species richness (the number of species counted at a study site) will change in the future due to the impacts of land-use change, pollution and invasive species (Newbold et al., 2015). In addition to recording the current state of global biodiversity, indicators can be projected forward to predict how close the world is to meeting the 2020 targets (Tittensor et al., 2014).

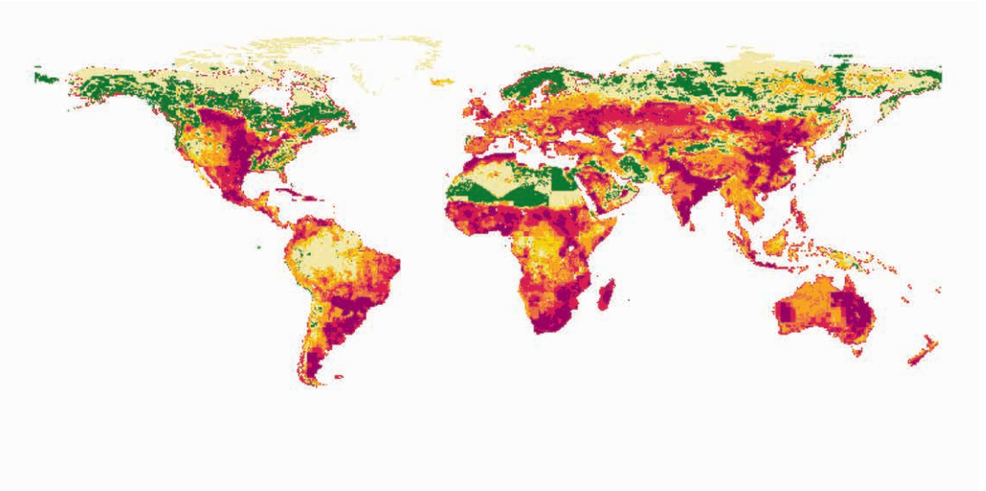
Figure 24: Predicted net loss of local species richness for 2090 using the PREDICTS framework
Net loss is shown for the 'business-as-usual' scenario, based on a pre-human baseline. Data derived from Newbold et al., 2015.

Key

- > 30%
- 25 - 30%
- 20 - 25%
- 10 - 20%
- 5 - 10%
- 0 - 5%
- Gain

Figure 24 shows LBII richness projected for 2090. The map demonstrates that if human enterprise continues to develop at the current pace (business-as-usual scenario) we can expect to see substantial changes in species richness across the globe. Red areas show regions that are expected to experience a loss of over 30 per cent of their initial species richness. The darker green areas are predicted to see a gain in species richness. These are primarily in northern regions and drylands where climate change may make environmental conditions more suitable for some species. For example the warming of some areas of the Arctic is already producing a longer growing season and more plant species are able to thrive (Snyder, 2013).

The LBII has also been used to evaluate anthropogenic impacts that have already happened. Newbold et al. (2016) estimate that the proposed Planetary Boundary for biodiversity has already been breached across 58.1 per cent of the world's land surface.



COMMUNITY MANGROVE RESTORATION MADAGASCAR

Mangroves protect and stabilize coastlines – particularly important as climate change brings more extreme storms and increased wave action. They also act as sinks, sequestering 3–5 per cent more carbon per unit area than any other forest system. But mangroves are disappearing, cleared for urban and tourism development or felled for fuel and building materials. Wise use of mangroves, such as creating coastal reserves and helping local communities develop livelihoods built on keeping them intact, is crucial for nature and people.

The most extensive mangrove cover, about a million hectares bordering the Western Indian Ocean, is found in the river deltas of Kenya, Madagascar, Mozambique and Tanzania. As an ecozone between land and sea, mangroves are home to a huge variety of creatures, from birds and land mammals to dugongs, five marine turtle species and many kinds of fish. And much of the economically important prawn harvest along this coast depends on mangroves for safe spawning and nursery grounds.

In the Melaky region on Madagascar's west coast, local people are taking action to remedy the loss of mangroves, which are crucial to their livelihoods. Since September 2015, men, women and children from the village of Manombo have become key players in mangrove conservation and restoration. Mangrove restoration benefits local communities by improving access to fish and crab stock, which provide a regular income, and builds resilience against climate change. The village community participated in a reforestation campaign, planting around 9,000 mangrove seedlings to restore degraded forests around their village. Next to Manombo, other communities have together planted 49,000 seedlings. For the local communities and the future of their forests, that equals a real success.

(source: WWF-Madagascar; WWF, 2016a)



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ECOSYSTEM SERVICES: LINKING NATURE AND PEOPLE

We need diverse ecosystems to deliver all the services we depend upon. Many of our essential foods and materials are derived from a variety of animals and plants. A great many species are critical for the functioning of ecosystem processes such as regulation and purification of water and air, climatic conditions, pollination and seed dispersal, and control of pests and diseases. And by affecting nutrient and water cycling systems and soil fertility, some species indirectly support the supply of food, fibre, fresh water and medicines (MEA, 2005).

HEALTHY ECOSYSTEMS ARE VITAL TO OUR SURVIVAL, WELL-BEING AND PROSPERITY

The observed decline in species populations is inextricably linked to the state of ecosystems and habitats that sustain our planet's species. Destruction of habitats represents a risk not just to plants and wildlife, but to humans as well. These habitats are vital to our survival, well-being and prosperity. The stock of renewable and non-renewable natural resources (e.g., plants, animals, air, water, soils, minerals) can be described as "natural capital". Natural capital delivers a flow of benefits to people both locally and globally, often referred to as "ecosystem services" (Figure 25).

INCREASED HUMAN PRESSURE IS DIMINISHING NATURAL CAPITAL AT A FASTER RATE THAN IT CAN BE REPLENISHED

The ecosystem-based assets of natural capital evolved to be self-sustaining. But increased human pressure on ecosystems and species – such as conversion of natural habitat to agriculture, overexploitation of fisheries, pollution of freshwater by industries, urbanization and unsustainable farming and fishing practices – is diminishing natural capital at a faster rate than it can be replenished (EEA, 2013). We are already experiencing the costs of natural capital depletion. These costs are expected to grow over time, increasing the risk of food and water insecurity, higher prices for many commodities, and increased competition for land and water. Over time, depletion of natural capital will exacerbate conflict and migration, climate change and vulnerability to natural disasters such as flooding and drought, and have a negative impact on physical and mental health and well-being (MEA, 2005).

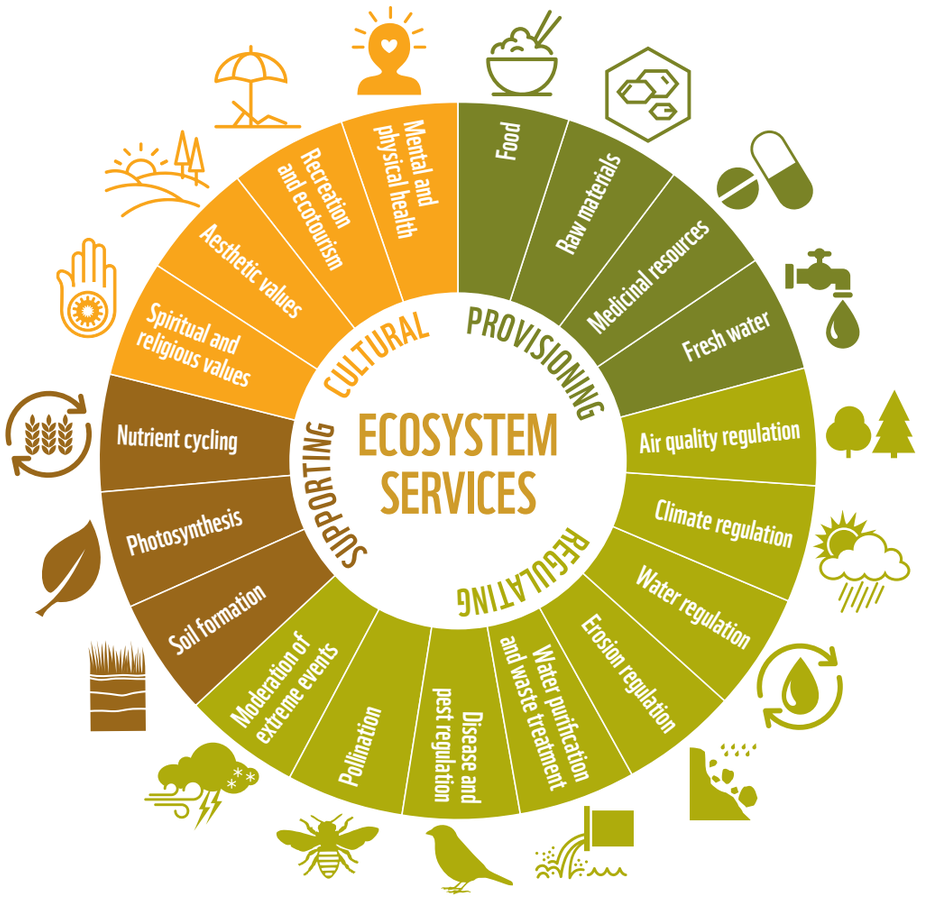


Figure 25: Ecosystem services
Provisioning services are the products obtained from ecosystems, regulating services are the benefits obtained from the regulation of ecosystem processes, cultural services are the nonmaterial benefits people obtain from ecosystems and supporting services are those services that are necessary for the production of all other ecosystem services. Adapted from the Millennium Ecosystem Assessment, 2005.

In spite of the critical importance of our natural capital stock, developing a meaningful way to monitor changes and how these are affecting human well-being is still a challenge. There are a number of approaches to track changes in specific aspects of natural capital and for understanding the consequences for humans. In the next pages some examples are presented of existing metrics that illustrate the relationship between natural capital stock, ecosystem services and human well-being.

Forest cover

Forests are critical to the way Earth functions. They lock up vast amounts of carbon and release oxygen. They influence rainfall, filter fresh water and prevent flooding and soil erosion. They produce wild foods, fuelwood and medicines for the people that live in and around them. They are storehouses of potential future crop varieties and genetic materials with untapped healing qualities. Wood and other fibre grown in forests can be used as a renewable fuel or as raw material for paper, packaging, furniture or housing.

FORESTS ARE VITAL FOR THE WAY EARTH FUNCTIONS

While the pressures on forests vary across regions, the biggest cause of deforestation is expanding agriculture – including commercial livestock and major crops such as palm oil and soy (Gibbs et al., 2010; Hosonuma et al., 2012; Kissinger et al., 2012). Small-scale farmers also play a role, often due to poverty and insecure land tenure. Mining, hydroelectricity and other infrastructure projects are also major pressures – new roads can have a large indirect impact through opening up forests to settlers and agriculture.

Next to deforestation, forest degradation is a threat to forest biodiversity. The key drivers of tropical forest degradation include unsustainable logging, fuelwood collection and uncontrolled fires (Kissinger et al., 2012). Degradation depletes the reproductive and ecosystem service provision capacity of standing forests. It is a direct source of greenhouse-gas emissions and can be a catalyst for eventual deforestation.



ON A GROSS BASIS, A TOTAL OF 239 MILLION HECTARES OF NATURAL FOREST WAS LOST SINCE 1990

The Global Forest Resources Assessment reported that the rate of net global deforestation had slowed down considerably in the last 25 years (FAO Forestry, 2015). Its latest data shows that 129 million hectares of forest have been lost since 1990 on a net basis – an area larger than South Africa. However, this net figure masks the changes in natural forests over planted forests. On a gross basis, a total of 239 million hectares of natural forest was lost over the same period. And the proportion of the world's forests that are planted rose from 4 per cent to 7 per cent. Although planted forests are important for the provision of timber, other resources and economic development, natural forests are often a more valuable source of ecosystem services overall and their loss should not be understated. They often provide better habitats with more species diversity, potentially more carbon storage and regenerative capacity (Gamfeldt et al., 2013). It is important that at the global level we are able to monitor not just the quantity of forests but also the quality of those forests.

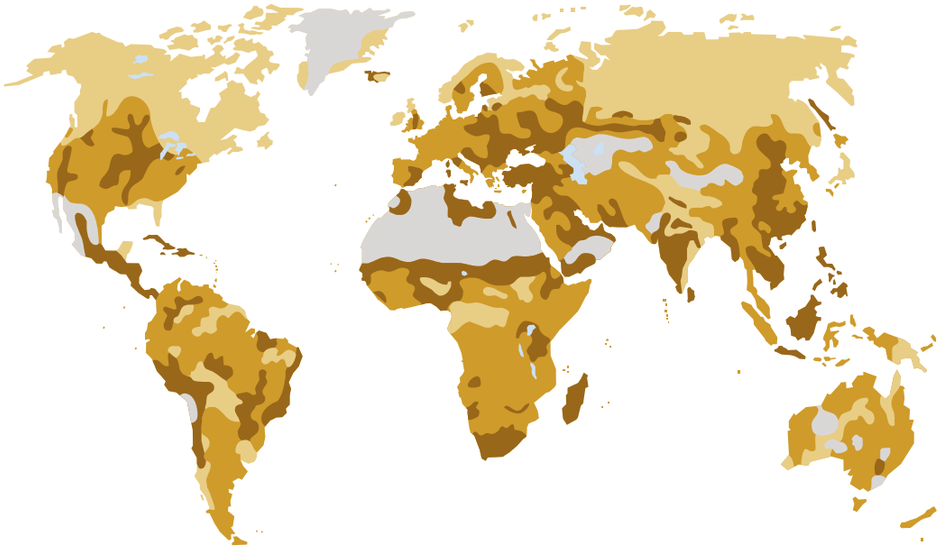
Soil quality

The world's food and water supply is greatly dependent upon good quality soil. However, about 30 per cent of global land area has already experienced significant degradation – that is, a reduction in the capacity of land to provide ecosystem services and assure its functions over a period of time. One third of grasslands, a quarter of croplands, and almost a quarter of forests experienced degradation over the last three decades. The annual cost of land degradation is estimated to be about US$300 billion. This includes losses to both agricultural production and other ecosystem services (Nkonya et al., 2016).



Land degradation arises in part from land-use change and also from poor agricultural management practices. The latter reduces the quality and fertility of soils and this further lowers agricultural productivity and associated yields. According to the FAO, the situation is most acute in Africa, where two-thirds of agricultural lands are degraded and per capita food production is declining as a result of soil quality loss (FAO, 2011a). Land degradation also reduces carbon fixation since above and below ground biomass is compromised. In the period 1981-2003 this led to a loss of nearly a billion tonnes of carbon (Bai et al., 2008).

Figure 26: The state of global soil degradation *(UNEP, 1997).*



Water availability

Reliable access to fresh water is vital for domestic life, agriculture and industry. Competition for water between these demands increases the risk of local and national-scale conflict (UNESCO, 2015).

Since 1992, the Food and Agriculture Organization of the United Nations (FAO) has calculated total renewable water resources available per capita (FAO, 2016b). The data shows that increased human population, combined with shifting consumption patterns, has resulted in steadily increasing pressure on water resources. Nearly 50 countries experienced water stress or water scarcity in 2014, up from just over 30 in 1992 (Figure 27). Africa has the highest proportion of countries experiencing water stress (41 per cent), but Asia has the highest proportion of countries experiencing absolute water scarcity (25 per cent).

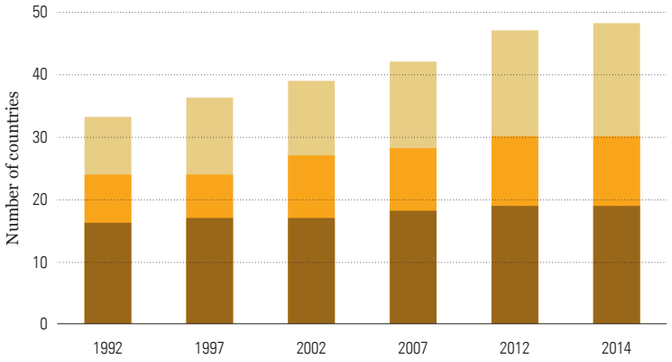


Figure 27: Number of countries experiencing different types of water stress
Number of countries experiencing different types of water stress from a total of 174 countries (FAO, 2016b). Water stress is defined as annual renewable water resources of less than 1,700 m³ per inhabitant, water scarcity as less than 1,000 m³ per inhabitant, and absolute water scarcity as less than 500m³ per inhabitant (UN-Water, 2011). Annual renewable water resources equals the amount of water available per person per year. Figure compiled by UNEP-WCMC.

Key

- Water stress
- Water scarcity
- Absolute water scarcity

NEARLY 50 COUNTRIES EXPERIENCED WATER STRESS OR WATER SCARCITY IN 2014

Fish stocks

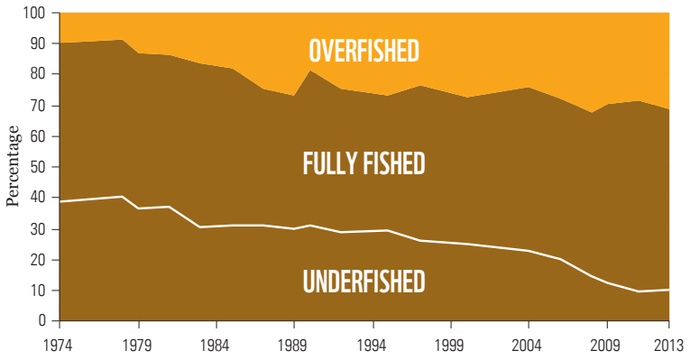
More than 3 billion people obtain up to 20 per cent of their animal protein from fish, and the majority of the planet's fish comes from the ocean (WWF, 2015a; FAO, 2016a). Per capita fish consumption continues to rise (FAO, 2016a) and so meeting the increasing demand for fish as food is a major global challenge.

Based on FAO's analysis of assessed commercial stocks (FAO, 2016a), the share of fish stocks within biologically sustainable levels decreased from 90 per cent in 1974 to 68.6 per cent in 2013. The remaining 31.4 per cent of fish stocks are estimated to be at a biologically unsustainable level and are therefore overfished. Of the total number of stocks assessed in 2013, fully fished stocks accounted for 58.1 per cent and underfished stocks – that is, those which could sustainably support increased harvesting – 10.5 per cent (Figure 28).

Figure 28: Global trends in the state of world marine fish stocks since 1974
31.4 per cent of assessed fish stocks were estimated as fished at a biologically unsustainable level and therefore overfished. Fully fished stocks accounted for 58.1 per cent and underfished stocks 10.5 per cent (FAO, 2016a).

Key

- At biologically unsustainable levels
- Within biologically sustainable levels



OVER 30 PER CENT OF FISH STOCKS ARE OVERFISHED

THE STORY OF SOY

3. worldwide demand threatens the Cerrado

High in protein and energy, soy is a key part of the global food supply. Mainly used as animal feed, soy has become one of the world's biggest crops due to rising demand worldwide for meat products. But its growth has come at a cost. Vast areas of forest, savannah and grassland have been cleared over the last few decades as soy production has expanded. In total, the area of land in South America devoted to soy grew from 17 million hectares in 1990 to 46 million hectares in 2010, mainly on land converted from natural ecosystems. And forests and other natural ecosystems are coming under ever greater pressure as production and demand continues to grow. Soy production is expected to increase rapidly as economic development leads to higher animal protein consumption, especially in developing and emerging countries. Today's main and fastest-growing soy importer is China, for animal feed and cooking oil. China´s meat consumption is rapidly increasing, and projections indicate a steady steep long-term increase of soy imports, which is likely to increase pressure on the Cerrado, the Amazon, the Chaco and other threatened ecosystems.

(source: WWF-Brazil; WWF, 2014)



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CHAPTER 2: HUMAN IMPACTS ON THE PLANET

AN EARTH SYSTEM PERSPECTIVE

Throughout history there has been a limit to nature's capacity to absorb the impact of human development. However, different societies, and different groups within society, have perceived and responded to these limits very differently (Costanza et al., 2006; Sörlin and Warde, 2009). At times, people have seemed particularly unaware of natural limits and the consequent risks of exceeding them. For example, early industrial societies often discharged waste or emissions from industrial processes directly into the ground, waterways or the air. The resulting damage to human health and ecosystems amassed to the point that it threatened to undermine industrialization's economic and social advances. Over time societies started to regulate emissions of environmental pollutants, control resource extractions, and limit the degree to which the natural environment could be changed by direct human modification (Bishop, 1978). This regulatory approach toward human impacts on the environment is based on the idea that we can define "safe limits" for human activities (Crowards, 1998).

HUMAN ACTIVITIES AND ACCOMPANYING RESOURCE USES HAVE GROWN SO DRAMATICALLY THAT THE ENVIRONMENTAL CONDITIONS THAT FOSTERED OUR DEVELOPMENT AND GROWTH ARE BEGINNING TO DETERIORATE

Establishment of safe limits at local and regional scales remains a necessity as local pollution is still damaging local environments. But we now face constraints at the planetary level as well. The world's population has grown from about 1.6 billion people in 1900 to today's 7.3 billion (UN, 2016). Over the same period, technological innovations and the use of fossil energy helped meet the many demands of this growing population. For example, in the early 1900s an industrial method was developed for fixing nitrogen into ammonia. The resulting synthetic fertilizer now sustains about half of the world's population (Sutton et al., 2013). Readily available fossil fuels provide energy for domestic use and industrial production, enabling global trade. But this also results in rising atmospheric CO_2 concentrations and global warming. Human activities and accompanying resource uses have grown so dramatically, especially since the mid-20th century (Steffen et al., 2007), that the environmental conditions that fostered our development and growth are beginning to deteriorate (Steffen et al., 2004; IPCC, 2012; IPCC, 2013) (Figure 29).

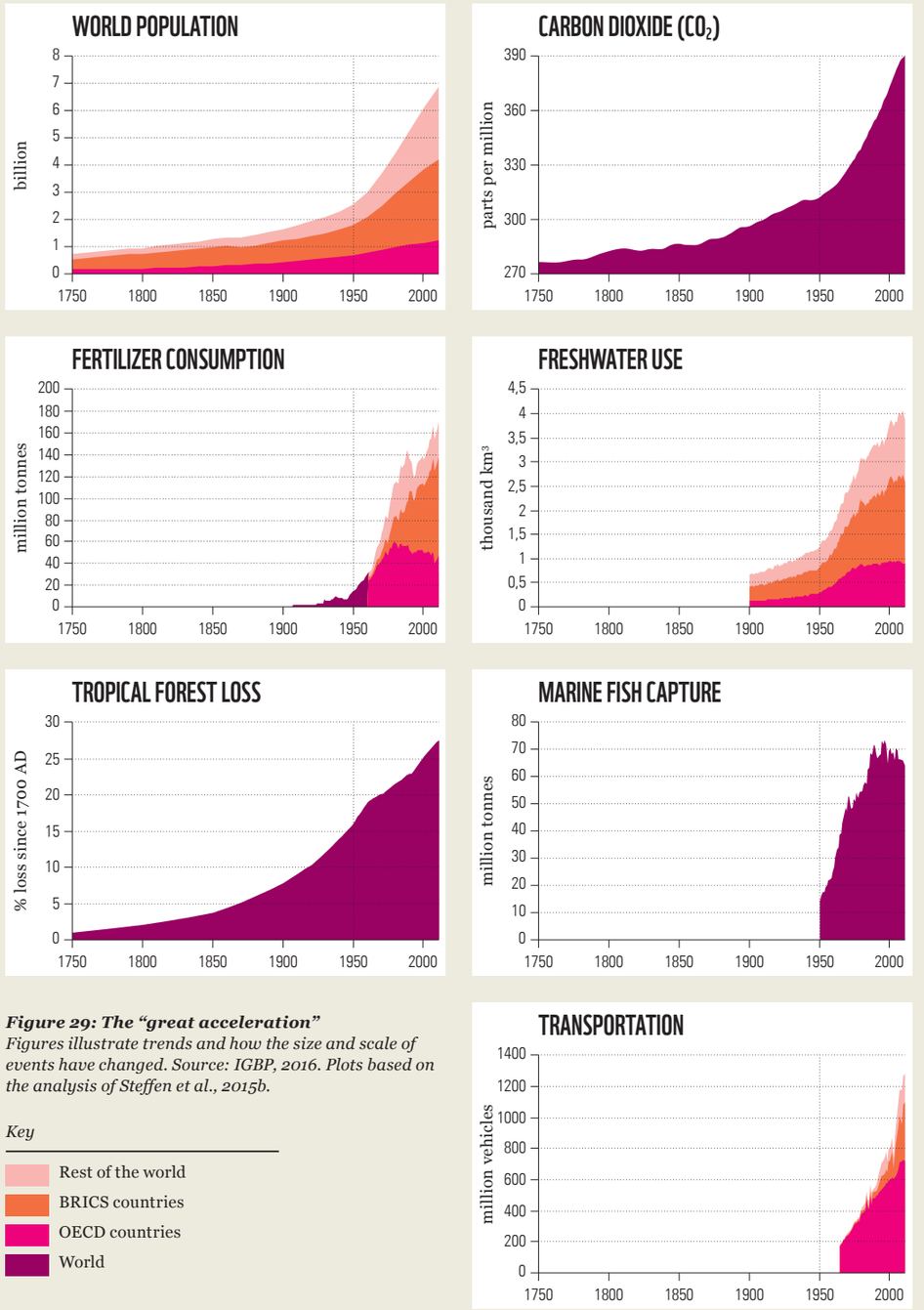


Figure 29: The "great acceleration"
Figures illustrate trends and how the size and scale of events have changed. Source: IGBP, 2016. Plots based on the analysis of Steffen et al., 2015b.

It is clear that responding to risks at the planetary scale will be vastly more challenging than anything we have dealt with before. At times, the complexity of global systems, the politics of designating limits and the consequences of ignoring constraints all seem insurmountably difficult. However, the strong international accord shown in the 2015 Paris Agreement for action on climate change affords us some assurance that the challenges ahead are not insurmountable.

We were unaware of planetary changes until relatively recently. Scientists are still compiling and analysing information to grasp the effects of these changes on nature and humans. An Earth system perspective can help us to perceive complex relationships between human actions and global impacts that affect the natural state of the planet. It enables us to see how local changes have consequences that play out at other geographic scales, and to recognize that impacts that influence one system might affect other systems as well.

THE PLANETARY BOUNDARIES CONCEPT ILLUSTRATES THE RISKS OF HUMAN INTERFERENCE WITH THE EARTH SYSTEM

The Planetary Boundaries concept (Rockström et al., 2009a; 2009b) is an attempt to provide this Earth system perspective. Although still evolving, it is a useful integrating framework for illustrating the risks of human interference with the Earth system through our patterns of consumption and production. It delineates safe boundaries for critical Earth system processes. Within this safe operating space – which is based on our evolving understanding of the functioning and resilience of the global ecosystem – human societies can develop and thrive.

Nine human-produced alterations to the functioning of the Earth system form the basis of the Planetary Boundaries framework (Rockström et al., 2009b; Steffen et al., 2015a) (Figure 30). It is clear that at a certain point our modifications will cause unacceptable and irreversible changes to resources that we depend upon (e.g. CBD, 2014a; IPCC, 2014a; UNEP, 2013).

ANALYSIS SUGGESTS THAT HUMANS HAVE ALREADY PUSHED FOUR OF THESE SYSTEMS BEYOND THE LIMIT OF A SAFE OPERATING SPACE

The nine Planetary Boundaries subsystems are 1) biosphere integrity (or destruction of ecosystems and biodiversity), 2) climate change, and 3) its twin problem ocean acidification, 4) land-system change, 5) unsustainable freshwater use, 6) perturbation of biogeochemical flows (nitrogen and phosphorus inputs to the biosphere), 7) alteration of atmospheric aerosols, and 8) pollution by novel entities, including 9) stratospheric ozone depletion (Steffen et al., 2015a).

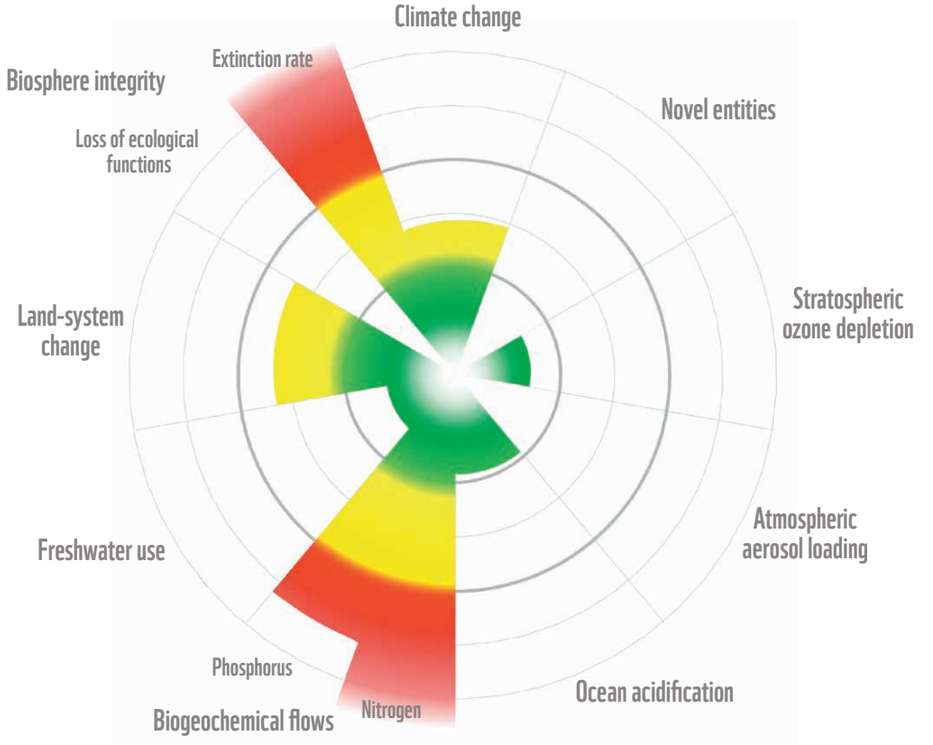


Figure 30: Planetary Boundaries
The green zone is the safe operating space (below the boundary), yellow represents the zone of uncertainty, with an increasing risk of disrupting Earth system stability; and red is the high-risk zone, pushing the Earth system out of a stable Holocene-like state. The Planetary Boundary itself lies at the inner heavy circle (Steffen et al., 2015).

Key
- Beyond zone of uncertainty (high risk)
- In zone of uncertainty (increasing risk)
- Below boundary (safe)

Current analysis suggests that humans have already pushed four of these systems beyond the limit of a safe operating space. There is some scientific uncertainty about the biophysical and societal effects of exceeding Planetary Boundaries. However, attributable global impacts and associated risks to humans are already evident for climate change, biosphere integrity, biogeochemical flows and land-system change (Steffen et al., 2015a). Other assessments suggest that freshwater use has also passed beyond a safe threshold (Mekonnen and Hoekstra, 2016; Vörösmarty et al., 2010).

Biosphere integrity and climate change

The biosphere and climate have co-evolved for nearly four billion years (Lenton and Watson, 2011). Organisms exploit and change their environment. Conversely, the environment constrains and naturally selects the organisms that can live there. Large changes, such as tectonic collisions or meteorite impacts, have propelled the Earth through different chapters that geologists describe as periods, eras, epochs or ages. Nowadays, human action occurs at such a magnitude that we have become a geologically significant force, creating great changes in climate and biosphere integrity (Figure 31). We initiate this both directly and indirectly by changing the seven other subsystem Planetary Boundaries, altering their feedbacks with the climate and biosphere systems (Arneth et al., 2010).

HUMAN ACTION OCCURS AT SUCH A MAGNITUDE THAT WE HAVE BECOME A GEOLOGICALLY SIGNIFICANT FORCE, CREATING GREAT CHANGES IN CLIMATE AND BIOSPHERE INTEGRITY

Because of the complex multiscale linkages and connections between the nine Planetary Boundaries, human modifications of one boundary category can lead to elevated risks or significant improvements in others. Similarly, consequences of human activity in a particular geographic region are not restricted to that area. Repercussions can play out across scales disproportionate to the original disturbance. For example, the loss of Amazonian forest affects the water cycle, reducing rainfall in southern South America (Nobre, 2014). Tropical deforestation (regional land-system change) also affects the carbon cycle, contributing to global climate change (Lawrence and Vandecar, 2015; Sheil and Murdiyarso, 2009; Ciais et al., 2013). Increased atmospheric CO_2 – a major cause of global climate change – is causing global acidification of the ocean. Ocean acidification affects the saturation states of biologically important calcium carbonate minerals. This inhibits the ability of some organisms to produce and maintain their shells. The consequences for biosphere integrity are seen at the regional scale, as tropical coral reefs are adversely affected (Kwiatkowski et al., 2015). Thus regional forest loss in the Amazon has ramifications that cross biomes, hemispheres and Planetary Boundary systems.

Biosphere integrity

Biosphere integrity plays a critical role in determining the state of the Earth system, regulating its material and energy flows and its responses to abrupt and gradual change (Mace et al., 2014). Lenton and Williams (2013) describe the biosphere as the totality of all ecosystems on Earth – terrestrial, freshwater and marine – and their living organisms. The biosphere not only interacts with the other Planetary Boundary categories, but also maintains the overall resilience of the Earth system.

Human impacts on the planet through unsustainable resource use

Figure 31: The interrelations between the Planetary Boundaries

All the Planetary Boundary processes are interlinked as they affect the interactions and feedbacks between biosphere integrity and climate. Some of these effects are stronger and more direct than others. In turn, harm to biosphere integrity and climate change reduces the safe operating space for other processes (Steffen et al., 2015a).



Species diversity is a particularly important aspect of biosphere integrity in that it helps maintain the resilience of terrestrial, freshwater and marine ecosystems (Biggs et al., 2012; Cumming et al., 2013). Protecting species is a way to protect the genetic code embedded in biota. The genetic code is ultimately responsible for the biosphere's functional role and its capacity to innovate and persist into the future (Mace et al., 2014).

SPECIES DIVERSITY IS AN IMPORTANT ASPECT OF BIOSPHERE INTEGRITY BECAUSE IT HELPS MAINTAIN THE RESILIENCE OF ECOSYSTEMS

Both genetic diversity and diversity in the functions that ecosystems perform are important measures of biosphere integrity (Steffen et al., 2015). Robust indicators for functional diversity are still being developed. The extinction rate of species is only a proxy for loss of genetic diversity until more appropriate data and indicators can be assessed (Steffen et al., 2015a).

Climate change

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 (IPCC, 2014a).

GROWING EVIDENCE SUGGESTS THAT THE EARTH HAS ALREADY EXCEEDED THE PLANETARY BOUNDARY FOR CLIMATE CHANGE

Growing evidence suggests that the Earth has already exceeded the Planetary Boundary for climate change and is approaching several thresholds in the global land and ocean environment. The loss of Arctic summer sea ice is almost a certainty within a few decades unless strong mitigation action is taken soon (Stocker et al., 2013). The loss of a year-round northern ice sheet is an example of a well-defined Earth system threshold (Miller et al., 2013; Stranne et al., 2014) which – if breached – would alter many physical feedback mechanisms that play a vital role in regulating global climate. The snow and ice of the Arctic region reflect solar energy and insulate the ocean against heat loss (IPCC, 2013). Other strong feedbacks involve sea-level rise, permafrost and changes in Arctic vegetation (Schuur et al., 2015; Callaghan et al., 2011). Another potential tipping point involves the deterioration of carbon sinks, such as the forests and soils that naturally store large amounts of carbon. For example, the ongoing destruction of the world's rainforests is triggering climate-carbon cycle feedbacks that accelerate Earth's warming and intensify the climate impacts (Raupach et al., 2014). These kinds of abrupt shifts in ice cover and the biosphere would take Earth into a new state (Drijfhout et al., 2015).

How species respond to climate change

Changes in climate and extreme weather events already affect biodiversity across the globe. Ecosystems are likely to undergo divergent responses to climate change dependent on the extent to which they are already degraded (IPCC, 2014b). Spatially restricted species, such as those occurring at high altitude/latitude, are particularly vulnerable (IPCC, 2014b). There is already evidence that the structure and dynamics of ecosystems are being redrawn as species adapt, disperse or become locally extinct (Walther et al., 2002).

Major impacts on species already observed include:



Poleward and altitudinal range shifts. E.g. butterflies are highly sensitive to climate, and are among groups of species which appear to be shifting their range in response (Parmesan et al., 2006).



Timing and volume of rainfall and water availability becoming more unpredictable. E.g. African elephants need up to 300 litres of water a day, just for drinking. As rainfall patterns change, both humans and wildlife are competing for diminishing sources of water (Mariki et al., 2015).



Complex responses for migratory species. E.g., due to the warming of their Arctic breeding grounds, red knot birds are becoming smaller, with smaller bills. Their survival rates are dropping in Africa, because it is increasingly difficult for them to reach deeply buried molluscs, their major food source in their overwintering grounds (Van Gils et al., 2016).



Changes in phenology (the timing of life-cycle events). E.g., hundreds of plant and animal species are beginning to respond to an earlier spring (Primack et al., 2009).



Changes in community composition and abundance. E.g., predicted changes in fish production indicate increased productivity at high latitudes and decreased productivity at low/mid latitudes, with considerable regional variations (Allison et al., 2009).

Threats such as habitat destruction and overexploitation are likely to be exacerbated by a changing climate. For example, plants and animals that might otherwise be somewhat resilient to a changing climate may face increased exploitation in the future. Faced with increased hardships due to changes in climate and extreme weather events, people may take advantage of alternative natural resources to sustain themselves. Thus the impacts on biodiversity are likely to intensify. This is a potentially severe, but under-researched threat: most assessments of species vulnerability to climate change have focused on direct impacts, and largely neglected indirect impacts, such as these human responses (Pacifici et al., 2015).

A closer look at the subsystem boundaries

Exceeding the thresholds of subsystems like biogeochemical flows or land-system change is likely to affect the well-being of many people but it will not – by itself – signify a transition to a new Earth system state. Nevertheless, crossing a subsystem boundary pushes the entire Earth system toward fundamental change represented by the boundaries of either biosphere integrity or climate change (Steffen et al., 2015a).

Biogeochemical flows



This subsystem category emphasizes two elements – nitrogen and phosphorus – as their cycles have radically changed in response to modern industrial and agricultural practices (Erisman et al., 2013; Carpenter and Bennett, 2011). Nitrogen deposition pollutes fresh waters and coastal zones and accumulates in the terrestrial biosphere (Erisman et al., 2013). Similarly, much of the phosphorus mobilized by humans ends up in aquatic systems (Carpenter and Bennett, 2011). Rivers, lakes and other water bodies can become oxygen-starved as bacteria consume decaying blooms of algae that grow in response to the high nutrient supply (e.g. Rabotyagov et al., 2014). This is an example of biogeochemical changes directly affecting biosphere integrity.

A significant amount of applied nitrogen and phosphorus makes its way to the sea, where it pushes marine systems into higher risk conditions. For example, the decline in marine life in the Gulf of Mexico's "dead zone" is the result of large quantities of nutrient runoff into the Mississippi River and other Gulf watersheds. Varying from year to year, the dead zone has at times stretched over 20,000km^2 (Rabotyagov et al., 2014).

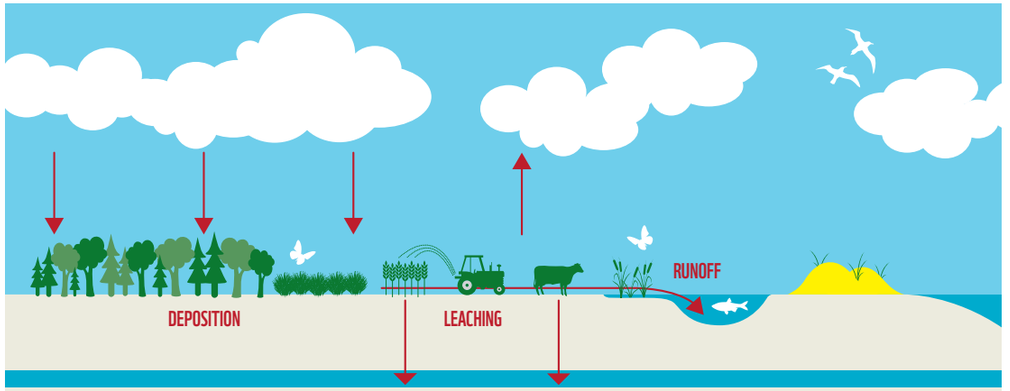
PLANETARY BOUNDARIES FOR BOTH NITROGEN AND PHOSPHORUS HAVE ALREADY BEEN BREACHED DUE TO HUMAN ACTIVITY

According to Steffen et al. (2015a) the Planetary Boundaries for both nitrogen and phosphorus have already been breached due to human activity (see box).

Land-system change



All over the planet, forests, grasslands, wetlands and other habitats have been and continue to be converted to agricultural and urbanized landscapes. The resulting habitat loss is a serious driving force behind reductions in biodiversity. Land conversion also holds consequences for water flows and for the biogeochemical cycling of carbon, nitrogen and phosphorus and other important elements (e.g. Erisman et al., 2013). While individual incidents of land cover change occur on a local scale, the combined results hold consequences for Earth system processes on a global scale.



Nitrogen - too much of a vital resource

The chemical element nitrogen (N) is a basic requirement for all living organisms, because it is essential for our structural growth and metabolisms. It is a key component of essential amino acids and proteins, vitamins and DNA itself. Moreover, 78 per cent of the Earth's atmosphere is comprised of the molecule di-nitrogen (N_2). Atmospheric nitrogen is harmless because it is in a chemically stable form. Everything in nature has evolved with this background of stable nitrogen gas in the atmosphere – that is Earth's "normal".

A relatively small amount of the Earth's total nitrogen exists in reactive forms that can be used by living organisms. When nitrogen is available in the wrong proportions compared with other essential elements, organisms can't thrive. In fact, the composition of much of the world's terrestrial biodiversity is the result of limitations in the availability of reactive nitrogen. Under conditions with high inputs of nitrogen in natural ecosystems, often as a result of leakage from agricultural production, faster-growing species that can rapidly assimilate N and acid-tolerant species are favoured (Erisman et al., 2013). This means ecosystems change as some species thrive more than others under different nutrient conditions. We see this in lakes: algae blooms while larger aquatic plants die.

Modern fertilizer production and application converts more atmospheric nitrogen into reactive forms than all of the Earth's terrestrial processes combined. Much of this new reactive nitrogen is inadvertently released into the environment instead of being taken up by crops. So when we convert (or "fix") atmospheric nitrogen in large quantities outside the natural pool of reactive nitrogen that cycles through Earth's ecosystems, we are interfering with Earth's normal (e.g. Sutton et al., 2013).

On a global scale, the negative consequences of human-generated nitrogen flows are becoming ever more apparent. Numerous (often interlinked) thresholds for human and ecosystem health have been exceeded due to excess reactive nitrogen pollution. These include thresholds for drinking water quality (due to nitrates) and air quality (smog, particulate matter, ground-level ozone). Eutrophication of freshwater and coastal ecosystems (dead zones), climate change and stratospheric ozone depletion are additional consequences of the human-modified reactive nitrogen cycle. Each of these environmental effects can be magnified by a "nitrogen cascade" whereby a single molecule of reactive nitrogen triggers a sequence of negative environmental impacts through time and space (Erisman et al., 2015).

A boundary for human changes to land systems needs to reflect not just the absolute quantity of land, but also its function, quality and spatial distribution (Steffen et al., 2015a). Forests play a particularly important role in controlling the linked dynamics of land use and climate, so they are the focus of the boundary for land-system change (Steffen et al., 2015a; Snyder et al., 2004). Steffen et al. (2015a) indicate that the boundary for land-system change has been exceeded.

THE PLANETARY BOUNDARY FOR LAND-SYSTEM CHANGE HAS BEEN EXCEEDED

Freshwater use

Humans have substantially disrupted hydrological systems through rising consumptive use and impoundment of water (Vörörsmarty and Sahagian, 2000). As a result, streams, wetlands and lakes have dried (Vörösmarty et al., 2010; Davidson, 2014; Jiménez Cisneros et al., 2014); regional atmospheric vapour flows have shifted (Nobre, 2014); and river levels have changed due to increased reservoir storage (Reager et al., 2016; Gornitz, 2000). Changing the water cycle affects both the climate and the biosphere. Some scientists have therefore proposed a Planetary Boundary based on total consumptive freshwater use (Steffen et al., 2015).



However, putting this proposed global boundary on freshwater use into practice raises many issues. Water resources are unevenly distributed across the Earth. The same volume of consumptive water use can have significantly different ecosystem impacts in arid basins than in humid ones. The timing of river flows and water use is also critical to freshwater ecosystem health; the impact of the same volume of water abstraction in a low flow season can be far greater than in a high flow season (Weiskel et al., 2014). It is difficult to take account of these spatial and temporal factors in a planetary-scale boundary. Yet it is obvious we need to give careful thought to water management at all scales as water resources and freshwater habitats globally are currently exploited beyond sustainable limits.

CHANGING THE WATER CYCLE AFFECTS BOTH THE CLIMATE AND THE BIOSPHERE

Ocean acidification

As with climate change, the cause of ocean acidification is increased atmospheric CO_2. Around a quarter of the CO_2 that humans release into the atmosphere is ultimately dissolved into the oceans (Heinze et al., 2015). This slows the planet's warming. However in the ocean it forms carbonic acid, altering ocean chemistry and decreasing the pH (acidity) of the surface water. Surface ocean acidity has already increased by 30 per cent since pre-industrial times (Royal Society, 2005). Beyond a threshold concentration, this rising acidity makes it hard for organisms such as corals, some shellfish and plankton species to grow and survive (e.g. Wittman and Pörtner, 2013).



Loss of these species would change the structure and dynamics of ocean ecosystems and could potentially lead to drastic reductions in fish stocks (CBD, 2014b; Gattuso and Hansson, 2011).

RISING OCEAN ACIDITY MAKES IT HARD FOR ORGANISMS SUCH AS CORALS, SOME SHELLFISH AND PLANKTON SPECIES TO GROW AND SURVIVE

Furthermore, changes in ocean acidity may in turn affect climate, by altering the way that marine life cycles carbon and contributes to its burial in deep ocean sediments, and by changing the emissions of biogenic climate-active gases (Reid et al., 2009; Yool et al., 2013; Six et al., 2013; Kroeker et al., 2013; Gattuso et al., 2015). The Planetary Boundary for ocean acidification is defined with reference to this chemical threshold, yet it is closely linked to both climate change and biosphere integrity boundaries. Large-scale spatial patterns of acidification are already evident (Steffen et al. 2015a), but better ocean monitoring is still needed to track chemical changes and ecosystem responses (Hyde et al., 2013).



Stratospheric ozone depletion

The stratospheric ozone layer is critical in that it filters out ultraviolet (UV) radiation from the sun. If this layer is diminished, increasing amounts of UV radiation will reach the Earth's surface. This would undoubtedly cause a higher incidence of skin cancer, cataracts and immune system disorders in humans and would inflict harm on terrestrial and marine biological systems as well (e.g. WHO/UNEP, 1994). The Antarctic ozone hole appeared when increased concentrations of anthropogenic ozone-depleting chemical substances, interacting with polar stratospheric clouds, passed a certain threshold and tipped the Antarctic stratosphere into a new regime (British Antarctic Survey, 2016). The Montreal Protocol, which came into force in 1989, initiated worldwide action to prevent our crossing into a higher-risk zone.



Novel entities

Emissions of toxic and long-lived synthetic substances such as organic pollutants, heavy metal compounds and radioactive materials create considerable risk to the Earth system. These compounds can have potentially irreversible effects on living organisms and on the physical environment. Depending on the situation, absorption and bioaccumulation of chemical pollution may or may not be lethal; but other effects – including reduced fertility and the potential of permanent genetic damage – can harm ecosystems far from the pollution source. For example, persistent organic compounds have caused dramatic reductions in bird populations and impaired reproduction and development in marine mammals. There are many examples of additive and synergic effects from these compounds, but these are still poorly understood scientifically (see box).

At present, scientists are unable to quantify a single chemical pollution boundary, but the nature of the risks are understood to the degree that novel entities have been included as a Planetary Boundaries category. In itself, this signals the need for precautionary action and further research (Persson et al., 2013).

Chemical pollution by plastic waste

The environmental fate of plastic is emerging as a serious anthropogenic disturbance to the Earth system. Plastics were first manufactured in large quantities in the mid-20th century, and rapidly became indispensable to modern society. By the 1970s, concern was growing over the quantity of plastic waste, and in particular the microplastic debris reaching the ocean. This concern has increased sharply in recent years, as evidence mounts that plastic waste has become a global, ecologically systemic problem. The current state of knowledge on the sources, fate and effects of microplastics in the marine environment has been assessed by a group of experts (GESAMP, 2015).

EVIDENCE MOUNTS THAT PLASTIC WASTE HAS BECOME A GLOBAL, ECOLOGICALLY SYSTEMIC PROBLEM

Knowledge about the ecological effects of plastic waste is still incomplete, yet it is already clear that both direct and indirect effects are damaging. Organisms that consume or become entrapped in plastic waste are harmed and often die. Chemical substances can become concentrated on plastic surfaces, especially on microparticles which have a high surface-area-to-volume ratio. Microparticles can also serve as physical catalysts for new chemical reactions.

Although evidence for the exact environmental pathway is still fragmented, the capacity of plastic to concentrate chemical substances has led to the concern that harmful substances could accumulate at higher trophic levels (Rochman et al., 2013). It is a global problem since there are high concentrations of plastic debris found almost everywhere in the world. Finally, the effects are essentially irreversible. Therefore, there is plenty of evidence that marine plastic debris meets the requirements for becoming a chemical pollution Planetary Boundary category (as argued by Persson et al., 2013).

Atmospheric aerosol loading

Aerosols are microscopic particles or droplets suspended in the atmosphere. Humans alter aerosol concentrations by emitting atmospheric pollution, as many pollutant gases condense into droplets and particles. Further, land-use change increases the release of dust and smoke into the air (Brasseur et al., 2003).



Aerosols affect climate by changing how much solar radiation is reflected or absorbed by the atmosphere (Boucher et al., 2013). Aerosols also play a critically important role in the global water cycle, because they interact with water vapour.

They provide a surface for various chemical reactions that would not otherwise occur (Andreae and Crutzen, 1997; Boucher et al., 2013). Because of these properties, aerosols affect cloud formation and regional weather patterns, such as the monsoon systems in tropical regions (e.g. Ramanathan et al., 2005). Efforts in defining a Planetary Boundary for atmospheric aerosol loading have focused on the physical changes to regional climate (Steffen et al., 2015a), but the complex interactions with the biosphere suggest that there is no single quantitative boundary.

Practical implications of Planetary Boundaries

WE CANNOT TACKLE JUST ONE BOUNDARY WITHOUT ADDRESSING THE OTHERS. CHANGES IN THE PLANETARY BOUNDARIES ARE NOT ISOLATED FROM ONE ANOTHER BUT CAN IN FACT REINFORCE EACH OTHER.

Only recently have we recognized planetary-level processes that affect the resilience and adaptive capacity of Earth. Scientists are still compiling and debating evidence on the dynamics and feedbacks of the Earth system, and the scope and nature of sustainable human activity. But even without full scientific understanding of these thresholds, the Planetary Boundaries concept is useful for framing our current understanding of potential tipping points and underlines the importance of applying the precautionary principle in the management of natural systems. Many researchers already point out that determining and respecting Planetary Boundaries could greatly reduce the risk that the Anthropocene will become inhospitable to life as we know it (Brandi, 2015; Griggs et al., 2013; MacLeod et al., 2014; Steffen and Stafford Smith, 2013).

The next challenge is to complement the Planetary Boundaries thinking with current and hard data on the state of these boundaries and their human drivers. Even as we continue to home in on the quantification of these boundaries, one thing is clear: we cannot tackle just one boundary without addressing the others. Changes in the Planetary Boundaries are not isolated from one another but can in fact reinforce each other. If we seek to fix climate change by removing CO_2 from the atmosphere through new technologies, but fail to consider the role of land-system change, biogeochemical flows and the other subsystems on the integrity of the biosphere, we cannot chart a sustainable course through the Anthropocene. Furthermore, finding better ways to translate the concept and global data into practical tools for decision makers will become increasingly critical.

SEOUL CLIMATE LEADERSHIP

To date, 328 cities from 26 countries on five continents have demonstrated climate leadership in WWF's Earth Hour City Challenge by publicly reporting their commitments and actions toward a sustainable future based on 100 per cent renewable energy. Seoul was elected the winner of this global challenge in 2015. The South Korean capital has taken a comprehensive approach to tackling climate change by moving away from fossil fuels and nuclear energy through massive investment in renewable energy, energy efficiency, and by engaging the public to participate in this transition.

The first phase of the city's One Less Nuclear Power Plant programme set and achieved the goal of reducing the city's energy consumption from external sources by 2 million tonnes of oil equivalent, roughly comparable to the energy production of a nuclear plant with 2-3 reactors. It did this in less than three years through heavy investments in energy efficiency and local renewables. Actions included investments in hydrogen cells, waste heat, geothermal energy, energy caps for new buildings, building retrofit programmes, replacing 8 million light bulbs with high efficient LEDs, eco-friendly transportation and solar PV – including the Sunlight City project, which involved installing rooftop solar panels on about 10,000 buildings, for a total capacity of 320 MW. The city also built solar power stations with a combined capacity of 30 MW in spaces such as sewage facilities and parking lots.

These actions replaced oil imports worth US$1.5 billion, and created 34,000 green jobs. The programme has also pioneered active citizen participation in energy savings, which accounted for 40 per cent of total reductions. Most of this saving came through the Eco-Mileage programme, which rewards people for saving energy with points that they can use to purchase eco-friendly products or to receive financial support for retrofitting buildings. Since 2009 this programme has more than tripled in size to over 1.7 million participants – almost half of the city's households. Much of Seoul's success can be attributed to the visionary leadership of Mayor Park Won-Soon, a former human rights lawyer, civic activist and social designer, who has made collaborative governance and innovation the two main principles of the city administration.

(Source: WWF, 2015b)



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MEASURING HUMAN PRESSURES

One way to track human demand for renewable resources and ecological services is with accounting tools known as footprint indicators. Footprint indicators can help illustrate the human-environment relationship through micro- and macroeconomic systems. The resulting understanding of social and economic drivers, and their environmental impacts, can guide decision-making in support of sustainability. There are several footprint accounts available and more in development. They have been used to gauge the appropriation of carbon, water, land, materials, nitrogen, biodiversity and other resources (Galli et al., 2012; Galli, 2015a). Among them, the Ecological Footprint – used in this report – is probably the most known and used.

Ecological Footprint of consumption



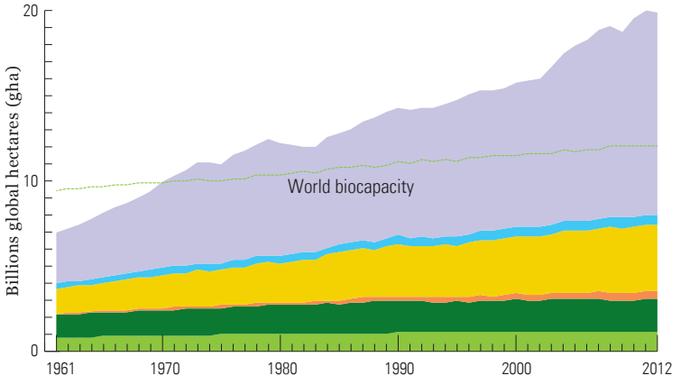
The general intent of the Ecological Footprint is to compare actual human consumption of renewable resources and ecological services against nature's supply of such resources and services (Wackernagel and Rees, 1996). It does this by estimating the biologically productive land and water surfaces required to supply the goods and services we use and then compares that with the area that exists – the Earth's biocapacity – using global hectares as the unit of measurement. Biocapacity functions as an ecological benchmark against which we can gauge the demand that human activities place on ecosystems (Galli et al., 2014; Wackernagel et al., 2014; Lin et al., 2015).

As with any metric, the Ecological Footprint uses just one lens – biocapacity – to track the human dependence on complex and interdependent environmental systems. It does not address all environmental pressures and consequences that are related to human consumption, such as pollution and loss of habitat (see Galli et al., 2012). Rather it provides insight on a minimum condition for sustainability: whether or not human consumption activities fit within the biological threshold defined by the Earth's biocapacity (Lin et al., 2015).

SINCE THE EARLY 1970S, HUMANITY HAS BEEN DEMANDING MORE FROM THE PLANET THAN IT CAN RENEW

Since the early 1970s, humanity has been demanding more from the planet than it can renew (Figure 32). By 2012, the biocapacity equivalent of 1.6 Earths was needed to provide the natural resources and services humanity consumed in that year (Global Footprint Network, 2016). Exceeding the Earth's biocapacity is possible only in the short term. Only for a brief period can we cut trees faster than they mature, harvest more fish than the oceans can replenish, or emit more carbon into the atmosphere than the forests and oceans can absorb. The consequences of "overshoot" are already clear: habitat and species loss, and accumulation of carbon in the atmosphere (Tittensor et al., 2014; UNEP, 2012).

Figure 32: Global Ecological Footprint by component vs Earth's biocapacity, 1961-2012
Carbon is the dominant component of humanity's Ecological Footprint (ranging from 43 per cent in 1961 to 60 per cent in 2012). It is the largest Footprint component at the global level as well as for 145 of the 233 countries and territories tracked in 2012. Its primary cause has been the burning of fossil fuels – coal, oil and natural gas. The green line represents the Earth's capacity to produce resources and ecological services (i.e., the biocapacity). It has been upward trending slightly, mainly due to increased productivities in agriculture (Global Footprint Network, 2016). Data are given in global hectares (gha).



Even as the consequences of human pressure on the environment are increasingly acknowledged and observed, there has yet to be a rational economic response. According to Ecological Footprint data from the past four decades, the few marked reductions in the total global Ecological Footprint do not correspond to intentional policies to limit human impact on nature. Rather they were temporary consequences of major economic crises, such as the 1973 oil crisis, the deep economic recession in the USA and many of the OECD countries during 1980-1982 and the 2008-2009 global economic recession. These reductions in total Ecological Footprint were only temporary and were followed by a rapid return of the Ecological Footprint to an upward climb (Galli et al., 2015). Similar patterns are found in several studies on global carbon emissions (Peters et al., 2011, 2012).

Exploring the Ecological Footprint of Consumption

The Ecological Footprint equates humanity's demand on nature to the amount of biologically productive area required to provide resources and absorb waste (currently just carbon dioxide from fossil fuel, land-use change and cement). It considers six demand categories:



CROPLAND FOOTPRINT

refers to the demand for land on which to produce food and fibre for human consumption, feed for livestock, oil crops and rubber.



GRAZING LAND FOOTPRINT

refers to the demand for rangelands to raise livestock for meat, dairy, leather and wool products.



FISHING GROUNDS FOOTPRINT

refers to the demand for marine and inland water ecosystems necessary to generate the annual primary production (i.e., phytoplankton) required to support seafood catch as well as aquaculture.



FOREST PRODUCT FOOTPRINT

refers to the demand for forests to provide fuel wood, pulp and timber products.



BUILT-UP LAND FOOTPRINT

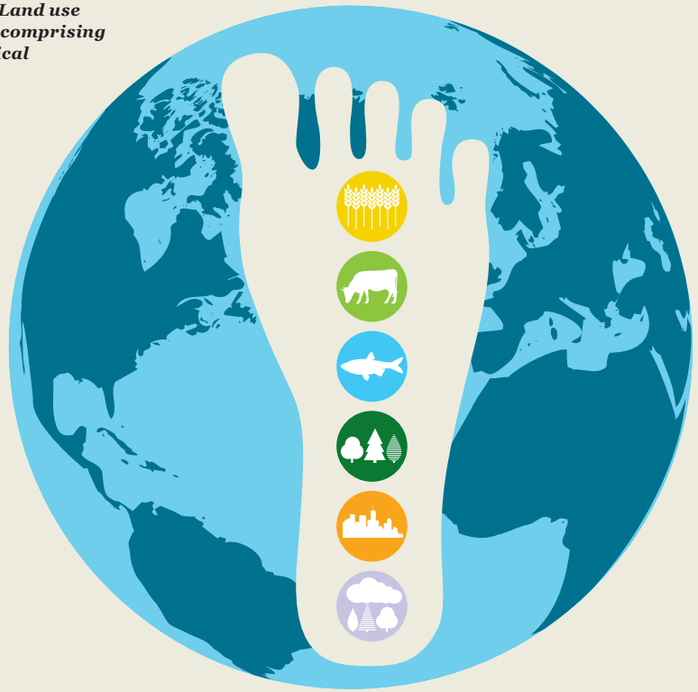
refers to the demand for biologically productive areas needed for infrastructure, including transportation, housing and industrial structures.



CARBON FOOTPRINT

refers to the demand for forests as the primary ecosystems available to long-term sequester carbon not otherwise absorbed by the oceans. It captures different rates of carbon sequestration depending on the degree of human management of forests and the type and age of forests, and includes the emissions related to forest wildfires, soil and harvested wood (see Mancini et al., 2016).

Figure 33: Land use categories comprising the Ecological Footprint



Biocapacity is a measure of the existing biologically productive area capable of regenerating natural resources in the form of food, fibre and timber, and of providing carbon dioxide sequestration. It is measured in relation to five categories of use: cropland, grazing land, fishing grounds, forest land, and built-up land. Together, these satisfy human demand in the six Footprint categories. This is because forest land satisfies two demand categories: forest products and carbon sequestration (Wackernagel et al., 2014; Mancini et al., 2016). Biocapacity can change from year to year due to climate, ecosystem management, changing soil conditions and agricultural inputs. Most of the biocapacity increase that the Earth has experienced in the last five decades comes from increasingly intensive agricultural practices.

Both Ecological Footprint and biocapacity are expressed in a productivity-adjusted hectare-equivalent unit called a **global hectare** (gha). One gha represents a biologically productive hectare with world-average productivity (Galli, 2015b). Conversion from actual land areas to global hectares is performed by means of yield factors and equivalence factors. Yield factors are country-specific and equivalence factors represent a global average, but both values vary by land use and by year (Borucke et al., 2013). By translating to global hectares, highly productive areas (like tropical forests) and low productivity areas (like alpine deserts) are normalized. According to these accounts, in 2012, the Earth's total biocapacity was 12.2 billion gha, or 1.7 gha per person, while humanity's Ecological Footprint was 20.1 billion gha, or 2.8 gha per person.

Mapping the Ecological Footprint of consumption

Average per capita Ecological Footprints vary among countries due to varying levels of total consumption, and also according to different relative demands for each Footprint component. They include the quantity of goods and services residents consume, natural resources used, and carbon generated to provide these goods and services. Figure 34 shows the average Ecological Footprint per person per country in 2012.

Among countries with highest per capita Ecological Footprints, the carbon Footprint component is particularly high due to both fossil fuels consumption and the use of energy-intensive goods. Per capita Ecological Footprints of several countries are as much as six times larger than the available per capita share of global biocapacity (1.7 gha). This implies that residents of these countries are placing disproportionate pressure on nature as they appropriate more than their fair share of the Earth's resources. At the other end of the scale, some of the world's lowest-income countries have per capita Ecological Footprints that are less than half the per capita biocapacity available globally, as many people in these countries struggle to meet basic needs.

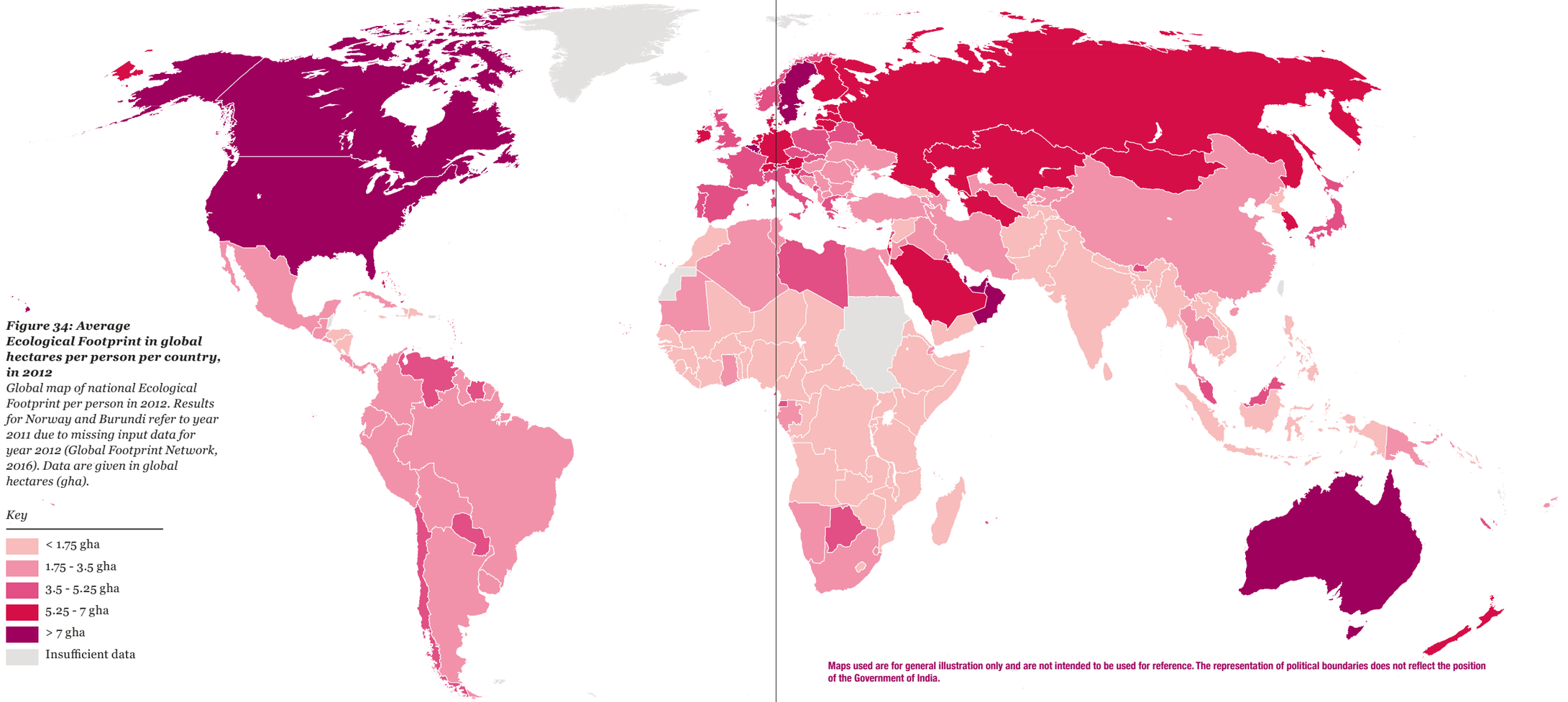


Figure 34: Average Ecological Footprint in global hectares per person per country, in 2012
Global map of national Ecological Footprint per person in 2012. Results for Norway and Burundi refer to year 2011 due to missing input data for year 2012 (Global Footprint Network, 2016). Data are given in global hectares (gha).

Maps used are for general illustration only and are not intended to be used for reference. The representation of political boundaries does not reflect the position of the Government of India.

The Ecological Footprint per income level

Grouping Ecological Footprints by national income level reveals the inequality in national demand for renewable resources and ecological services – as well as indicating how such inequality has changed over time (Figure 35). During the period 1961-2012, the average per capita Ecological Footprint increased from 5 gha to 6.2 gha, with a peak of 6.6 gha in 1985, in high-income countries; increased from 1.4 to 2.3 gha per capita in middle-income countries; and remained almost flat (at approximately 1 gha per capita) in low-income countries. The per capita Ecological Footprint for high-income countries in 2012 is lower than in 1985. Although there are quite some differences across this group of countries, the overall decline appears to be due to the effects of the economic crisis initiated in 2007-2008.

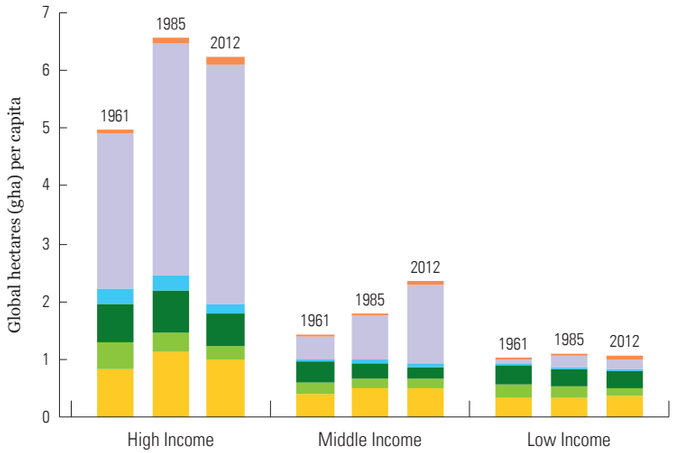


Figure 35: Per capita average Ecological Footprint for high-, middle- and low-income countries, by demand category, in 1961, 1985 and 2012
World countries are grouped in income groups according to relative GDP values in 2016. The World Bank classification is used here, grouping countries as 1) high income (per capita gross national income is equal toUS$10,066 per year or higher), 2) middle income (per capita gross national income is between US$826 and US$10,065) and 3) low income (per capita gross national income is below US$825). Data are given in global hectares (gha).

Moreover, Figure 35 seems to illustrate that, irrespective of the income level, countries are following – although at a different pace – a similar development pattern, characterized by a shift from agrarian (biomass-based) to industrialized (fossil-fuel-based) economies. In high-income countries, the carbon share of the Ecological Footprint grew, while its biomass-based share (i.e., the sum of cropland, grazing land, forest and fishing ground Footprints) decreased. The same patterns can be observed for middle-income countries. But in low-income countries, biomass-based components still represented the main Footprint share in 2012 although the underlying factors changed over time: the share of the cropland Footprint increased, while the share of forest and grazing land decreased. There was also an increase in the share of the carbon Footprint.

Patterns of consumption per income level

Not only does overall demand for biocapacity vary by country, patterns of consumption vary as well (Figure 36). In low-income countries like Tanzania, for example, 94 per cent of the Ecological Footprint is determined by food and housing demand. As disposable income rises, consumption increases beyond basic needs, and categories such as mobility, goods and services account for a larger share of the population's Ecological Footprint, as is the case for the USA.

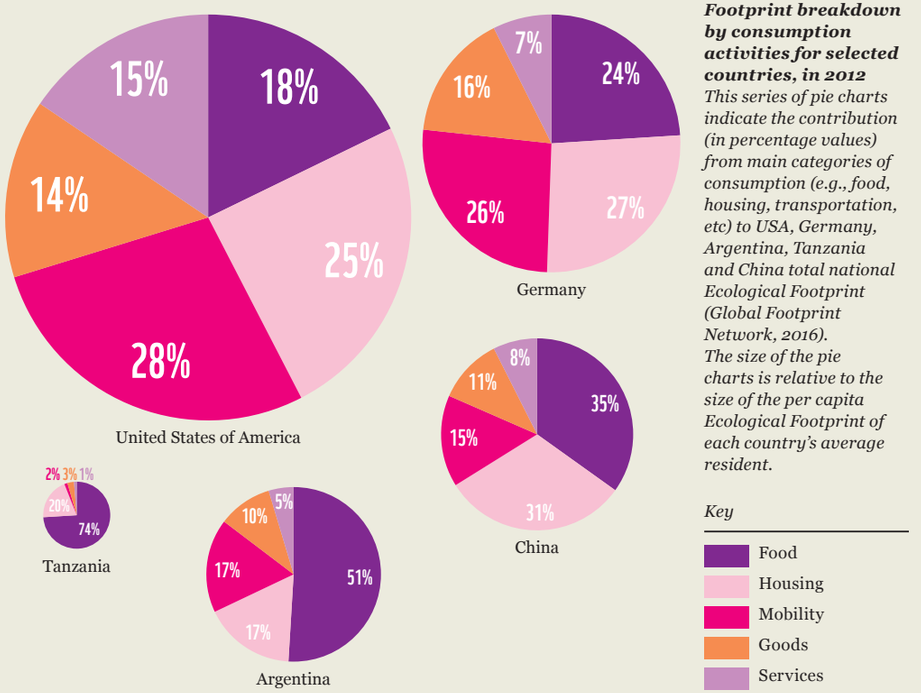


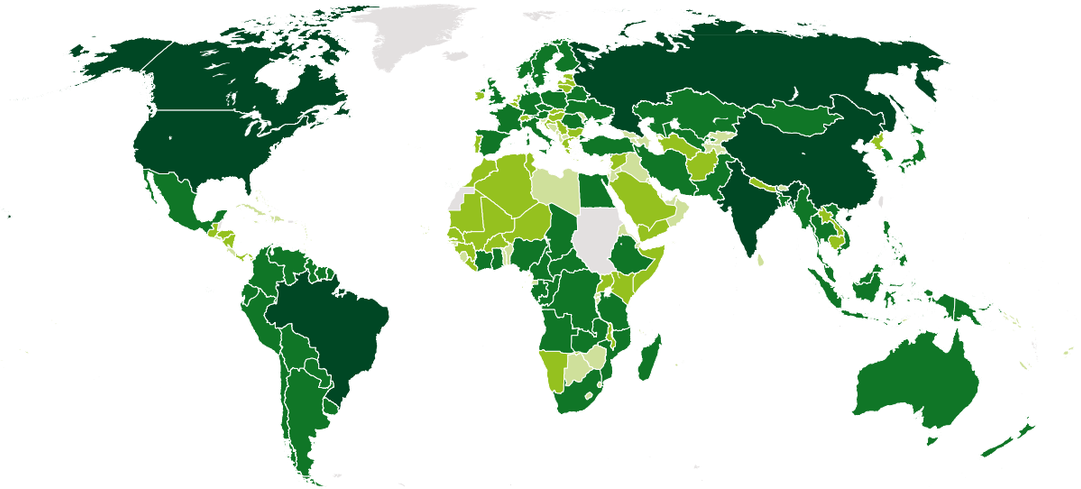
Figure 36: Ecological Footprint breakdown by consumption activities for selected countries, in 2012
This series of pie charts indicate the contribution (in percentage values) from main categories of consumption (e.g., food, housing, transportation, etc) to USA, Germany, Argentina, Tanzania and China total national Ecological Footprint (Global Footprint Network, 2016). The size of the pie charts is relative to the size of the per capita Ecological Footprint of each country's average resident.

Even among countries whose populations have similar Ecological Footprint levels, underlying consumption patterns may differ. China and Argentina, for example, have Ecological Footprints per capita of 3.4 gha and 3.1 gha, respectively. In Argentina, due to high levels of meat consumption, food accounts for slightly more than half of the total Footprint, while in China food only accounts for a third. Consumption related to housing, on the other hand, accounts for a far larger share of the Ecological Footprint in China than it does in Argentina. This is likely due to China's greater reliance on fossil fuels (e.g. coal) for heating (Chen et al., 2007; Hubacek et al., 2007). While both countries' populations place roughly equivalent pressures on the environment to fulfil their consumption, the consumption activities and therefore the drivers of demand vary greatly. Their respective Ecological Footprint profiles would steer policymakers wishing to address their countries' consumption of renewable resources and services toward different areas for interventions – food vs. housing, for instance.

Mapping biocapacity

Just as human demand on nature varies among countries, nature's capacity to provide goods and services, or biocapacity, is unevenly distributed (Figure 37). Brazil, China, the United States, Russia and India account for nearly half of the planet's total biocapacity. These few countries function as global biocapacity hubs as they are among the primary exporters of resources to the other countries. This results in great pressure on ecosystems in these countries, undoubtedly contributing to habitat loss. This is an example where pressure is driven by consumption activities in other, distant countries (Galli et al., 2014; Lazarus et al., 2015). To achieve global sustainability in the sense of living equitably within one planet will require that we recognize our societies' ecological interdependence and interconnectedness and become more receptive to global and interregional resource management agreements and policies (Kissinger et al., 2011; Rees, 2010).

Figure 37: Total Biocapacity per country, in 2012
Results for Norway and Burundi refer to year 2011 due to missing input data for year 2012 (Global Footprint Network, 2016). Data are given in global hectares (gha).



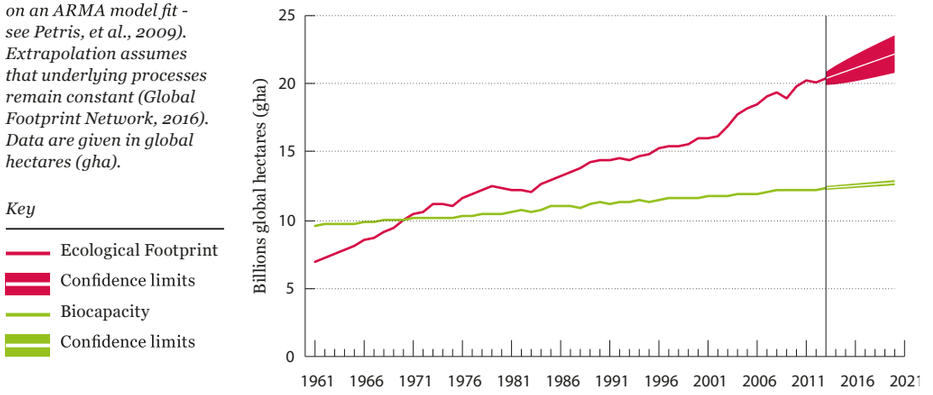
Maps used are for general illustration only and are not intended to be used for reference. The representation of political boundaries does not reflect the position of the Government of India.

Projecting the Ecological Footprint

Figure 38 shows the historical trends of humanity's Ecological Footprint and biocapacity, expressed in global hectares of bioproductive land respectively required and available, from 1961 to the latest calculated year (2012), as well as projected trends up to 2020. Since entering in a global overshoot situation in 1971, humanity's demand for the Earth's regenerative capacity has steadily increased.

Under a business-as-usual path for the underlying drivers of resource consumption, assuming current population and income trends remain constant, human demand on the Earth's regenerative capacity is projected to continue growing steadily and to exceed such capacity by about 75 per cent by 2020. Changing this course by design will require considerable shifts in technology, infrastructure and behaviour, in order to support less resource-intensive production and lifestyles (see for instance Moore et al., 2012).

Figure 38: Global Ecological Footprint trends for 1961-2012 and statistical extrapolation for 2013-2020
The red line represents humanity's Ecological Footprint while the green line represents the Earth's biocapacity. The shaded areas represent 95 per cent statistical confidence bounds for the modelled extrapolations (based on an ARMA model fit - see Petris, et al., 2009). Extrapolation assumes that underlying processes remain constant (Global Footprint Network, 2016). Data are given in global hectares (gha).



UNDER A BUSINESS-AS-USUAL PATH HUMAN DEMAND ON THE EARTH'S REGENERATIVE CAPACITY IS PROJECTED TO CONTINUE GROWING STEADILY AND TO EXCEED SUCH CAPACITY BY ABOUT 75 PER CENT BY 2020

Linking consumption to production: the case of soy

Footprint indicators – such as the Ecological Footprint – provide a picture of overall resource use. To look deeper into the nature of production-related impacts on the environment, it is necessary to obtain additional information on the location of production, production processes used, their reliance on external inputs (such as water and fertilizers) and so on (e.g. Croft et al., 2014; Van den Bergh and Grazi, 2014; 2015). Even moderate advances in disaggregating links between consumption and production have the potential to offer significant insights into supply chain dependencies and drivers of impact.

EXPANSION OF SOYBEAN PRODUCTION HAS BEEN ASSOCIATED WITH EXTENSIVE LAND-USE CHANGE AND DEFORESTATION IN BIOLOGICALLY-IMPORTANT HABITATS, SUCH AS THE BRAZILIAN CERRADO

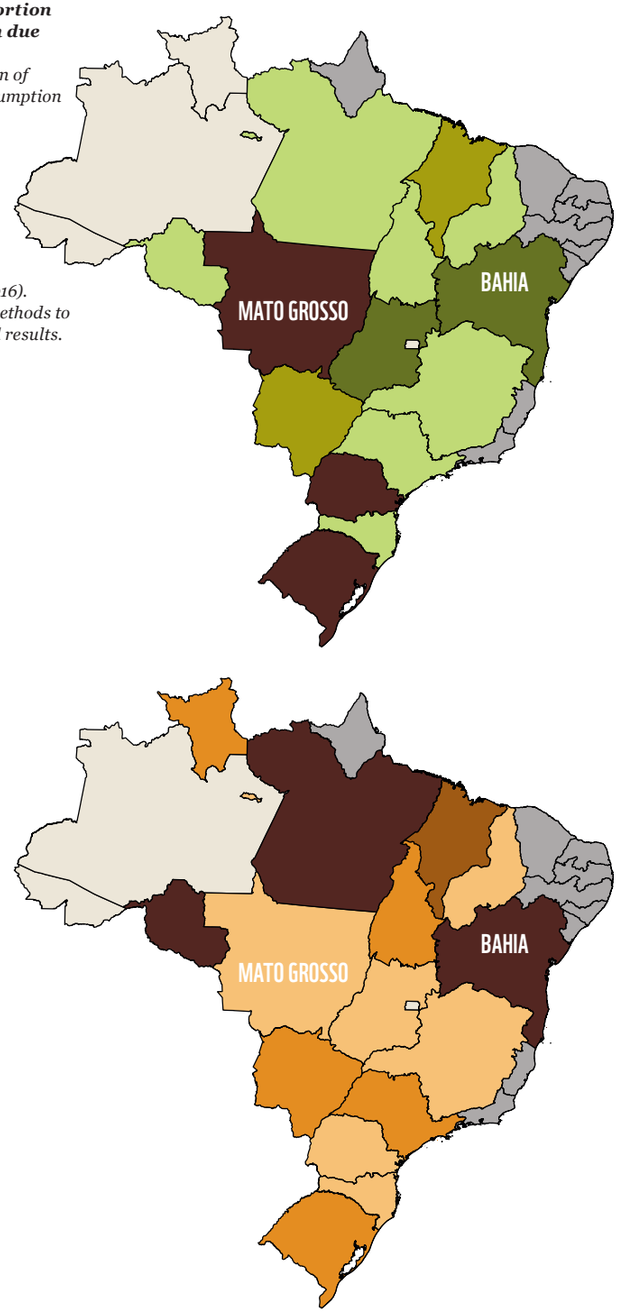
Global production of soybean has increased rapidly over the last half-century – reaching 278 million tonnes in 2013 according to FAO statistics (FAO, 2015). This increase is driven in significant part by growing demand for meat products, as one of the main uses of soybeans is as livestock feed. Expansion of soybean production has been associated with extensive land-use change and deforestation in biologically-important habitats, such as the Brazilian Cerrado (Gibbs et al., 2015).

Figure 39 quantifies Brazilian state-level production of soybean to fulfil demand for goods and services in the European Union – capturing important sources of demand such as use within animal feed. There are regional differences in production levels and production drivers. For example, Mato Grosso state in the centre-west of Brazil is the largest producer for EU consumption, but in the eastern state of Bahia – also a significant producer – a higher proportion of total production is destined for EU consumption. Both states contain important Cerrado habitat at risk from agricultural expansion.

Ongoing incorporation of fine-scale production data, such as municipality-level statistics (Godar et al. 2015), is increasing the spatial resolution of consumption-based approaches. Additionally, techniques are being developed to assess supply chain-driven impacts on biodiversity in key areas of conservation concern (e.g. Lenzen et al., 2012; Moran et al., 2016; Chaudhary and Kastner, 2016). In combination, these approaches have the potential to improve understanding of the cause-effect relationships between consumption activities and biodiversity loss. Alongside aggregate footprint indicators, they could represent a significant step forward in informing decision-makers and supporting their interventions to counter the negative impacts of consumption.

Figure 39: Brazilian state-level production of soybean and proportion of total state soybean production due to EU demand

a) 2011 Brazilian state-level production of soybean (tonnes) driven by EU28 consumption of goods and services, accounting for direct and embedded purchases.
b) Proportion of total state soybean production due to EU demand. National average is 0.21.
Source: West et al., 2013 and Godar et al., 2015; state-level production data sourced from Brazilian Institute of Geography and Statistics (IBGE, 2016).
Work is in progress to develop these methods to provide finer-scale, municipality-level results.



THE STORY OF SOY

4. Europe's livestock relies on soy from the Cerrado

Europe's intensive livestock sector relies on soy, most of it imported from South America, to meet demand for meat and dairy products. Demand for soy within the EU uses an area of 13 million hectares in South America, out of a total of 46 million hectares of soy production. This is equivalent to 90 per cent of Germany's entire agricultural area. The main European importers of soy are countries with large industrial-scale pig and chicken production. Under European agricultural policy, tariffs on animal feed are lower than for many other agricultural products, so soy meal is a relatively cheap import. European soybean imports also surged after the World Trade Organization was formed in 1995, removing many restrictions on international trade. European imports from South America may increase in the future. The increase in support for the production of biofuels is also a factor in soy imports into Europe as is the abandonment of local protein and legume production by European farmers.

(source: WWF-Brazil; WWF, 2014)



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CHAPTER 3:
EXPLORING ROOT CAUSES

TOWARD SYSTEMS THINKING

It is clear that we need to steer the course of socio-economic development onto a pathway that does not conflict with the welfare of people and the biosphere. But the increased risk associated with exceeding Planetary Boundaries, the upward trend in consumption footprints, and the continuous declining Living Planet Indices, signal that efforts directed at sustainability have been far from sufficient. So how can we begin to affect development in a way that will make essential changes at a relevant magnitude?

A prerequisite for affecting significant change in human systems is to understand the nature of the decision-making that results in environmental, social and ecological degradation. The industries, organizations and individuals who directly utilize natural resources, the end users of what is produced – as well as all the multiple entities in between – make choices based on a complex set of signals. They respond to market prices and other information to make decisions within the constraints of their physical, socio-economic and legal environments. These environments are themselves shaped by less apparent phenomena, including unsustainable consumption patterns, destructive production practices, malfunctioning governance structures, and financial systems that prioritize short-term returns (Macfadyen et al., 2015; Konefal et al., 2005; Dallas, 2012; Schor, 2005). All of these elements form a multi-level framework that shapes the behaviour of individuals, and vice versa. Trillions of decisions and actions take place within this systemic framework every day, resulting in both visible and invisible impacts on society and the Earth system.

A PREREQUISITE FOR AFFECTING SIGNIFICANT CHANGE IN HUMAN SYSTEMS IS TO UNDERSTAND THE NATURE OF THE DECISION-MAKING THAT RESULTS IN ENVIRONMENTAL, SOCIAL AND ECOLOGICAL DEGRADATION.

Problem-solving in a complex world

IN SPITE OF THE COMPLEXITY, WE OFTEN TURN TO SUPERFICIAL SOLUTIONS WHEN TRYING TO SOLVE COMPLEX PROBLEMS

In spite of the multi-layered complexity that defines the human experience, we often turn to superficial solutions when trying to solve complex problems (Hjorth and Bagheri, 2006). For example, say we are trying to solve a problem like traffic congestion. The initial response is likely to be to build more roads. Building new roads will possibly destroy habitats or lead to other impacts during construction, but the new roads will have a far less obvious effect; making driving more convenient attracts more people to driving, which will increase CO_2 emissions. More roads will also probably result in more loss of life since more cars means more accidents. Thus the resulting situation may even be worse than the original issue, while the rebound effect of increasing traffic flows may mean that congestion may not even be reduced in the long run.

FINDING SOLUTIONS REQUIRES A MUCH DEEPER UNDERSTANDING OF PRESSURES, DRIVERS, ROOT CAUSES AND THE BASIC DYNAMICS OF SYSTEMS

Instead, the envisioning of complex problems and implementation of solutions requires a much deeper understanding of pressures, drivers, root causes and the basic dynamics of systems. For the examples above perhaps we should be asking why so many people like or need to drive? How can we design cities so that driving is less necessary? What are the alternative forms of transportation that can be made more attractive and convenient? How can we get people to try these alternative forms of transport? System thinking can help us ask the right questions by examining complex problems layer by layer and then analysing the connections between these layers.

The four levels of thinking model

Systems thinking provides a set of conceptual and analytical methods used for modelling and decision-making. It represents a rigorous yet flexible way to facilitate thinking, visualizing, sharing, and communication of change in complex organisations and organizational decision-making over time (Wolstenholme 1997 in Cavana and Maani, 2000).

A common tool used in systems thinking is the “four levels of thinking” model. This model is designed to break a problem down into four levels so that we can more easily define the root causes and the basic dynamics of the system (Maani and Cavana, 2007). More specifically, the model teases out the hierarchical relationship between events or symptoms, patterns or behaviours, systemic structures, and mental models.

In Figure 40, events represent only the "tip of the iceberg" phenomena within a system. Because events are tangible or visible and immediate, most policy discussion and problem-solving interventions occur at this level. But when addressing events we are treating symptoms but not the source of the problem. By applying the four levels of thinking it becomes clear why tip-of-the-iceberg solutions may not have long-lasting effects. If the issue has deep roots within our socio-economic system, it will simply re-emerge at different times or in different places.

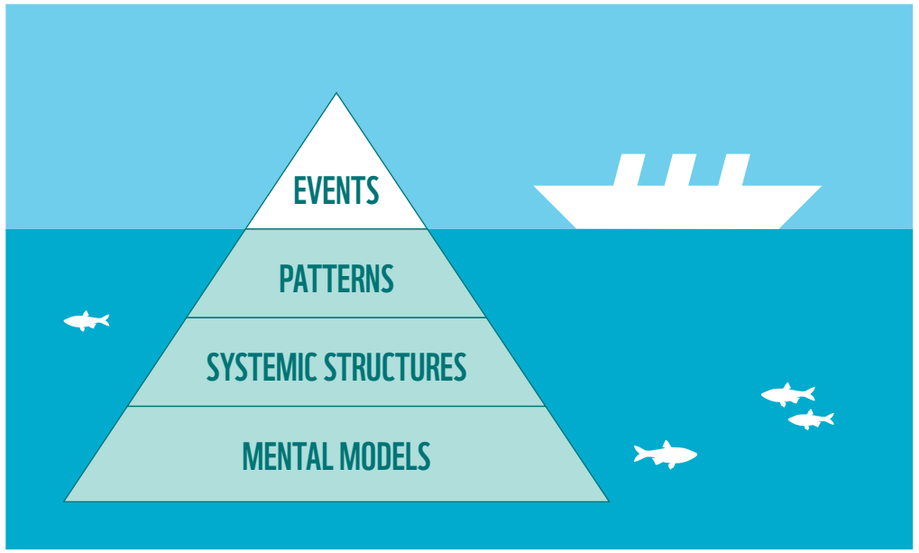


Figure 40: An illustration of the "four levels of thinking" model
showing that events or symptoms are only the tip of the iceberg in the overall dynamics of a system. Meanwhile the underlying determinants of the system's behaviour are less apparent. The deeper we go below the surface events, the closer we get toward "root causes". Adapted from Maani and Cavana (2007).

The second level of thinking concerns the patterns that emerge when a set of events repeatedly occurs to form recognizable behaviours or outcomes. Single events can range in magnitude from an individual choice about what to buy in the supermarket, to the periodic occurrence of a large hurricane. Only when these events are grouped together and arranged on a timeline can we see the bigger pattern forming from the choices of many individuals in the supermarket – or from the frequency, magnitude and locations of hurricanes. For instance, by grouping individual hurricane events over time, we have observed that large hurricanes (single events) have been increasing in both frequency and intensity, creating a detectable shift in weather patterns, due at least in part to climate change (Holland and Bruyere, 2014). Once we see a pattern or trend, we can extrapolate what future events might occur.

The third level of thinking uncovers systemic structures, which are the political, social, biophysical or economic structures that define the way different elements in the system can behave and interact. It is at this level that we truly begin to understand the causal relationships between events and various actors within the system. One of these systemic structures is the prevailing economic model. Our economy is the emergent result of our collective behaviour, beliefs and values.

The global economic growth generated through our current economic system has reduced poverty and given rise to significant improvements in standards of living (World Bank, 2013). However, this GDP-growth-focused economic model has led to severe wealth inequality as well as culturally entrenched aspirations for material consumption. It has encouraged growth well beyond our basic needs and beyond what can be supported by the carrying capacity of a single Earth (Hoekstra and Wiedmann, 2014).

At the fourth and deepest level of thinking are the mental models of individuals and organizations that reflect the beliefs, values and assumptions that we personally hold. They are often hidden beneath a surface of rationalization for acting in a particular way (Maani and Cavana, 2007). Mental models – which can vary across cultures – are rarely taken into account in decision-making (Nguyen and Bosch, 2013). However, belief systems – "we need to get richer in order to be happier", "people are poor because they don't try hard enough" – significantly affect all layers above. They influence the design of system structures, the guidelines and incentives that govern behaviours, and ultimately, the individual events that make up the flow of daily life.

After we have considered and analysed all four levels, we are in a position to identify points of leverage. For instance, individual consumers can change their purchasing behaviour, or people with greater political or economic influence can formulate strategies for policy change. Though more difficult, it is also possible to change the mental models upon which the structures, patterns and events are based. Certain types of activities will have greater impact and influence than others. To understand where each of us has the greatest leverage to lead toward a systemic transition in favour of sustainable development, it is important to recognize what elements we are working on within the complex system, and that we need to adjust our mental models for problem-solving. Only then can we effect genuine and lasting change.

ECOLOGICAL RESTORATION OF THE LOESS PLATEAU IN CHINA

China's Loess Plateau, the birthplace of the largest ethnic group on the planet, was once an abundant forest and grassland system. One of the central civilizations on Earth grew on the plateau while simultaneously reducing biodiversity, biomass and accumulated organic matter. Over time, the landscape lost its ability to absorb and retain moisture, causing an area the size of France to dry out. Without the constant nutrient recycling from decaying organic matter, the soil lost its fertility and was eroded away by the wind and water, leaving a vast barren landscape. By 1,000 years ago the site of the magnificent early dynasties in China had been abandoned by the wealthy and powerful. By the mid-1990s the plateau was mainly famous for the recurrent cycle of flooding, drought and famine known as "China's Sorrow".

Today, large areas of the Loess Plateau have been restored. The changes have been brought about by differentiating and designating ecological and economic land, terracing, sediment traps, check dams and other methods of infiltrating rainfall. At the same time, efforts have been made to increase biomass and organic material through massive planting of trees in the ecological land and using sustainable, climate-smart agricultural methods in the economic lands.

The crucial step toward restoration was the understanding that, in the long run, safeguarding ecosystem functions is vastly more valuable than the production and consumption of goods and services. It therefore made sense to designate as much of the land as possible as ecological land. This also led to a counter-intuitive outcome: concentrating investment and production in smaller areas was found to increase productivity. It's a clear illustration of how functional ecosystems are more productive than dysfunctional ones.

The work on China Loess Plateau shows that it is possible to restore large-scale degraded ecosystems. This helps us adapt to climate impacts, makes the land more resilient and increases productivity. The Loess Plateau also shows that valuing ecosystem function higher than production and consumption provides humanity with the logical framework to choose to make long-term investments and see the positive results of trans-generational thinking.

(Source: Liu, 2012; Liu & Bradley, 2016)



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SYSTEMS THINKING APPLIED TO THE FOOD SYSTEM

To understand how the four levels of thinking can be applied to solve complex problems, we take a closer look at the food system, one of the most complex sectors of the global economy. Food production is one of the primary causes of biodiversity loss through habitat degradation, overexploitation of species such as overfishing, pollution and soil loss (Rockström et al., 2009b; Godfray et al., 2010; Amundson et al., 2015). It is also a primary force behind the transgression of the Planetary Boundaries for nitrogen, phosphorus, climate change, biosphere integrity, land-system change and freshwater use (Rockström et al., 2009b). Even though its current environmental impacts are immense, the food system is expected to expand rapidly to keep up with projected increases in population, wealth and animal-protein consumption. It is reasonable to question whether this is possible without triggering an environmental and agricultural collapse (Searchinger et al., 2013). In the analysis below, the focus is on the agricultural production system as part of the food system.

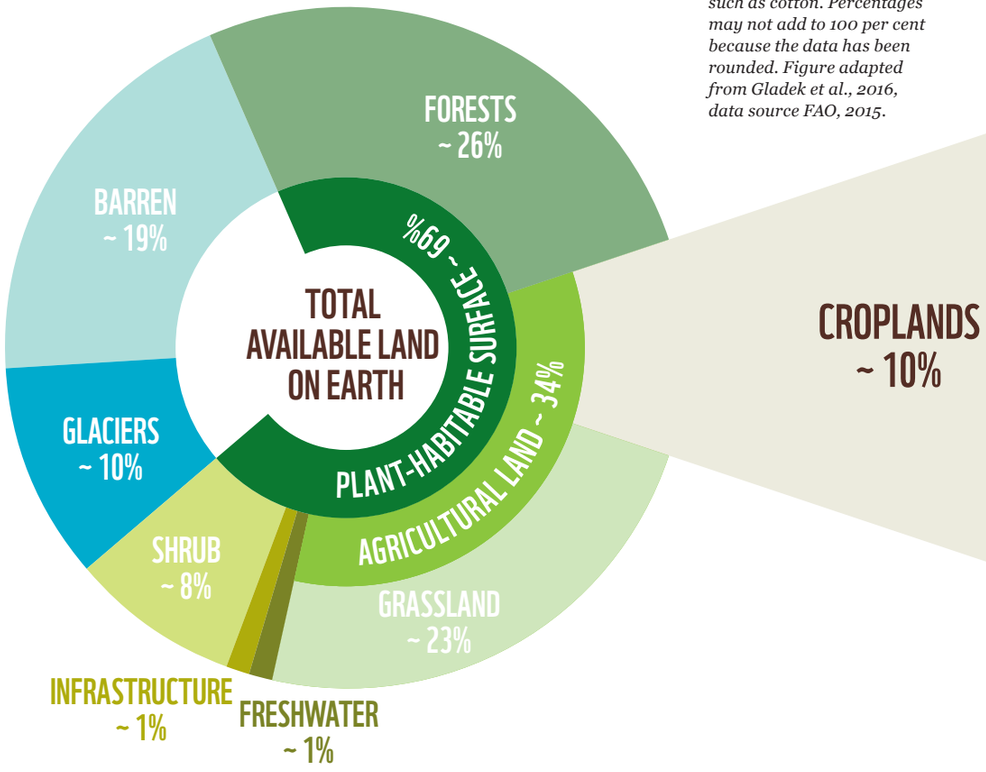


Figure 41: A breakdown of how global land is divided into basic functional categories and how arable land is specifically divided into different functions
In the graphic below, "food crops for industry" refers to food crops grown and used for industrial uses, as in the case of corn for biofuel production, whereas non-food crops include plants grown directly and exclusively for fibre, pharmaceuticals or fuel, such as cotton. Percentages may not add to 100 per cent because the data has been rounded. Figure adapted from Gladek et al., 2016, data source FAO, 2015.

Agricultural land mainly used for livestock production

Agriculture occupies about 34 per cent of the total land area on the planet and roughly half of the plant-habitable surface (Figure 41) (FAO, 2015). Agricultural production is estimated to account for 69 per cent of water withdrawals (FAO, 2016b). Together with the rest of the food system, agriculture is responsible for 25-30 per cent of greenhouse-gas emissions (IPCC, 2013; Tubiello et al., 2014).

From the 1.5 billion hectares of cropland globally, a third is used to produce animal feed (calculations based on FAO, 2015). An additional 3.4 billion hectares of grasslands are used as pasture for animals. A very large proportion of agricultural land, almost 80 per cent, is thus directly or indirectly allocated to livestock for the production of meat, dairy and other animal proteins (calculations based on FAO, 2015). Yet these land-based animal products provide only about 17 per cent of calories and 33 per cent of protein consumed by humans globally (calculations based on FAO, 2015).

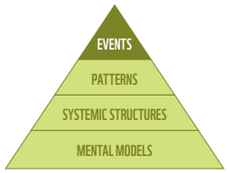
Even so, more than enough food is produced for today's global population (Gladek et al., 2016). Yet over 795 million people remain undernourished. In addition, many millions more suffer from chronic protein and micronutrient deficiencies, even though they may consume enough calories. On the other end of the spectrum, the number of overweight people reached 1.9 billion in 2014, with over 600 million obese (WHO, 2015). Furthermore, an estimated one third of food globally is wasted due to harvest loss, losses during storage and distribution, and discards of expired food by consumers – an enormous loss of financial, human and natural capital (FAO, 2013).

Four levels of thinking and the food system

Agricultural production in the food system is characterized by fundamental problems such as widespread hunger and poverty, concentration of power and lock-ins in trade, agricultural research and technology that reinforce the current unsustainable situation. Many of the problems emerge from complex interactions between people, policies and the environment, and can only be addressed by considering all the levels of the system: events, patterns, systemic structures and mental models. Applying the four levels of thinking model to the problem of poverty will show us both the depth of the problem and where the leverage points for change might lie.

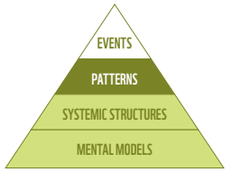


Level 1: Events – crop failures, famine, spike in food prices
Examples of food system events include crop failures, spikes in food prices, food safety crises and famine. When taking a closer look at a famine, we can see that hunger is often rooted in poverty. People living in poverty cannot afford to buy nutritious food for themselves and their families. This puts them at an extreme disadvantage, rendering them less able to earn the money that would help them escape poverty and hunger. This is not just a day-to-day or seasonal problem: when children are chronically malnourished, it can affect their future income, condemning them to a life of continued poverty and hunger leading to a so-called "poverty trap". Policy responses to hunger that only considered solutions at the level of events might involve simply providing food or monetary aid. However, the high incidence of hunger has much deeper roots that will cause poverty-related events to resurface in the future. The issue of famine and poverty is especially entwined with the global food system, as the world's lowest-income countries are those most dependent on agriculture as a primary source of livelihoods for large parts of their populations. The incidence of poverty among small- and medium-scale farmers is high (Carter and Barrett, 2006); in fact, the vast majority of the world's poorest people are farmers (UNCTAD, 2013).



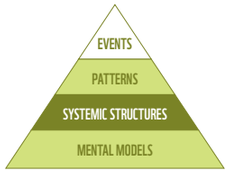
MANY OF THE TRENDS WITHIN THE FOOD SYSTEM ARE FORMED BY CHOICES WE MAKE ABOUT WHAT FOOD TO CONSUME

Level 2: Patterns – land degradation, levels of fertilizer consumption, meat consumption trends
Many of the patterns or trends within the food system are formed by choices we make about what food to consume. In their turn, these patterns shape global agricultural practices. Expansion of soy production as feed for livestock to meet the increased demand for meat and dairy, and rising levels of fertilizer consumption, are examples of patterns resulting from demand. Equally important, supply patterns, which include food availability, prices and marketing, have a very strong influence on what people choose to consume.



These daily market interactions between producers and consumers give the food system its current form.

Take the example of poverty and hunger among small-scale farmers. At this level we could identify a pattern of many small-scale farmers without access to sufficient resources such as seeds, tools, water or knowledge. These farmers are unable to improve their agricultural production techniques to provide for their families (Tittonell and Giller, 2013). And as soil without the right resources becomes increasingly nutrient-depleted and eroded, it becomes more difficult to rehabilitate. Eventually, its quality is so poor that production must either shift to new land, or demand for imported food increases (Vanlauwe et al., 2015). As such, poverty is one of the main drivers of the low yields and unsustainable agricultural practices that are leading to widespread land degradation, crop failures and biodiversity loss.



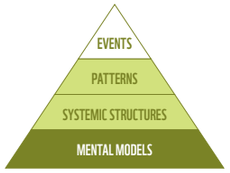
THE CURRENT FOOD SYSTEM PRIVILEGES A SELECT FEW, WHILE MARGINALIZING A VAST NUMBER OF OTHERS AND SEVERELY DAMAGING NATURE AND ECOSYSTEMS.

Level 3: Systemic structures – agricultural subsidies, trade agreements, commodity markets
Influential structures in the food system include agricultural policies (including subsidies), cultural dietary practices, commodity markets and biophysical limitations. These underlying structures and processes keep the food system more or less fixed in place. Taking the example of hunger and poverty, the increased dependence on unsustainable industrial farming techniques is often reinforced by governing structures. Desiring to serve the needs of their impoverished populations, many governments encourage the exploitation of natural resources or the development of lands for the production of cash crops for export, at the expense of local food security (Matondi et al., 2011). In countries across the globe, export commodities have developed into an essential source of income, employment and government revenues. This orientation of agriculture toward global markets has also resulted in risks by exposing economies to price shocks and "commodity-induced poverty traps" (IPES-Food, 2016).

While drivers and root causes are specific per region, they can be aggregated into broad and recurring categories. What emerges is a dominant model of food production and provisioning that privileges a select few, while marginalizing a vast number of other actors, and severely damaging nature and ecosystems (Gladek et al., 2016). For instance, structures supporting the above-mentioned poverty trap include educational systems, trade policies and price structures. Creating solutions at this level would lead to more significant results than addressing trends in production techniques or simply providing food aid.

Level 4: Mental models – higher economic status triggers higher levels of consumption

There are certain belief systems, or paradigms, that drive unsustainable patterns of consumption and production, resulting in a host of social and environmental problems. For example, in many parts of the world consumers associate a high level of meat consumption with wealth. Therefore, as wealth increases, so does meat consumption, along with the demand for resources required to produce it – often at the cost of food that can be directly consumed by humans. Another paradigm is that the supply of natural resources is unlimited and that ecosystem benefits such as clean water or air do not figure into cost-benefit accounting. This way of thinking underlies the depletion or degradation of many natural resources.



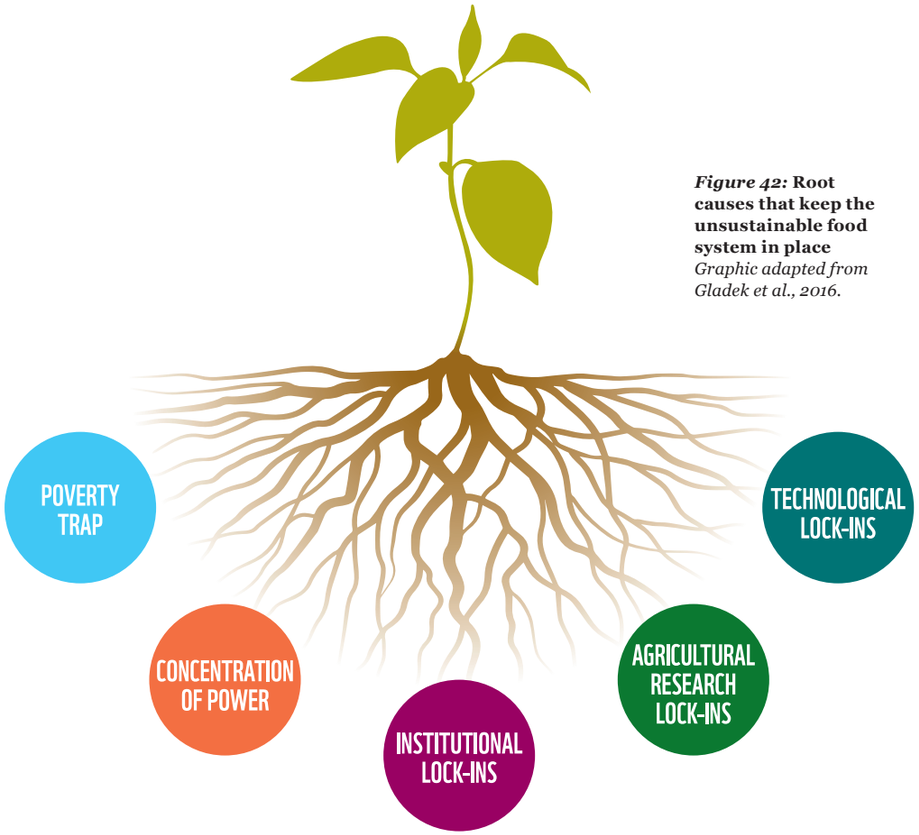


Figure 42: **Root causes that keep the unsustainable food system in place**
Graphic adapted from Gladek et al., 2016.

What is keeping the unsustainable food system in place?

Many of the patterns, systemic structures and mental models that shape the current food system will prevent us from enjoying a viable food system in the future. This system has already helped usher the Earth into the Anthropocene. Continuing without significant change will lead to further, untenable transgressions of Planetary Boundaries and diminish the very resources on which the food system is based. New models of both production and consumption are needed to form a sustainable, resilient food system that can absorb and recover quickly from shocks, while continuously providing food to many more people (Macfadyen et al., 2015). However, this will require a weakening of the feedback loops or "lock-ins" that reinforce the current system. The poverty trap in which many small farmers are caught is one such example; some other key lock-ins are presented below.

Concentration of power

Liberal economic policies, such as the removal of agricultural trade barriers and corporate deregulation, have facilitated the restructuring of power and wealth within the global food system (Food & Water Watch, 2013). Trade liberalization often limits diversification of crops and locks countries into unsustainable development patterns. It increases the vulnerability of developing countries by weakening the position of local agricultural producers and increasing dependency on international trade. Trade liberalization also tends to reshape supply chains in favour of transnational corporations. Corporate power is strengthened while state power to regulate is curtailed. The consequences are not solely economic: international trade in agricultural commodities has had a profound negative effect on the environment, and on healthy nutrition (De Schutter, 2009).

75 PER CENT OF THE WORLD'S FOOD IS GENERATED FROM ONLY 12 PLANTS AND FIVE ANIMAL SPECIES

Mega companies affect biodiversity in a number of ways. Firstly, the sheer scale of their operations translates into massive land-use intensification and land conversion, which results in habitat loss (German et al., 2011). Secondly, local agrobiodiversity is usually reduced to just a few crops, resulting in a dramatic loss of genetic diversity (Gladek et al., 2016; FAO, 2011b). Nowadays 75 per cent of the world's food is generated from only 12 plants and five animal species (FAO, 2004). Finally, large-scale monoculture operations rely on high volumes of chemical inputs that impact wild species and habitat either directly or indirectly through pollution to land or water (Matson et al., 1997).

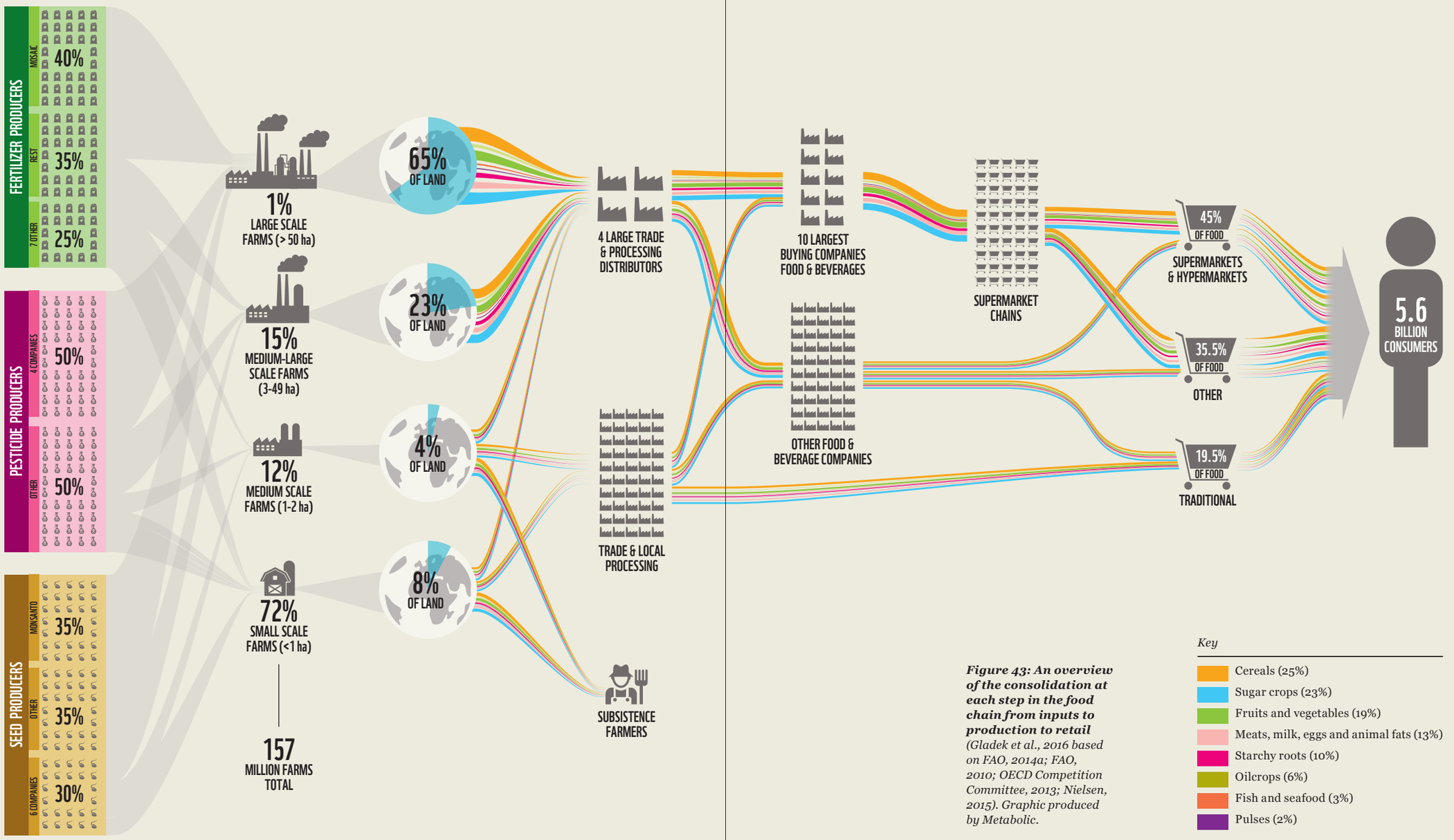


Figure 43: An overview of the consolidation at each step in the food chain from inputs to production to retail *(Gladek et al., 2016 based on FAO, 2014a; FAO, 2010; OECD Competition Committee, 2013; Nielsen, 2015). Graphic produced by Metabolic.*

In addition to strengthening inequalities, power dynamics contribute to a fundamental systemic fragility. If just a couple of companies within the agri-food supply chain were to fail, the food system would suffer major disruptions. These concentrated supply chains also support lock-ins in terms of technology, production practices, research and education, and create a climate of unbalanced influence in political lobbying.

CONCENTRATION OF POWER

Meanwhile, deregulation means a few transnational corporations such as big food traders, producers and retailers increasingly direct what and how food is produced across the globe. Figure 43 illustrates this highly consolidated food chain. In the farming sector, 1 per cent of farms now control 65 per cent of agricultural land (FAO, 2014). These large farms dominate production methods in the market (FAO, 2014). Large-scale farmers and landowners often have a dominant political and economic role, and are able to maintain their positions of power and privilege, leaving small farmers at a disadvantage (Piketty, 2014). Similarly, powerful groups of crop breeders, pesticide and fertilizer manufacturers, grain traders and supermarket retailers encourage food systems in which uniform crop commodities can be produced and traded on a massive scale (IPES-Food, 2016).

In spite of all the drawbacks, there are some benefits resulting from consolidated, large-scale operations. These include often more efficient resource use, and the ability of large organizations to leverage change. Concentration of power, when wielded responsibly, can also bring positive change (Stephan et al., 2016): companies with significant market share are able to single-handedly create new standards and put pressure on their supply chains to innovate toward, for example, emissions reductions.

INSTITUTIONAL LOCK-INS

Institutional lock-ins in trade

Developed countries and emerging economies use a number of tools to protect their markets, such as export tariffs, fiscal barriers, trade quotas, export subsidies and monetary policy instruments, among others (Serpukhov, 2013). Subsidies represent 22 per cent of farm receipts in OECD countries (OECD, 2010). These allow farmers to buy fossil fuels, water and fertilizers at reduced costs, leading to further market distortions, and further entrenching production techniques that harm the environment (Anderson et al., 2013). Because these techniques rely heavily on automation (and its associated fuel use) as well as fossil-fuel derived chemicals (fertilizers, pesticides), the agricultural system is now more tightly bound than ever to the volatility of the fossil-fuel market. This results in a feedback loop or lock-in effect that undermines the structural resilience of the food system (Pfeiffer, 2006).

AGRICULTURAL RESEARCH LOCK-INS

Agricultural research lock-ins

The “green revolution” played an important role in establishing intensive agricultural production methods globally and helping to avert anticipated large-scale food shortages following the Second World War. However, some of these methods have been criticized for driving ecological degradation, for example through soil erosion, water, air and soil pollution from fertilizers and pesticides, and increased use of non-renewable resources like fossil fuels (Pfeiffer, 2006). Regardless, from 1960 to 2000, 70 per cent of the total increase in global crop production in developing nations could be traced to agricultural intensification (FAO, 2003).

Continued emphasis on intensification and consolidation in the global agricultural system can partially be attributed to the structure of global agricultural research and development funding. Agricultural research and development still reinforces unsustainable and environmentally destructive industrial practices, even those that are associated with the greatest negative environmental impacts. Research sponsors still emphasize yield gains through the application of synthetic inputs such as chemical fertilizers, and often focus on maximizing yields in the near term at the expense of productive capacity in the future (Tilman et al., 2002; Deguines et al., 2014). The criteria against which farming is typically measured – e.g. yields of specific crops, productivity per worker – tend to favour large-scale industrial monocultures (IPES-Food, 2016). Consequently research supports yield maximization, even though such production systems rarely result in a maximum profit for farmers (Vanloqueren and Barrett, 2008) and almost never in healthy, sustainable environments.

TECHNOLOGICAL LOCK-INS

Technological lock-ins

Despite a wide variety of production methods, technological lock-ins explain why the input-intensive model of production is so dominant today. Industrial agriculture requires significant upfront investment, which usually requires farmers to scale up production (IPES-Food, 2016). Furthermore, technological innovations have generally favoured large-scale producers due to their capital- and resource-intensive nature. Once these investments and structural shifts have been made, it is increasingly difficult for farmers to change course. For example, when farmers invest in expensive equipment, like machinery for monoculture crop production, it is difficult for them to switch to a different system of production until the equipment is paid off. And the use of alternatives may not yield enough short-term benefits to be considered viable (IPES-Food, 2016).

THE STORY OF SOY

5. healthy and sustainable diets reduce the pressure on nature

Increasing meat consumption is the main driver behind soy's rapid expansion. Around 75 per cent of soy worldwide, and 93 per cent in Europe, is used for animal feed. Most people consume far more soy than they think: while many people imagine soy is eaten mainly by vegetarians, the average European consumes 61kg of soy per year, most of it indirectly in the form of animal products like chicken, pork, beef and farmed fish as well as eggs, milk, cheese and yogurt. If high-income countries adopted a healthy, balanced diet, bringing animal protein consumption in line with nutritionists' recommendations, it could reduce the pressure on natural ecosystems as well as benefiting people's health. This transition should start immediately – but in the short term, switching to deforestation-free and conversion-free soy is vital. Consumers of all food products using soy have the future of forests, savannahs and grasslands at the point of their fork.

(source: WWF Brazil; WWF, 2014; WWF, 2016a)



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CHAPTER 4: A RESILIENT PLANET FOR NATURE AND PEOPLE

THE DUAL CHALLENGE OF SUSTAINABLE DEVELOPMENT

The 21st century presents humanity with a dual challenge: to maintain nature in all of its many forms and functions and to create an equitable home for people on a finite planet. This dual challenge is outlined in the UN 2030 Agenda for Sustainable Development. The goals for sustainable development combine the economic, social and ecological dimensions necessary to sustain human society through the Anthropocene (Figure 44). These dimensions are all interconnected and must therefore be addressed in an integrated manner. We must minimize climate change while securing our future freshwater supply; and we should protect forests and grasslands as well as our oceans and atmosphere. Modification of any of these interconnected facets of the biosphere can affect the others, thereby altering the biosphere as a whole. For example, the use of biofuels to reduce CO_2 emissions can have adverse effects on food availability and the environment if biofuel crops compete for land, water and other resources. An integrated approach for managing our biosphere will improve social stability, economic prosperity and individual well-being. We are not going to develop a just and prosperous future, nor defeat poverty and improve health, in a weakened or destroyed natural environment.

THE GOALS FOR SUSTAINABLE DEVELOPMENT COMBINE THE ECONOMIC, SOCIAL AND ECOLOGICAL DIMENSIONS NECESSARY TO SUSTAIN HUMAN SOCIETY THROUGH THE ANTHROPOCENE

The analyses presented in this report suggest that if current trends continue, the UN Global Goals for Sustainable Development will be increasingly difficult to meet. Indeed we are already off track for reaching the UN biodiversity targets that aim to halt the loss of biodiversity by 2020. In the future, a basic fact must therefore inform development strategies, economic models, business models and lifestyle choices: we have only one planet and its natural capital is limited.

Figure 44: The UN Global Goals for Sustainable Development *(UN, 2015).*





Figure 45: WWF One Planet Perspective
The better choices outlined in the figure lead to ecosystem integrity, biodiversity conservation and food, water and energy security.

The WWF "One Planet Perspective"

The WWF One Planet Perspective outlines better choices for using, sharing and managing natural resources within the Earth's ecological boundaries and thus will help nations meet their Sustainable Development Goal commitments (Figure 45). It helps to align individual initiative, corporate action and government policy in order to attain a sustainable global society. When applied to business, "One Planet Thinking" encourages companies to align their activities so that they are actively contributing to a healthy and resilient planet for future generations (Kerkhof et al., 2015; Cranston et al., 2015).

Minor changes to improve efficiency in resource use or reduce pollution through end-of-pipe solutions will simply not bring about badly needed change. Instead, we must adopt an entirely new perspective that will guide decision making at all levels. The goal of making better choices is to create a situation where food, energy and water is available to all, biodiversity is maintained, and ecosystem integrity and resilience are ensured. Resilient ecosystems are able to absorb and recover from shocks and disturbances, maintain functionality and service by adapting to disruptions, and transform when necessary.

Toward sustainable development

How do we define what constitutes a better choice? As explained in the previous chapter, systems thinking can help us understand the underlying causes of unsustainable development. Once the patterns, systemic structures and mental models that shape the destructive aspects of the human enterprise are identified and analysed, leverage points are easier to perceive. Leverage points are those places in a system where a given amount of change can result in the largest possible impact. Common leverage points for sustainability include government and corporate planning efforts, technological innovation, trade agreement negotiations, and the influence of large social organizations.

Leverage points and corresponding strategies are meant to trigger a transition. A relatively smooth and successful transition often involves a dual process. The old system structures, attitudes and behaviours are gradually improved; simultaneously, radical innovations are introduced that will eventually transform the system in a fundamental way (Kemp and Rotmans, 2005; Kemp et al., 2007). Incremental improvements within the confines of the old system maintain and improve functionality during the time it takes for new system innovations to take effect (Kemp and Rotmans, 2005). For example, developing techniques within the current energy system that improve efficiency of cars and other appliances can contribute substantially to the reduction of carbon emissions, especially in the short term. But if the use of these appliances and cars increases, so do overall emissions. Only the transition toward 100 per cent sustainable and renewable energy sources will assure a real future-proof solution. Examples of such solutions might be the further development, production and large-scale adoption of the electric car or the development and wide implementation of alternative green transport systems.

TRANSITIONING THE GLOBAL ECONOMIC SYSTEM

"What we measure informs what we do. And if we are measuring the wrong thing, we are going to do the wrong thing"

Joseph Stiglitz, Nobel Prize-winning economist at the World Economic Forum in Davos (2016) pointing out the shortcomings of GDP as indicator of progress.

Ideally, changing the global economic system would entail a transformation in which human development is decoupled from environmental degradation and social exclusion. For this to occur, a number of significant changes – both incremental and radical – would need to take place in the areas of natural capital protection, governance, financial flows, markets, and the energy and food systems.

TO PRESERVE NATURAL CAPITAL, RESOURCES NEED TO BE USED SUSTAINABLY, AND THE GLOBAL NETWORK OF PROTECTED AREAS NEEDS TO BE EXPANDED.

Protecting natural capital

Earth's species and habitats have their own intrinsic value, but they also form the foundation of human societies and economies. Efforts must particularly focus on protecting and restoring key ecological processes necessary for food, water and energy security, as well as climate change resilience and adaptation. To adequately protect natural capital, resources need to be used sustainably, and the global network of protected areas needs to be expanded. Adequate funding mechanisms are needed if protected area management is to be effective.

Achieving Zero Net Deforestation and Degradation

The full value of forests will only be realized if deforestation and forest degradation is stopped. Zero net deforestation leaves some room for change in the configuration of the land-use mosaic, provided the net quantity, quality and carbon density of forests is maintained. Avoiding forest degradation is equally important for reducing carbon emissions, preserving biodiversity, and maintaining critical services for people, particularly, local communities and indigenous groups. Zero Net Deforestation and Degradation (ZNDD) will require a mosaic of protected and sustainably managed forests, integrated with other land uses such as farms, settlements and infrastructure. Strategies and policy changes by governments and industry are needed to:



prevent forest loss and degradation through good governance and control of outside pressures that lead to forest loss and degradation; protect and restore the most ecologically valuable forests; introduce incentives for sound stewardship of production forests; increase efficiency of wood use; reduce waste of farm and forest products; and optimize alternative land uses that will ease the pressure to clear more forest land.



Encouraging strategic river basin management

Societies throughout history have gone to great lengths to exploit river resources by building dams, diverting water to irrigate agricultural land and using rivers as sewers of first resort. Such approaches have certainly brought some social and economic benefits. But they have also fragmented rivers, interrupted the seasonal flows of water and caused massive pollution. Unfortunately, rivers have typically been managed in a piecemeal fashion with insufficient consideration of the cumulative impacts of development. A strategic, basin-level approach to management by governments, communities and businesses can optimize the balance between water resources development and maintenance of critical ecosystem functions. It can also help to minimize costly restoration activities in the future.



Expansion of marine protected areas

Marine natural capital should be built into national accounting, and the importance of ecosystem services and natural assets should be considered in key decisions that affect the marine environment. Marine protected areas are important for conserving and replenishing the oceans' natural capital and build resilience of marine ecosystems. To date, only 3.9 per cent of total ocean area is under some form of protection (Boonzaier & Pauly, 2016): concerted action is needed to reach the 2020 UN biodiversity target to protect at least 10 per cent of coastal and marine areas. Governments, businesses and local communities around the world can all contribute to establish effectively and equitably managed, ecologically representative and well-connected networks of marine protected areas.

Equitable resource governance



Legal and policy frameworks should support equitable access to food, water and energy, and stimulate inclusive processes for sustainably managed land and sea use. This will require an evolved definition of well-being and success that considers personal, societal and environmental health. It will also necessitate decision-making that respects future generations and the value of nature.

An inclusive definition of economic success
Taking full account of the impact of human activities will require fundamental changes to the way we value economic success and how we perceive well-being and prosperity. A high or increased GDP is the goal for most governments. But GDP represents only the monetary value of all the finished goods and services produced within a country's borders in a specific time period. Today's overemphasis on GDP needs to be replaced by goals and associated indicators that combine economic performance with ecological and social aspirations. For example, a measure of the inventory and regenerative capacity of natural capital within a country can be an equally valid way to assess long-term economic performance and future prospects.

WE NEED TO MAKE FUNDAMENTAL CHANGES TO THE WAY WE VALUE ECONOMIC SUCCESS AND HOW WE PERCEIVE WELL-BEING AND PROSPERITY

Future generations decision-making
Policymakers should take account of long-term sustainability and resilience. At present, many governments still focus on relatively short-term time horizons when developing policy. In doing so they fail to take account of medium- to long-term risks associated with environmental degradation such as soil erosion, freshwater shortages, pollution and waste; and exhaustion of natural resources. Fixed-term electoral cycles compound this problem, by encouraging individual politicians and party campaigns to focus on policies that will promote benefits within this short timeframe. The creation of legislation that will embed longer-term horizons into policymaking, beyond any one government's tenure, could help to overcome the dominance of temporary solutions and near-sighted policies.



Valuing nature in economic and policy decisions
The value of nature can be incorporated into many kinds of decision making, but especially those concerning development strategies, infrastructure and the use of land, water and other natural assets. Despite the considerable ecological and social costs of unsustainable production and consumption, factoring these into cost-benefit accounting is still rare. However, some decision-makers are beginning to incorporate the value of nature and its services, recognizing that not to do so will ultimately undermine society's well-being. Countries such as Botswana, Colombia, Costa Rica, Indonesia, Madagascar and the Philippines are already developing natural capital accounts that measure the state of their natural assets over time (World Bank, 2015). Greater emphasis on land-use planning will enable governments to better understand and manage competing, ever-increasing demands on land and water resources. This is illustrated in the recent history of the area around Lake Navaisha, Kenya's second largest freshwater body (see box).



Resilient landscapes for nature and people: the case of Lake Naivasha

An integrated landscape approach can help to reconcile the sometimes-competing objectives of economic development and environmental sustainability. This is illustrated by the story of Lake Naivasha. The lake is Kenya's second largest freshwater body and supports a large horticulture industry, representing about 70 per cent of Kenya's cut-flower exports and 2-3 per cent of the country's GDP. The lake supports a fishing industry, a growing tourism and holiday homes sector, as well as dairy and beef industries. Geothermal energy production has grown rapidly and contributes 280 MW to the country's energy grid (Denier et al., 2015). The lake's catchment area is predominantly devoted to smallholder agriculture that collectively produces large quantities of fresh produce for local Kenyan markets. The human population of the basin has grown rapidly, with 650,000 people in 2009, and a current estimated growth rate of 13 per cent throughout the current decade (Pegram, 2011). The basin is recognized for its rich biodiversity evidenced by a Ramsar site, an International Bird Area, a key water tower and a national park.

The diversity of stakeholders, ecological zones and economic activities and the interconnectivity of the upper and lower catchment areas make this relatively small basin (3,400km2) prone to conflicts over natural resource access and quality. A severe drought in 2009 was a wake-up call to develop an integrated approach to natural resource management (Denier et al., 2015). Formerly antagonistic stakeholders came together to develop a common vision for the Lake Naivasha basin, and this process was supported by political commitment (Kissinger, 2014). This led to the formation of the Imarisha Lake Naivasha Management Board, a public-private partnership, in 2011.

Together the stakeholders have implemented a number of critical measures under the multi-partner Integrated Water Resources Action Plan (Denier et al., 2015). They piloted a payment for environmental services scheme in which stakeholders in the lower reaches of the catchments offer small incentive payments to upstream smallholders for carrying out good land-use practices. In 2012, 785 farmers were involved in this scheme (Bymolt and Delnoyne, 2012). The stakeholders also developed and agreed to a water allocation plan for the basin that will take effect during times of increased water stress. (Denier et al., 2015).

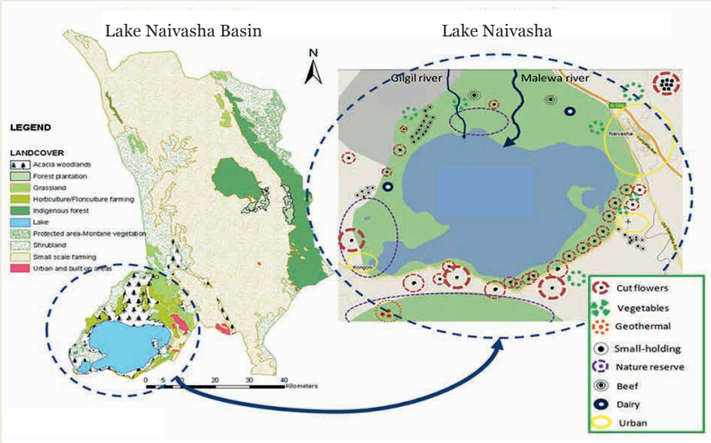


Figure 46: Land use in the Naivasha Basin *(WWF, 2011)*

Redirecting financial flows

Sustainable financial flows that support conservation and sustainable ecosystem management are an essential enabling condition for both preserving natural capital and promoting resilient and sustainable markets. Still, many financial institutions continue to invest substantially in harmful and unsustainable activities such as coal mining, environmentally damaging agriculture and oil drilling.



Long-term perspective on financial risks

Recognizing the interdependence of human demands for food, water, energy and environment, and our reliance on the Earth's core physical and natural systems, is a holistic and powerful vehicle for analysing business and policy problems (Reynolds & Cranston, 2014). There are two reasons why businesses should be interested in the food-water-energy-environment nexus. Firstly, financial stability will be improved by avoiding the cost implications of resource scarcity and environmental damage such as floods, storms and drought. Secondly, businesses want to avoid the cost burden of future regulation in markets that begin to regulate in reaction to environmental decline or to reputational disasters. One way for public policy and regulations to bring this about is to ensure that externalities are included on balance sheets (Reynolds & Cranston, 2014).

Currently financial markets focus on short-term income and reduction of immediate risk when making investment decisions. There is little private sector incentive to consider long-term risks from environmental degradation or declining opportunities from investment. Instead many continue to invest in economic activities that result in environmental damage. Somewhat perversely, they can record incrementally less damaging activities as progress (Reynolds & Cranston, 2014). Changes to financial sector regulation could address this by requiring financial institutions to report on sustainability impacts. Then the private sector would be compelled to scrutinize the sustainability of their business operations, as it would affect their ability to access capital. An even more effective leverage point might be the mental models of investors – that is, all individuals who hold any form of financial asset, as well as institutions such as pension funds, insurance companies and sovereign wealth funds. If investors were concerned enough about environmental performance – and understood the importance of their own role in safeguarding natural capital – they would monitor performance and hold financial institutions to account.

THERE IS STILL LITTLE PRIVATE SECTOR INCENTIVE TO CONSIDER LONG-TERM RISKS FROM ENVIRONMENTAL DEGRADATION OR DECLINING OPPORTUNITIES FROM INVESTMENT

Resilient markets for production and consumption

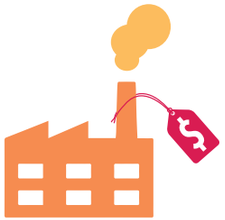
Producing better and consuming more wisely are key to establishing resilient markets that stay within our planet's safe operating space, safeguard our natural wealth, and contribute to our economic and social well-being. Sustainable resource management and incorporation of the true costs of production in the value chain will encourage these better choices.



Sustainable resource management

An economy in which resources are kept in use for as long as possible and in which products and materials are recovered and regenerated at the end of their life is a way to decouple economic development from environmental degradation. Equally, a shift away from dependence on fossil-based resources toward sustainably produced renewable resources is key for sustaining human needs over time.

This transition to sustainability requires fundamentally different business models, where businesses depend on the fees generated through ongoing servicing of a product, or from reusing materials, rather than profiting from the total number of products sold. Stronger regulation to promote resource efficiency and penalize pollution, possibly through changes in the law or tax system, could help promote such an approach and stimulate the business innovation required.



Incorporating true costs

Businesses can also incorporate the value of nature into their decisions. This can be encouraged through appropriate government regulation. For example, businesses can be required to pay the true costs of environmental damage or natural capital depletion, or they can be subject to sustainability reporting requirements. Requiring financial markets to take responsibility for environmental (and associated financial) risks as a result of capital allocation can also have a far-reaching impact. It could alter the incentive balance in favour of sustainability.

TRANSFORMATION OF ENERGY AND FOOD SYSTEMS

Redirecting our path toward sustainability requires fundamental changes in two critical systems: energy and food. Current structures and behaviours within these systems have a tremendous impact on biodiversity, ecosystem resilience and human well-being.

Toward sustainable renewable energy sources

Alternative energy source development
As fossil-fuel burning is the largest manmade driver of climate change, the vast majority of fossil fuels would be best left in the ground. Fortunately, renewable energy alternatives are becoming more and more competitive. Further development and rapid widespread adoption of renewable energy innovations are expected to reduce climate risks, while improving human health, boosting our economies, and creating jobs to replace those in fossil-based industries. While the global transition toward sustainable renewable energy sources such as wind and solar remains an immense task, many countries are already committed to transforming their traditional energy supply systems.

Shifting demand to renewable energy
Governments can promote a shift away from intensive carbon use by implementing policies that favour sustainably produced renewable energy over fossil sources. Additionally, some financial institutions are already in the process of reducing climate-related risks; these innovators are leaders in the new, low-carbon economy. Other institutions could be encouraged with incentives or policies to shift money out of fossil fuels.



FURTHER DEVELOPMENT AND RAPID WIDESPREAD ADOPTION OF RENEWABLE ENERGY INNOVATIONS CAN HELP REDUCE CLIMATE RISKS, WHILE IMPROVING HUMAN HEALTH, BOOSTING OUR ECONOMIES, AND CREATING JOBS TO REPLACE THOSE IN FOSSIL-BASED INDUSTRIES

Toward resilient food systems

AGRICULTURAL PRODUCTION IS HIGHLY INFLUENCED BY CONSUMPTION CHOICES, LIFESTYLES, WASTE AND DISTRIBUTION

Transitioning toward an adaptive and resilient food system that provides nutritious food for all within the boundaries of a single planet – while at the same time supporting livelihoods and well-being – is a daunting but essential goal. As we have seen, various structures within the current industrialized global food system reinforce the status quo; i.e., agricultural subsidies, governmental research programmes, and metrics that do not consider the environmental, social, ethical and cultural impacts in the costs of production. These same structures also represent leverage points for change.

Among other factors, agricultural production is highly influenced by consumption choices, lifestyles, waste and distribution. So, while reducing agriculture's environmental impacts and reducing waste along the food chain will be instrumental in meeting future needs, reducing the footprint of food consumption can make a significant contribution.



Promoting healthy and sustainable consumption patterns
More food can be delivered by changing our dietary preferences, especially those in high-income countries characterized by a high share of animal proteins. Food availability (in terms of calories, protein and critical nutrients) can be increased by shifting crop production away from livestock feed, bioenergy crops, foods with low nutritional value and other non-food applications. Encouraging consumers to eat healthy diets with moderate animal protein could enhance food availability and reduce the environmental impacts of agriculture. Other targeted efforts – such as reducing waste associated with the production and consumption of our most resource-intensive foods, especially meat and dairy – could be pursued.

Scaling up existing niche innovations
To meet the vast and interconnected challenges in food systems, efforts to improve or alter the specific aspects of current mainstream agricultural practices will not be sufficient (IPES-Food, 2016). Fortunately, the seeds of a more transformative shift toward sustainability may already have germinated via niche innovations appearing in various locations around the globe. Many promising trends started out as small-scale developments. For example, organic agriculture started as a niche market (Smith, 2007), but has now become more mainstream in many areas (Darnhofer et al., 2010). Farmers on China's Loess Plateau practice methods such as terracing to regenerate soil quality. If such practices spread to other parts of the world, we could have a more sustainable global food system.

Toward yield optimization

Within today's food systems success is often reduced to increased yields, net outputs and net calorie availability (Tittonell et al., 2016). Just as with the GDP, if the goal for agriculture is too narrowly focused on quantity per hectare or on short-term maximization of yields instead of optimizing productivity within the boundaries of the ecosystem it depends upon, its long-term prospects will suffer. Safeguarding long-term productivity, preserving the natural resource base for the future, ensuring resilience of yields in the face of environmental shocks and disease outbreaks, and where and for whom food is produced are all important. They should be recognized as publicly valued goals, with corresponding measures of performance. (De Schutter and Gliesman, 2015; IPES-Food, 2016).

SAFEGUARDING LONG-TERM PRODUCTIVITY, PRESERVING THE NATURAL RESOURCE BASE FOR THE FUTURE, ENSURING RESILIENCE OF YIELDS IN THE FACE OF ENVIRONMENTAL SHOCKS AND DISEASE OUTBREAKS, AND WHERE AND FOR WHOM FOOD IS PRODUCED ARE ALL IMPORTANT

The design and production methods of agricultural landscapes should support the functional biodiversity necessary for long-term production. Agricultural systems should also protect or enhance ecosystem services that are essential for agriculture and food security. For this will make production systems more resilient to climate impacts, fluctuations in water availability and other disturbances. In general, producers should seek an optimal balance between productivity and diversity in the system to meet both human needs and ecosystem integrity. The quantity and type of inputs (agro-chemicals and water) should be sustainable – as the goal is to optimize long-term productivity, rather than maximize short-term production and profit. In doing so, the environmental, social and economic needs of present and future generations will all be represented.

Promoting agroecological practices

Sustainable agricultural solutions are highly diverse, and are dependent on a broad range of factors such as climate, soil type and fertility, water availability, rainfall patterns, technology availability and preferences, labour requirements, and cultural factors. Emerging evidence shows that practices based on agroecology are capable of sustaining, stabilizing and improving yields, preserving the environment, providing decent employment and secure livelihoods, and delivering diverse, nutrient-rich foods – in the places where they are needed most (De Schutter and Gliesman, 2015) (see box). Agroecology projects in 20 African countries already demonstrate a doubling of crop yields over a period of 3-10 years (De Schutter, 2011). Furthermore, a study in semi-arid Burkina Faso shows how native woody perennial shrubs could support the restoration of soil productive capacity and enhance yields within one year in farmers' fields (Tittonell et al., 2016).

Agroecology: farming with nature

Agroecology achieves sustainability by reintegrating modern agriculture with the ecosystems on which it relies. Agroecology replaces external chemical inputs with alternatives that mimic natural processes and enhance beneficial biological interactions and synergies in the farm environment. For example, trees can be reintroduced to provide shade for crops, sequester carbon and provide habitat for beneficial organisms. Agroecology also encourages integrated systems, such as the pairing of rice and fish. For crops in the right combinations can enhance growing conditions for one another (De Schutter and Gliesman, 2015).

Agroecological approaches deliver significant benefits in terms of resource efficiency and greenhouse-gas savings, while sparing soils and ecosystems from long-term degradation by chemical fertilizer and pesticides (Figure 47). And while agroecology shifts the focus away from narrow measures of productivity, it is nonetheless highly productive. Particularly in developing countries, there is the potential for sustaining and even increasing production when the multiple outputs of integrated systems (e.g. rice and fish) are considered. Malawi, a country that launched a massive chemical fertilizer subsidy programme a few years ago, has now switched to agroecology. Consequently, maize yields have increased from 1 tonne/ha to 2-3 tonnes/ha, to the benefit of more than 1.3 million of the country's poorest people. Projects in Indonesia, Vietnam and Bangladesh have recorded reductions of up to 92 per cent in insecticide use for rice, leading to financial savings and better health for poor farmers (De Schutter, 2011). Agroecology therefore facilitates ecological intensification while ensuring that any production gains can be sustained into the future. Reliance on local inputs and the recycling of waste as inputs significantly reduces the costs of production, making it a financially sustainable option for farmers who are risk-averse or who have poor access to credit (De Schutter and Gliesman, 2015).

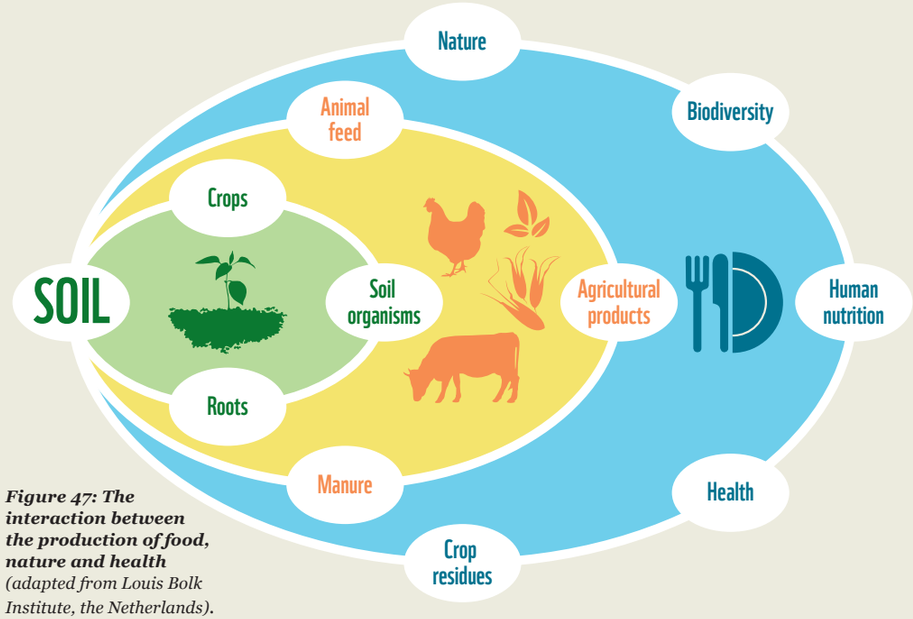


Figure 47: The interaction between the production of food, nature and health *(adapted from Louis Bolk Institute, the Netherlands).*

Diversified farms and farming landscapes

The landscape is the scale at which the various components of a resilient agricultural system should be integrated. Landscapes offer the necessary ecological structure and ecosystem services to support agricultural production (Tittonell et al., 2016). Also, certain sustainable agricultural practices are best implemented at the landscape-level. For example, it would not make sense to apply area-wide pest management, water purification and distribution, and prevention of soil erosion in isolated patches (Macfadyen et al., 2015).

Diversifying farms and farming landscapes, increasing biodiversity and stimulating interactions between different species can be part of holistic strategies to build healthy agro-ecosystems, secure livelihoods, protect natural systems and preserve biodiversity. Diversified farming is applicable to all types of agriculture, including highly specialized industrial agriculture and subsistence farming (IPES-Food, 2016) (Figure 48).

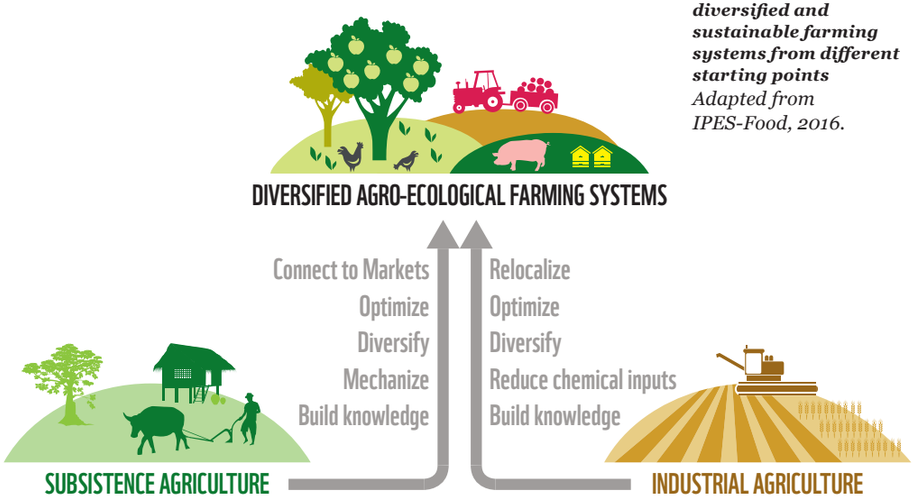


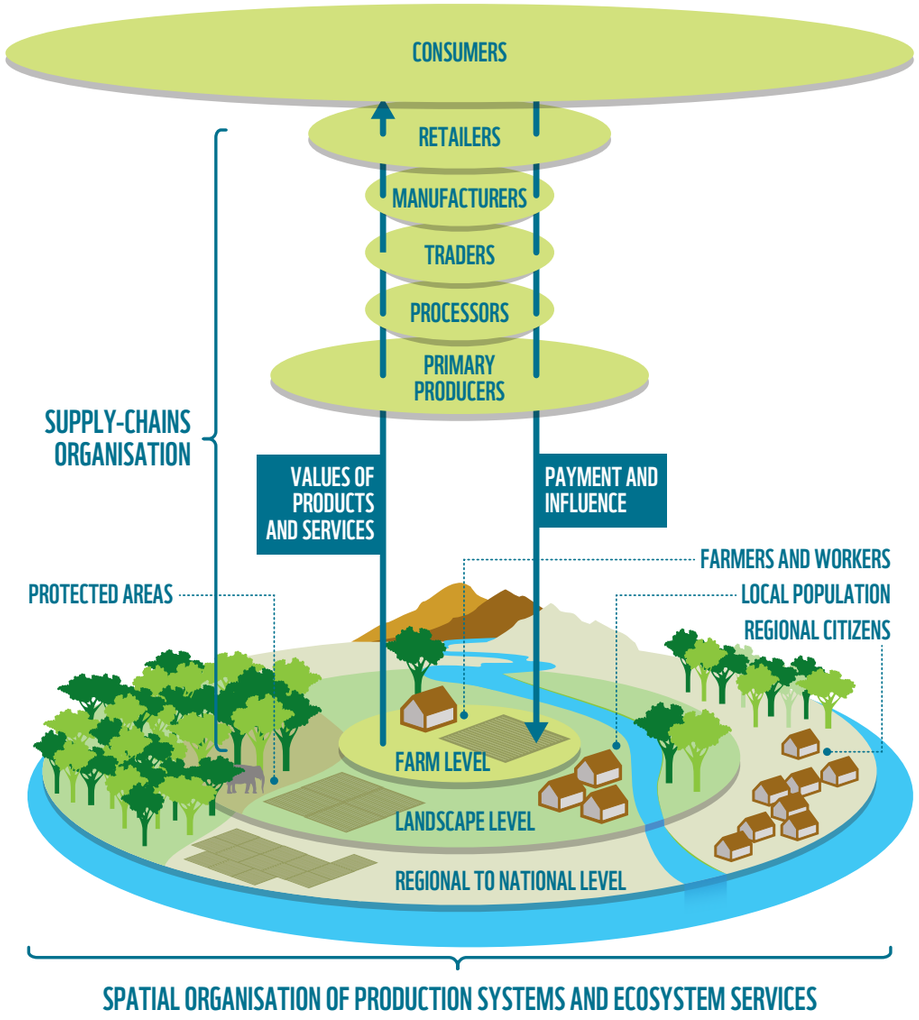
Figure 48: Transitioning towards diversified and sustainable farming systems from different starting points
Adapted from IPES-Food, 2016.

Promoting landscape approaches in supply chains

In addition to farmers, other stakeholders along the food supply chain can contribute to and promote sustainable agricultural practices at the landscape level (Figure 49). For example, food retailers operate at the interface between producers and consumers. They can influence production practices at the landscape scale (Jennings et al., 2015), and – through prices – they can alert consumers to environmental costs of production, thereby increasing demand for sustainable products (Lazzarini et al., 2001).

Companies in the supply chain could encourage landscape-scale diversification as it will reduce variability in supply and improve recovery from shocks, making their own business interests more resilient to risk (Macfadyen et al., 2015). This is because landscapes that integrate crop, livestock and forestry systems with natural areas experience a higher, and more resilient, provision of ecosystem services such as crop pollination and pest control by natural enemies (Kremen and Miles, 2012; Liebman and Schulte, 2015; Tscharntke et al., 2005).

Figure 49: Interaction between supply-chain and integrated landscape approach
Adapted from Van Oorschot et al., 2016; WWF MTI, 2016.



THE PATH AHEAD

The facts and figures in this report tend to paint a challenging picture, yet there is still considerable room for optimism. If we manage to carry out critically needed transitions, the rewards will be immense. Fortunately, we are not starting from scratch. There are several countries that have managed to raise the standards of living for their populations with much lower resource intensity than industrial countries. Furthermore, the world is reaching a consensus regarding the direction we must take. In 2015, the 2030 Sustainable Development Goals were adopted. And at the Paris climate conference (COP21) in December 2015, 195 countries adopted a global agreement to combat climate change, and to accelerate and intensify the actions and investments needed for a sustainable low-carbon future. Furthermore, we have never before had such an understanding of the scale of our impact on the planet, the way the key environmental systems interact or the way in which we can manage them.

IF WE MANAGE TO UNDERGO THE CRITICAL TRANSITIONS NECESSARY, THE REWARD WILL BE IMMENSE

Ultimately, addressing social inequality and environmental degradation will require a global paradigm shift toward living within safe Planetary Boundaries. We must create a new economic system that enhances and supports the natural capital upon which it relies. Earlier in this chapter, leverage points were identified to support the necessary transitions. These were mainly focused on changing societal patterns and systemic structures either by implementing incremental changes or by supporting the development of niche innovations. Changing mental models, societal attitudes and values underlying the current structures and patterns of our global economy is a more challenging course of action. How can we "repurpose" businesses so that they are not just focusing on short-term profit but are also expected to be accountable for social and environmental benefits? Or how should we redefine what desirable economic development looks like? And how can we reduce the emphasis on material wealth, confront consumerism and the throw-away culture, and promote the desirability of more sustainable diets? These kinds of changes to societal values are likely to be achievable only over the long term and in ways that we have not yet imagined.

ADDRESSING SOCIAL INEQUALITY AND ENVIRONMENTAL DEGRADATION WILL REQUIRE A GLOBAL PARADIGM SHIFT TOWARD LIVING WITHIN PLANETARY BOUNDARIES

Still, the speed at which we transition to a sustainable society is a key factor for determining our future. Allowing and fostering important innovations and enabling them to undergo rapid adoption in a wider arena is critical. Sustainability and resilience will be achieved much faster if the majority of the Earth's population understand the value and needs of our increasingly fragile Earth. A shared understanding of the link between humanity and nature could induce a profound change that will allow all life to thrive in the Anthropocene.



GLOSSARY OF TERMS

Biocapacity	Biocapacity refers to the amount of biologically productive land and water areas available within the boundaries of a given country, and how productive they are. Biocapacity is calculated for each of the five major land use types: cropland, grazing land, fishing grounds (marine and inland waters), forest, and built-up land.
Ecological Footprint of Consumption	The most commonly reported type of Ecological Footprint, it is defined as the area used to support a defined population's consumption. The consumption Footprint (in gha) includes the area needed to produce the materials consumed and the area needed to absorb the carbon dioxide emissions.
(Ecological) overshoot	Overshoot: Global overshoot occurs when humanity's demand on nature exceeds the biosphere's supply, or regenerative capacity. Such overshoot leads to a depletion of Earth's life supporting natural capital and a buildup of waste. At the global level, ecological deficit and overshoot are the same, since there is no net-import of resources to the planet. Local overshoot occurs when a local ecosystem is exploited more rapidly than it can renew itself.
Global hectare	Global hectares are the accounting unit for Ecological Footprint and biocapacity accounts. These productivity-weighted biologically productive hectares allow researchers to report both the biocapacity of the Earth or a region, and the demand on biocapacity (the Ecological Footprint). A global hectare is a biologically productive hectare with world average biological productivity for a given year. Global hectares are needed because different land types have different productivity. A global hectare of, for example, cropland, would occupy a smaller physical area than the much less biologically productive pasture land, as more pasture would be needed to provide the same biocapacity as one hectare of cropland. Because world bioproductivity varies slightly from year to year, the value of a gha may change slightly from year to year.
Living Planet Index	The LPI reflects changes in the health of the planet's ecosystems by tracking trends in over 14,000 populations of vertebrate species. Much as a stock market index tracks the value of a set of shares over time as the sum of its daily change, the LPI first calculates the annual rate of change for each species' population in the dataset. The index then calculates the average change across all populations for each year from 1970, when data collection began, to 2012, the latest date for which data is available (see supplement for more details).
Lock-ins	Lock-ins are an emergent property of systems that occur through a combination of factors, including the system's own path dependency and self-reinforcing and regulatory mechanisms and prevent the system from changing to a different state.
Natural capital	Natural capital is defined as the stock of environmental assets such as soil, biodiversity and freshwater which generate benefits to humans.
IUCN Red list of Threatened Species	The IUCN Red List of Threatened Species™ provides taxonomic, conservation status and distribution information on plants, fungi and animals that have been globally evaluated using the IUCN Red List Categories and Criteria. This system is designed to determine the relative risk of extinction, and the main purpose of the IUCN Red List is to catalogue and highlight those plants and animals that are facing a higher risk of global extinction.
Red List Index	The Red List Index (RLI), based on the IUCN Red List of Threatened Species, is an indicator of the changing state of global biodiversity. It is based on movement of species status through the IUCN Red List Categories, and measures trends in extinction risk over time.
Resilience	The ability of a social-ecological system to absorb and recover from shocks and disturbances, maintain functionality and service by adapting to chronic stressors, and transform when necessary.
Root causes	A root cause is a critical component, among many contributing ones, whose presence is determinant to a problematic outcome of interest. It is usually, but not necessarily, identified as an initial cause in a chain, so that addressing the root cause is necessary to preventing the outcome.
Systems thinking	Systems thinking is a holistic perspective on reality that stems from the awareness of the interconnectedness of all things and the recognition that complex wholes with emergent properties (ie: systems) arise from the interactions of their component elements. As a discipline, it applies a wide range of tools and frameworks in the understanding, communication, and analysis of transdisciplinary issues, including sustainability, engineering and management.

LIST OF ABBREVIATIONS

ARMA	Autoregressive-moving-average model
BRICS	Association of five major emerging national economies: Brazil, Russia, India, China and South Africa
CBD	Convention on Biological Diversity
CITES	The Convention on International Trade in Endangered Species of Wild Fauna and Flora
CO_2	Carbon dioxide
E/MSY	Extinctions per million species-years
EBCC	European Bird Census Council
EEA	European Environment Agency
EF	Ecological Footprint
EU	European Union
FAO	United Nations Food and Agricultural Organization
FAOSTAT	Statistics Division of FAO
GDP	Gross Domestic Product
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GFN	Global Footprint Network
gha	global hectares
GROMS	Global Register of Migratory Species
IGBP	International Geosphere-Biosphere Programme
IPCC	International Panel on Climate Change
IPES-Food	International Panel of Experts on Sustainable Food Systems
IUCN	International Union for the Conservation of Nature
IUGS	International Union of Geological Sciences
IUU	Illegal, Unreported and Unregulated
LBII	Local Biodiversity Intactness Index
LED	Light-Emitting Diode
LPI	Living Planet Index
MEA	Millennium Ecosystem Assessment
MW	Megawatt
MYA	Million Years Ago
NASA	National Aeronautics and Space Agency
NOAA	National Oceanic and Atmospheric Administration
OECD	Organisation for Economic Cooperation and Development
PB	Planetary Boundaries
PIKE	Proportion of Illegally Killed Elephants
PREDICTS	Projecting Responses of Ecological Diversity In Changing Terrestrial Systems
PV	Photovoltaics
RLI	Red List Index
RSPB	Royal Society for the Protection of Birds
SEI	Stockholm Environment Institute
SRC	Stockholm Resilience Centre
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNEP-WCMC	United Nations Environment Programme – World Conservation Monitoring Centre
UNESCO	United Nations Educational, Scientific and Cultural Organization
WET index	Wetland Extent Trend index
WHO	World Health Organization
WWF	World Wide Fund for Nature
WWF MTI	World Wide Fund for Nature – Market Transformation Initiative
ZNDD	Zero Net Deforestation and Degradation
ZSL	Zoological Society of London

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