Assessment of global megatrends — an update

Global megatrend 10: Increasing environmental pollution

European Environment Agency

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Europe is bound to the rest of the world through an enormous number of systems — environmental, economic, social, political and others. Such networks enable complex flows of materials and ideas across the globe, producing uncertain feedbacks and knock-on effects over time. Greenhouse gas emissions in Europe today can affect the climate in distant locations and far into the future. Land management choices on the other side of the world can influence food and energy prices in Europe. Global communication and trade networks fuel innovation — sometimes boosting efficiency, sometimes creating new environmental pressures.

Most of these interactions are intimately linked and set to unfold over decades. All are likely to have important implications for living standards and well-being.

The European environment's status, trends and prospects have always depended in part on events outside its borders. Yet the growing importance of global networks and flows has augmented this interdependence, creating complex challenges for traditional governance systems framed within national or regional territories. To design effective ways to manage the environmental changes ahead, societies and governments need to understand the global drivers at work and their potential implications.

With this challenge in mind, the European Environment Agency in 2010 produced its first assessment of emerging global trends as part of its five-yearly flagship report on the European environment's state and outlook (SOER 2010). The exploratory analysis summarised 11 global megatrends grouped into five clusters — social, technological, economic, environmental and governance. Introducing the issues succinctly, it sought to trigger a discussion about how Europe should monitor and assess future changes in order to better inform environmental policymaking.

In preparation for its next report on the European environment's state and outlook (SOER 2015), the EEA has initiated an update of the assessment of global megatrends, analysing each of these drivers in a little more detail than previously in terms of their impacts on the European environment and well-being. During the second half of 2013 and early-2014, the EEA is reassessing the 11 megatrends and publishing the updates separately on its website. In 2014 the chapters will be consolidated into a single EEA technical report and will provide the basis for the analysis of megatrends included in SOER 2015. The present chapter addresses megatrend 10: 'Increasing environmental pollution'.

Again, it needs to be emphasised that the complexity of highly interconnected human and natural systems introduces considerable uncertainty into projections and forecasts. As much as anything, the assessment of megatrends aims to encourage readers to acknowledge this interdependence and uncertainty. In so doing, it may help point the way towards systems of planning and governance better adapted to meeting the challenges ahead.

Global megatrend 10
Increasing environmental pollution load

Across the world, ecosystems are today exposed to critical levels of pollution in increasingly complex mixtures. Human activities (such as energy generation and agriculture), global population growth and changing consumption patterns are the key drivers behind this growing environmental burden.

Historic trends and business-as-usual projections suggest that in the coming decades pollution may reduce in some regions but could increase markedly in others. For example, emissions to air of nitrogen oxides, sulphur and tropospheric ozone are projected to decrease in Europe and North America but may increase significantly in Asia. The trends in Asia could, however, impact other world regions — including Europe — via long-range transport of pollutants.

Nutrient effluents from agriculture and wastewater into the soil and oceans are projected to increase in most world regions, driven in part by the demand for increased agricultural production. The increasing complexity of chemical mixtures released into the environment is also a concern globally.

There is clear evidence of the detrimental effects of pollution on the natural environment, ecosystem services and biodiversity, for example through processes such as eutrophication and acidification. The number of marine dead zones due to eutrophication has increased markedly in recent years. Modelling suggests that, depending on crop type, between 3 % and 12 % of annual crop production is lost due to elevated ozone levels. Moreover, these rates may increase, particularly in Asia.

Humanity's social and economic systems exert a wide variety of pressures on the natural environment; including growing demand for non-renewable resources and ecosystem depletion (see GMTs 7 and 8). This chapter addresses another type of pressure: the increasing global pollution burden.

Section 10.1 reviews the drivers of environmental pollution. Section 10.2 describes past, current and projected trends of selected pollutants that warrant global attention. Section 10.3 reviews potential impacts of these trends on the environment and related ecosystem services. The impacts of pollution on human health and climate are addressed in GMTs 3 and 9.

10.1 Key drivers of globally increasing pollution loads

Throughout much of human history, environmental pollution has been a local phenomenon linked to activities such as subsistence farming and burning vegetation. In more recent times, pollution has turned into a global problem. Technological advances, for example in the automobile and chemicals industries, have hugely increased emissions, creating an increasingly complex mix of critical pollutants with interrelated environmental effects (see Box 10.1 and Box 10.2).

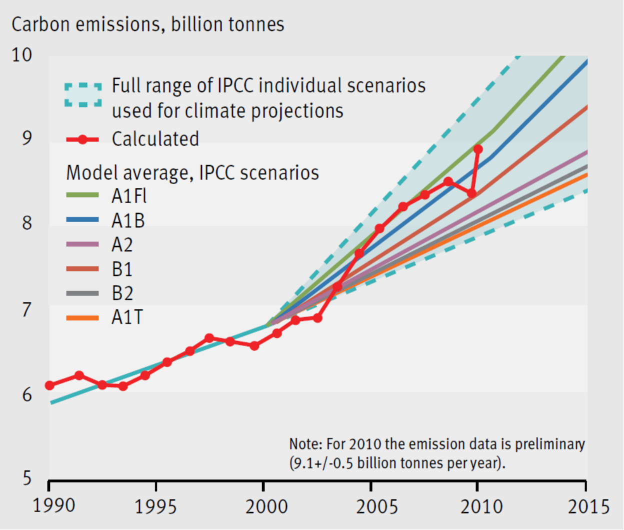
Population growth has also played a role. The world population reached 1 billion in 1804, and surpassed 2 billion in 1927. After that, it took just 84 more years to reach 7 billion (see GMT 1). Although the rate of growth has eased in recent decades, the global population is projected to be between 8.3 billion and 10.9 billion in 2050, with a medium variant of 9.6 billion (UN, 2013).

These technological and demographic trends have driven rapid economic growth (GMT 5) and increased earnings, increasing demand for energy (GMT 7) and food (GMT 8). They have also manifested in a huge expansion of the global middle class, bringing associated shifts in consumption patterns. Collectively, the impact of these changes has been a substantial increase in environmental pollution loads.

10.1.1 Sources and types of pollution

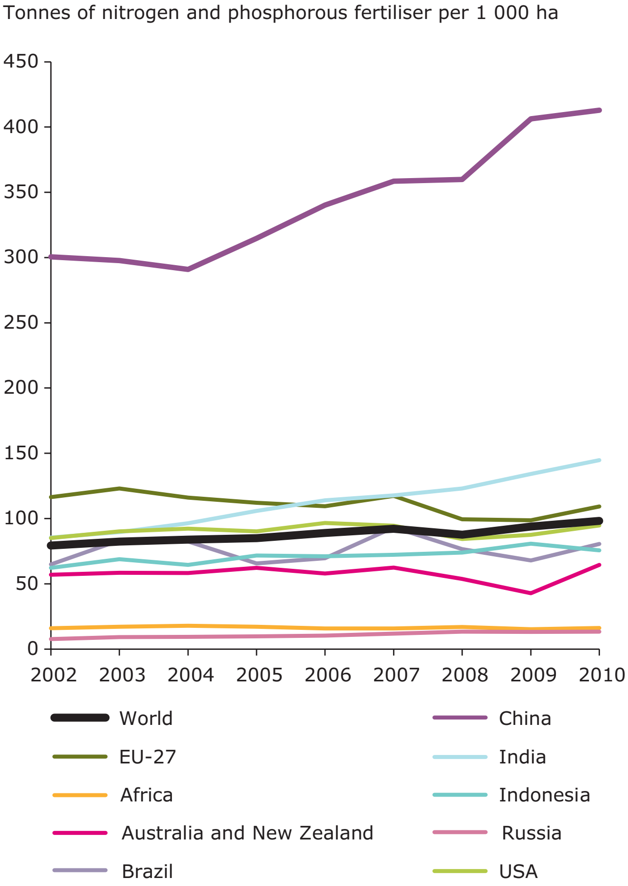
Fossil fuel combustion (related to industrial production and transport) is a key source of

Figure 10.1 Global carbon emissions form combustion of fossil fuels (1990–2011) and IPCC projected emission scenarios (2000–2015)



Source: UNEP, 2012a.

Figure 10.2 Intensity of fertiliser use on arable land in selected world regions and countries, 2002–2010



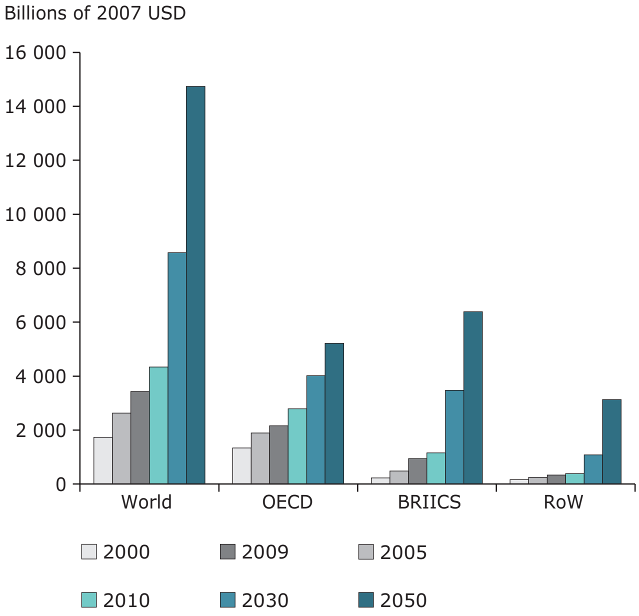
Source: FAO, 2013.

pollutant emissions, in particular for air pollution. As shown in Figure 10.1, annual global greenhouse gas emissions from fossil fuels have risen by 50 % from around 6 billion tonnes in 1990 to almost 9 billion tonnes in 2010, in accordance with the most pessimistic Intergovernmental Panel on Climate Change (IPCC) scenario (A1FI) in that year (IPCC, 2000).

Fertiliser use varies across countries and world regions, with particularly intensive use in China (Figure 10.2). India and China have sharply increased synthetic fertiliser input per unit of agricultural land over the last decade, whereas the rate has remained stable in other world regions such as the USA and the EU-27. Countries within Europe show mixed trends, however. Many eastern European countries have increased their fertiliser use markedly over the last decade, while most southern European countries have considerably reduced fertiliser inputs (EEA, 2013c).

Chemicals released into the environment are another concern. In Europe alone, more than 100 000 commercially available chemical substances are registered in the European Inventory of Existing Commercial Chemical Substances (EINECS), and the number of new substances introduced to the global market is increasing rapidly. Annual global sales from the chemical industry sector doubled between 2000 and 2009, with increases in all world regions (OECD, 2012). Chemicals production is projected to continue growing. Particularly large increases are anticipated in BRIICS countries and output there may surpass aggregate OECD chemicals production by 2050 (Figure 10.3). Of particular concern are persistent, bioaccumulative and toxic substances that remain in the environment for a long time (Box 10.1).

Figure 10.3 Chemicals production by world region (in sales), 2000–2050



Source: OECD, 2012 (data for 2010, 2030 & 2050: projections from ENV-Linkages model).

10.2 Status and trends of emissions

Pollutants enter the environment via various means, such as particulate emissions to air or as effluents to soils or aquatic environments. Some pollutants interact in air, water or soil, triggering the formation of new pollutants, such as tropospheric (ground-level) ozone (O_3) (^{1}). Table 10.1 provides an overview of key pollutants of natural ecosystems and their effects. The remainder of this section presents historical trends and future projections for some of these pollutants. Their impacts and implications are addressed in Section 10.3.

10.2.1 Emissions to the air

Atmospheric nitrogen pollution

Atmospheric nitrogen pollution primarily consists of emissions of nitrogen oxides (NO_X) from the industry and transport sectors, and emissions of ammonia (NH_3) and nitrous oxide (N_2O) from agriculture (UNEP, 2012a). Nitrogen oxides are precursors of tropospheric ozone and cause multiple effects in the atmosphere that contribute to climate change (see GMT 9). In addition, nitrogen deposited in terrestrial and aquatic ecosystems can harm biodiversity through processes such as

Box 10.1 Persistent, bioaccumulative and toxic substances

Persistent, bioaccumulative and toxic chemicals (PBTs) have emerged as an important environmental and health concern. Such substances can remain in soil and sediment for a long time, being absorbed by microorganisms and plants. Ultimately they accumulate in wildlife, increasing in concentration as they move up the food chain. PBTs are associated with toxic effects in animals, such as cancer, immune system dysfunction and reproductive disorders.

A range of activities emit PBTs, including agriculture, cement production, mining, waste management and ship dismantling. Although these activities occur throughout the world, many are specifically associated with developing countries and countries in economic transition (UNEP, 2009). PBTs can travel long distances via wind and ocean currents, and can move readily between water, soil and air. As such, local emissions contribute to a global burden of pollution. PBTs tend to concentrate in cold regions through a process known as 'global distillation'. Monitoring data confirm bioaccumulation and biomagnification of PBTs in the tissue of Arctic wildlife and fish (Swackhamer et al., 2009).

Recognising the global character of PBT pollution, governments have agreed measures to reduce PBT releases and emissions, notably the Stockholm Convention on Persistent Organic Pollutants. Global monitoring under the Convention indicates that persistent organic pollutant concentrations in air have declined in the past 10–15 years (UNEP, 2009). However, concentrations of PBTs in wildlife show more mixed trends, and there is growing scientific evidence of their toxicity to mammals, birds and reptiles (UNEP, 2012b).

(^{1}) 'Tropospheric ozone' or 'ground-level ozone' comprises the ozone concentrations in the lowest part of the atmosphere, which directly affect humans, crops and ecosystems. The troposphere stretches from ground level to around 15–20 kilometres.

Table 10.1 Matrix of pollutants and their effects on natural ecosystems

	Sulphur dioxide (SO_2)	Nitrogen oxides (NO_X)	NMVOCs	Ammonia (NH_3)	Carbon monoxide (CO)	Carbon dioxide (CO_2)	Methane (CH_4)	Nitrogen fertiliser	Phosphorus fertiliser
Ground-level ozone (O_3)		X	X		X		X	X	
Acidification	X	X		X		X		X	
Eutrophication		X		X				X	X

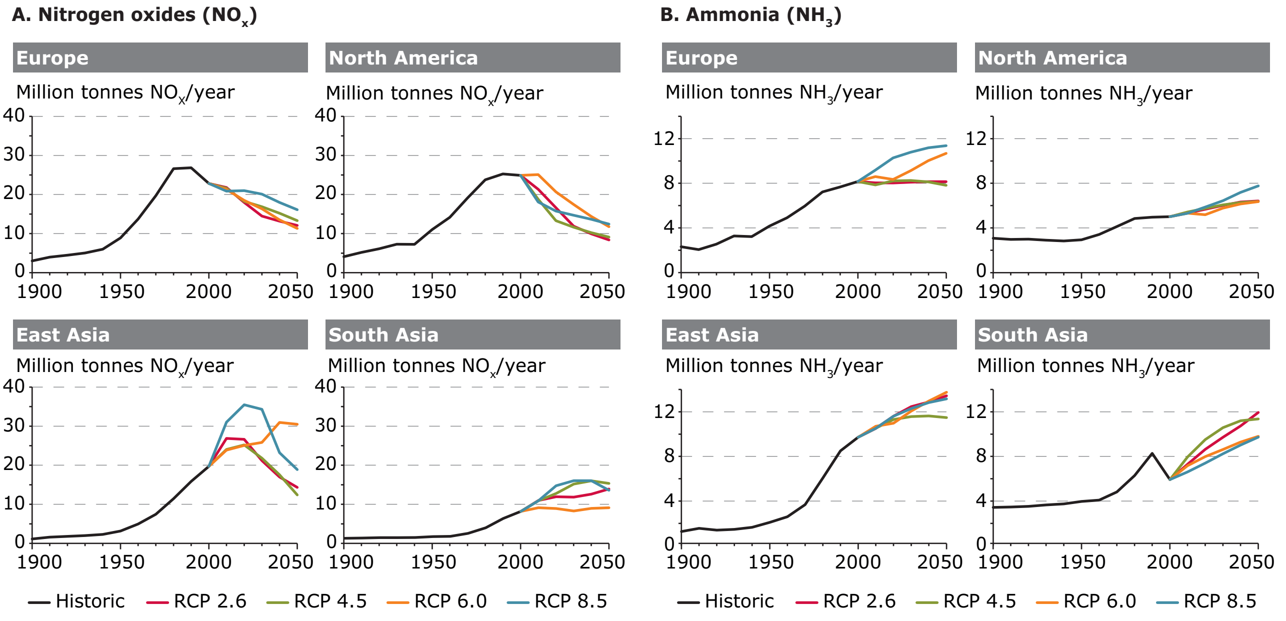
Note: NMVOCs are 'non-methane volatile organic compounds'.
Particulate matter (PM) is not included here as it is addressed in more detail in GMT 3 on human health.

eutrophication and acidification (see Section 10.3 for details).

Global emissions of NO_X increased rapidly until approximately 1990 in Europe, North America, east Asia and south Asia (Figure 10.4) (²). They then fell significantly in Europe and stabilised in North America but continued to grow in Asia. According to projections based on the concepts of the representative concentration pathway (RCP) scenarios (³) (van Vuuren et al., 2011), emissions will continue to decrease in Europe and North America up to 2050. In Asia, decreases may only commence following another two or three decades of increased emissions (HTAP, 2010; Figure 10.4).

Global ammonia (NH_3) emissions have also increased significantly since the 1950s in all four regions shown (Figure 10.4). The strongest increase was in east Asia, where China is the largest agricultural producer. In contrast to nitrogen oxides, ammonia emissions are projected to increase further

Figure 10.4 Historical and projected trends in nitrogen oxides and ammonia emissions for Europe, North America, east Asia and south Asia, 1900–2050



Source: HTAP, 2010.

(²) The analysis in this section focuses on four regions addressed by the Task Force on Hemispheric Transport of Air Pollution (HTAP) organised under the auspices of the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP Convention). These regions were selected because of their dominant share in global emissions.

(³) The representative concentration pathways (RCPs) were developed to aid climate modelling, and will underpin the forthcoming fifth assessment report of the IPCC. They do not necessarily represent probable future socio-economic pathways.

in coming decades in all the four regions, with the possible exception of Europe.

Tropospheric ozone

Formation of tropospheric ozone (O_3) is mainly driven by anthropogenic emissions of atmospheric precursors, namely NO_X, volatile organic compounds (VOCs), CO and methane (NH_4). O_3 causes significant damage to vegetation, for example diminishing forest growth and crop yields (e.g. Mills et al., 2011). Ozone is a relatively short-lived pollutant, with an average tropospheric lifetime of approximately 22 days (Stevenson et al., 2006). Despite this characteristic, hemispheric (intercontinental) transport of O_3 is a growing concern (HTAP, 2010). This phenomenon is a result of complex atmospheric chemistry, which enables precursors to form O_3 long after they are emitted (Stevenson et al., 2006).

According to regional modelling for the period 1960 to 2000, peak ground-level ozone concentrations in Europe and North America increased until about 1990 and then decreased (Figure 10.5). This is mainly attributed to decreased levels of precursors, such as nitrogen oxides (Figure 10.4). In east Asia and south Asia, peak concentrations continued to increase during the 1990s, although less rapidly than previously (Figure 10.5).

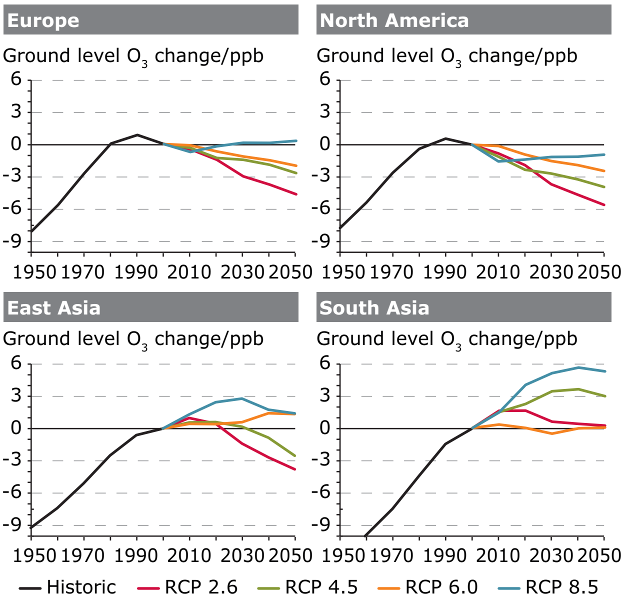
Projections of future peak ground-level ozone concentrations are heavily dependent on global and regional emission pathways (UNEP, 2012a), as well as on changes in the climate system. As illustrated in Figure 10.5, regional projections up to 2050 vary greatly depending on the RCP assumption employed. Ground-level ozone concentrations in Europe and North America are projected to decline based on three of the four RCPs. At the other extreme, increases are projected in south Asia according to all four scenarios.

In contrast to peak concentrations, observed background tropospheric ozone concentrations in Europe and North America increased steadily over recent decades. Increasing methane concentration are likely to play a role in this development (Royal Society, 2008).

Sulphur dioxide

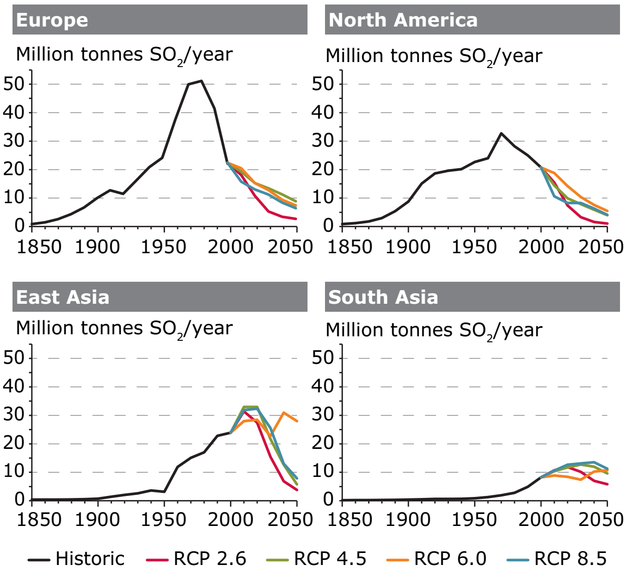
Sulphur dioxide (SO_2) contributes to acidification of terrestrial and freshwater ecosystems, thereby affecting biodiversity. Volcanic eruptions and human activities are the major sources of sulphur dioxide emissions. The latter includes burning of sulphur-containing fossil fuels, combusting biomass for domestic heating, and biofuel use in the transport sector (EEA, 2013b).

Figure 10.5 **Historical and projected trends in peak concentrations of tropospheric ozone for Europe, North America, east Asia and south Asia, 1950–2050**



Source: Wild et al., 2012.

Figure 10.6 **Historical and projected trends in emissions of sulphur dioxide for Europe, North America, east Asia and south Asia, 1850–2050**



Source: HTAP, 2010.

SO_2 emissions have increased significantly since 1850 (Figure 10.6). They grew fastest in Europe and North America before peaking in the late 1970s. Implementation of legislation such as the EU's National Emission Ceiling (NEC) Directive resulted in strong emission reductions in both regions (around 50 % in Europe). Global emissions have only dropped by around 20 %, however, due to increasing emissions in Asia. Projections based on the IPCC's RCP scenarios suggest that SO_2 emissions will continue to decline in Europe and North America but the patterns will be more varied in Asia. Again, future emissions largely depend on the development and implementation of emission mitigation measures.

Particulate matter

Particulate matter (PM) consists of a variety of airborne particles, of varying size and chemical composition. PM is emitted either directly through human activities such as energy generation, industrial production or transport, or can be formed in the atmosphere from precursor gases such as sulphur dioxide, nitrogen oxides and ammonia. Recent studies show that PM can be transported across continents, for example via atmospheric brown clouds. Although local emissions of PM are considered to account for the majority of PM-related harm, long-distant sources can contribute significantly (HTAP, 2010). While PM affects plant growth and animals, it is primarily a concern due to its harmful effects on human health (WHO, 2006). It is therefore addressed in more detail in GMT 3.

10.2.2 Releases to aquatic systems and soils

Apart from deposition of airborne sources, pollution of water and soils also results more directly from releases from diffuse agricultural or urban sources, or from point sources such as industrial plants. In some cases, for example nitrogen pollution of marine ecosystems (OSPAR, 2010), direct releases create a much greater environmental burden than deposits from the air. These direct releases are often more local but can have far-reaching effects when transported over long distances, for example via rivers. Increasingly complex cocktails of chemicals and heavy metals (Box 10.2) released from industrial plants are also a growing concern.

Box 10.2 Potential risks from mixtures of chemicals

Assessments of the environmental risks of chemical pollution have traditionally focused on individual chemicals and sought to establish a 'concentration threshold' or 'dose', below which negative effects are not seen. In reality, however, multiple chemicals interact in the environment, producing combined effects that exceed the sum of individual impacts (Kortenkamp et al., 2009). As a result, a substance present in concentrations below the threshold level may still contribute to combined and possibly synergistic effects. The combined ecotoxicity of a chemical mixture is always higher than the individual toxic effect of even the most potent compound present (KEMI, 2012). In particular, robust evidence exists of combination effects for endocrine disrupting chemicals (EEA, 2012b).

Since the number of chemical combinations is enormous, there is a need to develop methods for prioritising mixtures most likely to occur in the environment and assessing the associated risks. Continued research is needed into priority mixtures, synergistic effects and likely exposure scenarios. Kortenkamp et al. (2009) found that available methods are sufficiently advanced to enable risk assessment of the combination effects of chemicals in a wide range of settings. But there is currently no systematic, comprehensive and integrated regulatory approach to managing mixture effects globally.

Many EU Member States have experience applying mixture testing approaches to emissions and environmental monitoring. However, EU legislation only requires Member States to assess the risks of intentionally produced chemical mixtures, such as in pesticides, cosmetics, or medicinal products. Some Member States have therefore called for a coherent approach to managing chemical mixtures (NCM, 2012). In May 2012, the European Commission launched a process to identify priority mixtures for assessment, ensure consistent risk assessment requirements across EU legislation and address data and knowledge gaps regarding mixture toxicity (EC, 2012).

At the global scale, the World Health Organization (WHO) promotes the development of Toxic Equivalence Factors (TEF) for assessing mixtures of dioxin-like chemicals (IPCS, 2001, 2009). In addition, the UN Globally Harmonised System for Classification and Labelling of Chemicals (GHS) provides detailed guidance on the classification of commercial mixtures for human health and the environment.

Nitrogen and phosphorus

At the global scale, increasing nitrogen and phosphorus pollution has become a major concern because of direct negative impacts on natural ecosystems and biodiversity (see Section 10.3). Triggered by agricultural intensification and global population growth, the total production of nitrogen reactive in the environment (see Box 10.3 for details on its formation) has more than doubled since the 1970s (Galloway et al., 2008).

Synthetic nitrogen fertilisers have enabled a significant increase in global food production. But if global loads of nitrogen (and phosphorus) continue to increase then it may at some point significantly perturb the natural nitrogen and phosphorus cycles. According to Rockström et al. (2009), current levels may already exceed globally sustainable limits.

The role of agriculture

Nutrient effluents from agriculture occur if there is surplus nitrogen or phosphorus in the soil. For example, if synthetic fertiliser is applied but not fully taken up by crops then it may leach into groundwater or surface waters. Thus, effluent quantities depend on the intensity of fertiliser use and the efficiency in fertiliser application.

Several recent studies have suggested that global fertiliser use will increase markedly during the 21st century from the 90 million tonnes consumed in 2000 (Winiwarter et al., 2013). The projections in the studies vary greatly, depending on assumptions regarding population, consumption, biofuels and efficiency. Most estimate that annual nitrogen fertiliser use will be in the range of 100–150 million tonnes in 2050. The FAO (2012) argues, however, that if developing countries shift their models of agricultural production to those already used in developed regions then global nitrogen fertiliser use could well exceed 150 million tonnes in 2050.

The projections of nitrogen fertiliser demand based on IPCC RCP scenarios suggest that there may be trade-offs between greenhouse gas mitigation and pollution abatement. In the two lower global warming scenarios (RCP 2.6 and RCP 4.5), intensified biofuel production could lead to high nitrogen fertiliser consumption (Winiwarter et al., 2013; Figure 10.7). It could also increase concentrations of tropospheric ozone, since certain plant species used for biofuel production (e.g. poplars) emit more isoprene (a biogenic ozone precursor) than the crops they are replacing (Beltman et al., 2013).

Scenarios indicate a mixed picture for the efficiency of future fertiliser use. In most OECD countries, agricultural output is expected to grow more rapidly than nutrient inputs, implying increased efficiency of fertiliser use. This could lead to reduced nutrient effluents from agriculture. In contrast, in China, India and most developing countries, effluent rates may increase strongly as growth in agricultural production is likely to outpace increases in efficiency of fertiliser use (OECD, 2012).

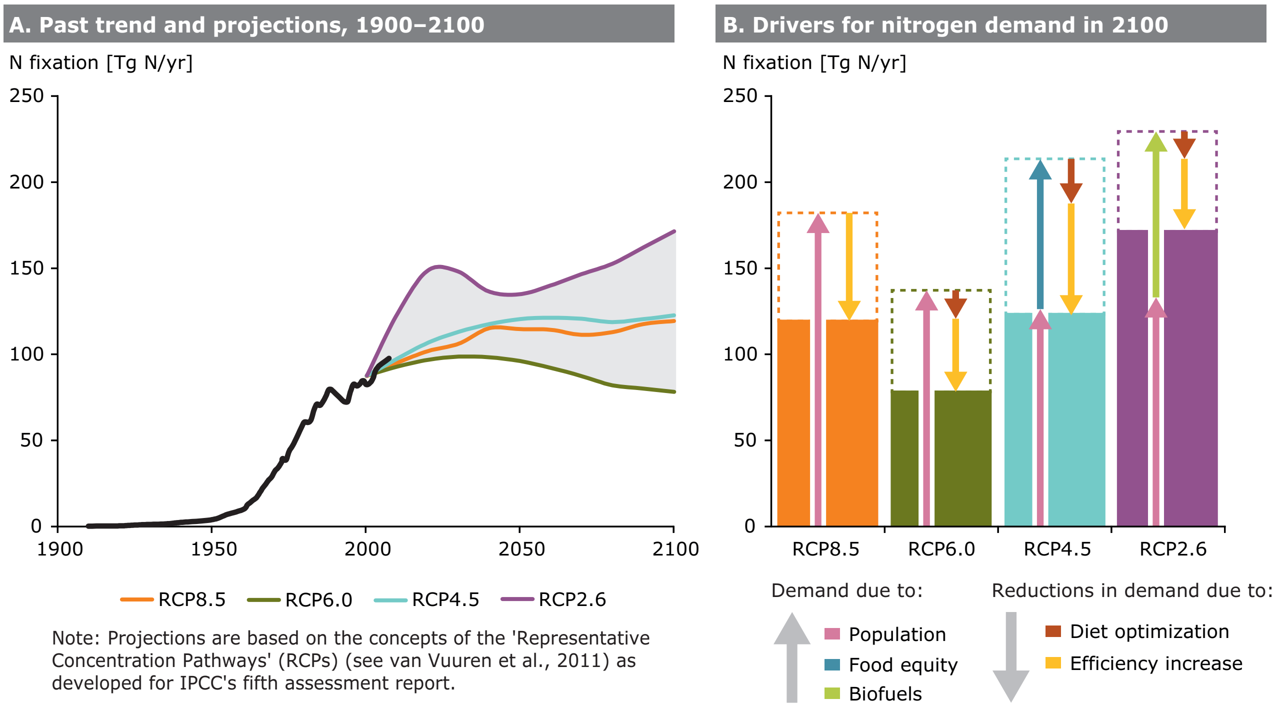
Box 10.3 Formation of reactive nitrogen

Nitrogen makes up almost 80 % of the atmosphere in the form of N_2 gases but can only be used by plants and animals if converted into another chemical form: reactive nitrogen. This process of 'nitrogen fixation' can occur in three main ways:

- by lightning or high-temperature combustion (e.g. car exhausts and power stations);
- by nitrogen-fixing plants (e.g. legumes);
- by the industrial creation of synthetic nitrogen fertiliser.

Reactive nitrogen is also released from animal manure. For a more detailed explanation of the nitrogen cycle and the role of agriculture see, for example, Mosier et al. (2004).

Figure 10.7 Historical trend in global agricultural demand for industrial nitrogen fertiliser, 1910–2008, projections to 2100 based on RCP scenarios, and drivers of the projected changes in demand in 2100



A. Past trend and projections, 1900–2100

B. Drivers for nitrogen demand in 2100

Note: Projections are based on the concepts of the 'Representative Concentration Pathways' (RCPs) (see van Vuuren et al., 2011) as developed for IPCC's fifth assessment report.

Note: 'Diet optimisation' refers to a shift in consumption towards foods produced with more effective nitrogen uptake. 'Efficiency increase' refers to the ratio of nutrients taken up by crops to the total amount of nutrients applied to soil.

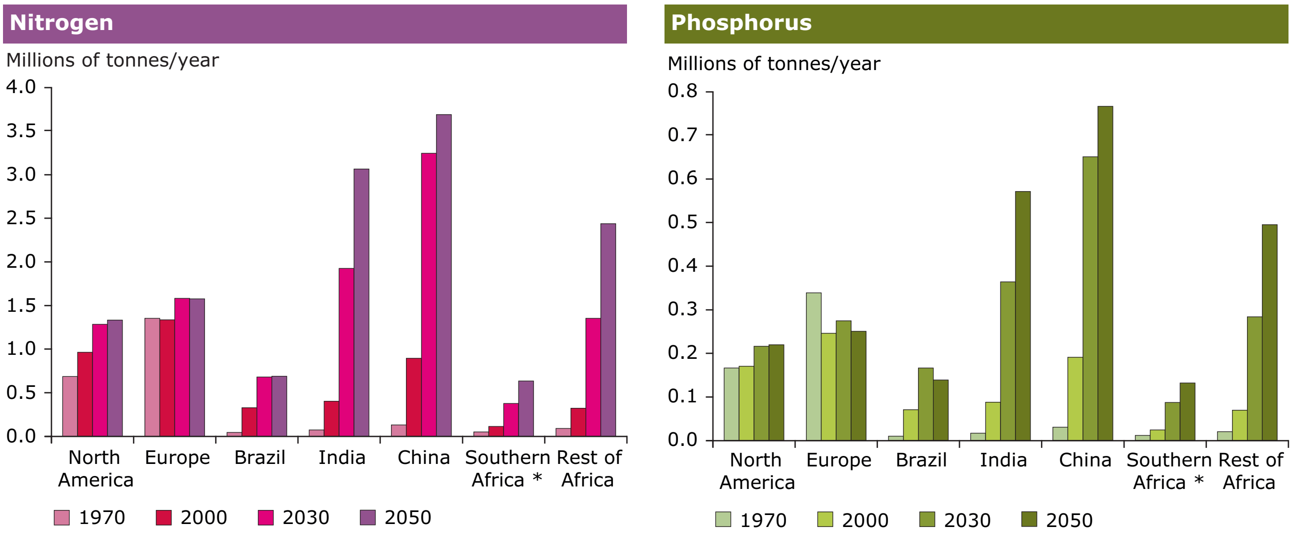
Source: Winiwarter et al., 2013.

The role of wastewater

Nitrogen and phosphorus effluents from wastewater are projected to increase in developed and developing regions (OECD, 2012). Key drivers include global population growth, rapid urbanisation and the high cost of removing nutrients in wastewater treatment systems. Globally, OECD scenarios suggest that nitrogen effluents will increase by 180 % between 2000 and 2050, reaching 17 million tonnes per year. Phosphorus effluents might rise by more than 150 % to 3.3 million tonnes per year. In each case, the largest increases are projected in China and India (Figure 10.8).

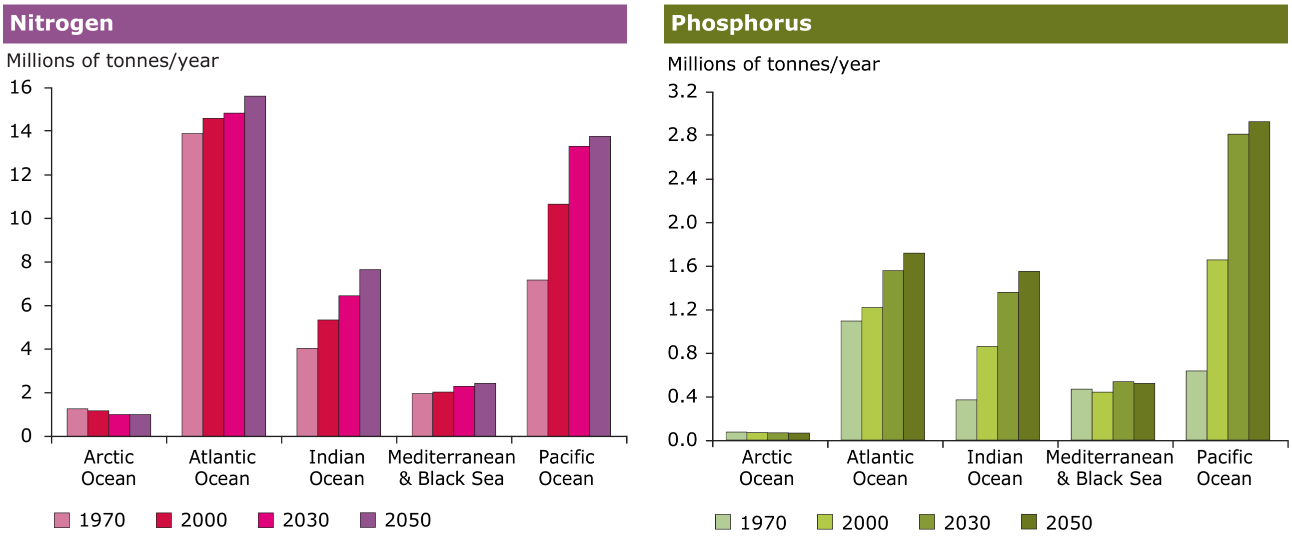
Under current global policy settings, projected discharges of nutrients via rivers into the sea vary considerably across the world's main seas (OECD, 2012). While nutrient discharges into the Mediterranean and the Black Sea are projected to increase only slightly, the Indian Ocean and the Pacific Ocean may face strong increases. The amount of phosphorus discharged annually into the Pacific Ocean may almost double from 2000 to 2050 (Figure 10.9).

Figure 10.8 Effluents of nitrogen and phosphorus from wastewater, 1970–2050



Source: OECD, 2012 (output from IMAGE model).

Figure 10.9 River discharges of nitrogen and phosphorus into the sea, 1970–2050



Source: OECD, 2012 (output from IMAGE model).

10.3 Implications of increasing ecosystem pollution

Environmental pollution often triggers harmful processes in the environment. For example, atmospheric deposition of sulphur and nitrogen compounds causes acidification of soils and freshwater resources; elevated nitrate and phosphate levels lead to eutrophication of terrestrial and aquatic ecosystems; and high concentrations of ground-level ozone and ammonia damage vegetation. Synthetic pesticides used in agricultural production can have significant effects on freshwater quality, marine ecosystems and soil biodiversity (OECD, 2012). In addition, various pollutants are emerging whose effects are not yet well studied. These include chemical substances that may interfere with the hormonal system of humans and animals (see Box 10.1).

This section highlights two related sets of potential pollution impacts that are of particular concern in the context of global population growth and resource scarcity: impacts on biodiversity and ecosystem services; and impacts on agriculture and food provision.

10.3.1 Biodiversity and ecosystem services

Terrestrial ecosystems

The capacity of ecosystems to provide valuable services, such as regulating the environment, provisioning resources and delivering non-material cultural benefits (see GMT 8) can be reduced by chronically elevated reactive nitrogen deposition, thus causing widespread harm. In such conditions, species well adapted to nitrogenous or acidic environments are likely to thrive, displacing other plants. Susceptibility to stress such as frost damage or disease may also be enhanced (Dise et al., 2011). Over time, these factors could alter species composition and reduce diversity. In many European ecosystems, exceeding critical loads of reactive nitrogen has been linked to reduced plant species richness (Bobbink et al., 2010; Dise et al., 2011). An annual deposition of 5–10 kg N per ha has been estimated as a general threshold value for adverse effects (Bobbink et al., 2010), although such effects may also occur over the long term at even lower levels (Clark and Tilman, 2008).

Acidic deposition trends differ markedly across the world's regions. In Europe, they have declined significantly since the 1980s (Vestreng et al., 2007). Although reduced atmospheric emissions do not result in immediate recovery of impacted ecosystems, there is clear evidence of recovery in European ecosystems (e.g. Vanguelova et al., 2010).

In contrast to Europe, Asian and African ecosystems may face increased risk of acidification in the coming 50 years, depending on individual site management practices and policies from regional to international levels. Areas at particular risk are south, south-east and east Asia, where little of the emitted substances are neutralised by alkaline desert dust in the atmosphere (Hicks et al., 2008). At the global scale, Bleeker et al. (2011) find that 40 % of the current protected areas designated under the Convention on Biological Diversity (CBD) received annual nitrogen deposition exceeding the threshold of 10 kg N per ha in 2000. In 950 protected areas, primarily in south Asia or south-east Asia and Africa, the nitrogen load is projected to double by 2030.

Ground-level ozone may also have significant effects on biodiversity (Wedlich et al., 2012). This might, for example, take the form of changes in species composition of semi-natural vegetation communities (e.g. Ashmore, 2005) or reductions in forest biomass (Matyssek and Sandermann, 2003), the latter potentially compromising some of the ecosystem services delivered by forests (see GMT 8 for details).

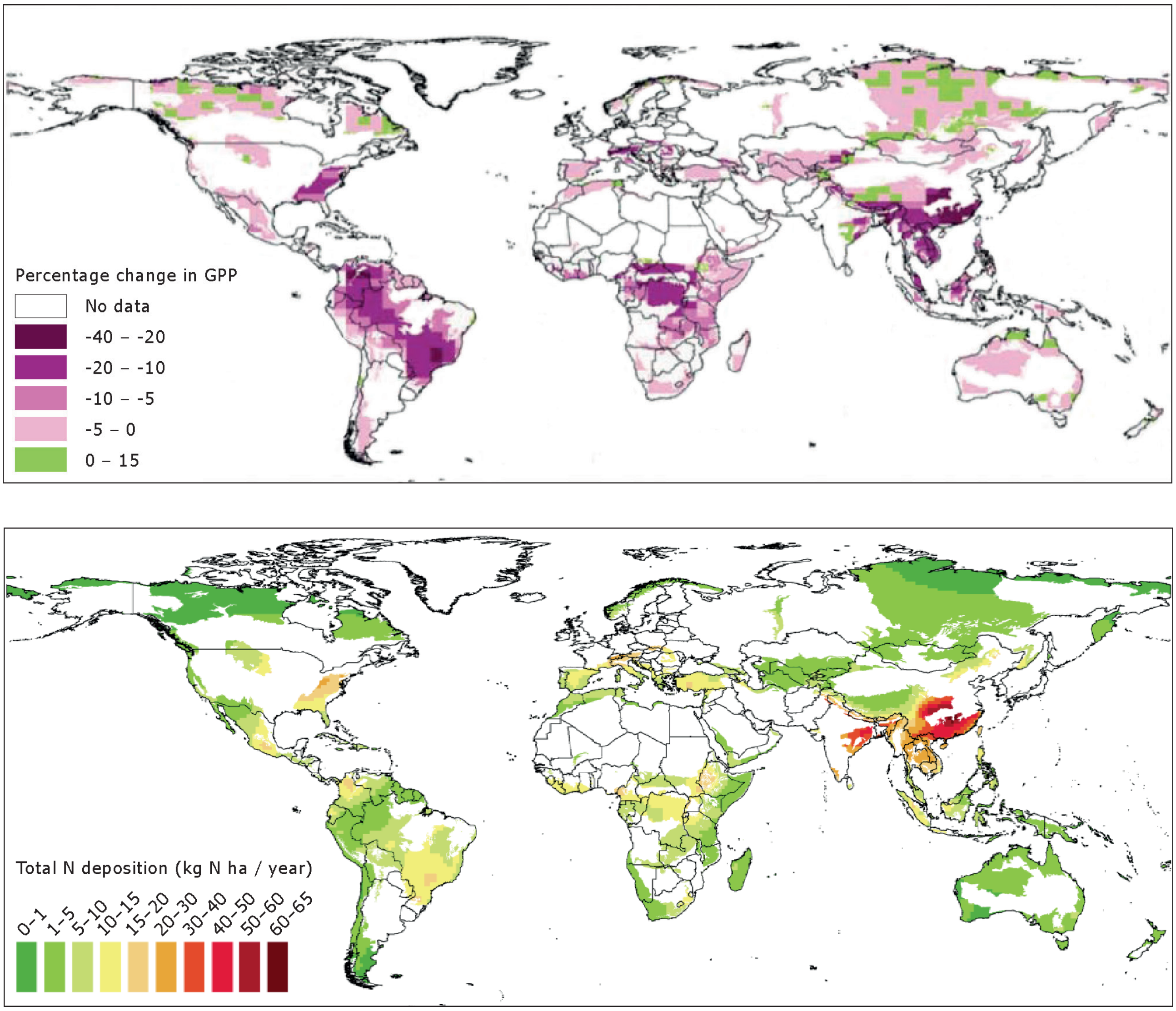
Studies of ozone impacts on ecosystems have so far focused mainly on North America and Europe. As a result, global effects are subject to substantial uncertainty. A global study based on the SRES high emission A2 scenario (IPCC, 2000) suggests that the risk of reduced plant productivity are greatest in eastern North America, central Europe, large parts of South America, central Africa and south-east Asia (see Figure 10.10, top).

Bobbink et al. (2010) show that some locations at high risk of ozone effects also face substantial risks from nitrogen deposition (Figure 10.10, bottom). Examples include the forests of south-east Asia and south-west China. These findings also need to be considered in the context of additional major threats to biodiversity such as habitat destruction and climate change (see GMTs 8 and 9).

Aquatic ecosystems

Many aquatic ecosystems are threatened or affected by eutrophication. Here, eutrophication refers to the process by which water bodies acquire high nutrient concentrations (in particular phosphates and nitrates) typically followed by excessive growth and decay of plants (algae) in the surface water. It may occur naturally (e.g. in deep waters)

Figure 10.10 Comparison of modelled changes in risks to biodiversity from ground-level ozone for the period 1900–2100 (top) and projected nitrogen deposition rates in 2030 (bottom)



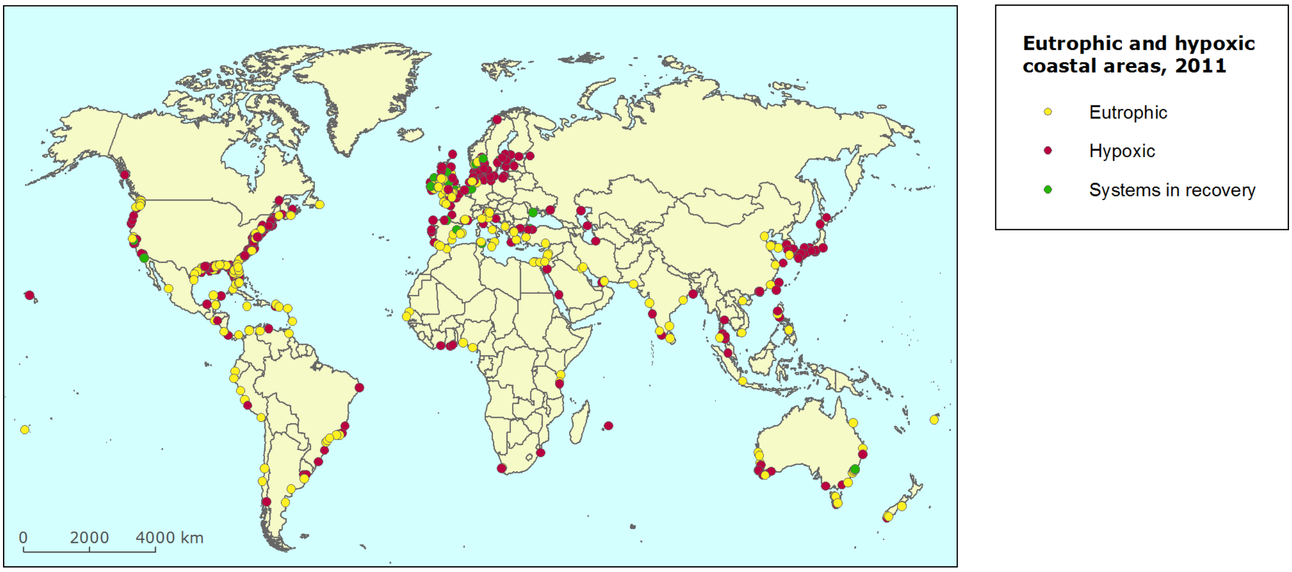
Note: GPP refers to global plant productivity and is here used as a proxy for the impacts of ground-level ozone on biodiversity

Source: Royal Society, 2008 (upper map); Bobbink et al., 2010 (lower map).

but is most often the result of pollution related to human activity, such as fertiliser runoff and sewage discharge and the atmospheric deposition of nitrogen compounds. This process has been linked to serious losses of fish stocks and other aquatic life (e.g. Jenkins et al., 2013).

Eutrophication may cause hypoxia, a state whereby aquatic ecosystems lack sufficient oxygen to support most forms of life, producing 'dead zones' (Rabalais et al., 2010). In marine ecosystems, most dead zones have developed along coasts since the 1960s due to environmental pollution associated with human activities. Just over 400 cases were reported globally in 2008 (Diaz and Rosenberg, 2008). By 2011 the number of documented cases increased to 762 coastal areas, with 479 sites identified as experiencing hypoxia, 55 sites improving after experiencing hypoxia, and 228 sites experiencing other symptoms of eutrophication (Figure 10.11). 'Dead zones' are particularly common along the coasts of Europe, North America and east Asia.

Figure 10.11 Eutrophic and hypoxic coastal areas, 2011



Note: Eutrophic areas are those with excessive nutrients (orange dots), putting them at risk of adverse effects. Hypoxic areas are those where oxygen levels in the water are already depleted and adverse effects expected due to nutrient and or organic pollution (red dots). Blue dots are systems that were hypoxic at one time but are recovering.

Source: WRI, 2013.

Many are concentrated near the estuaries of major rivers, and result from the build-up of nutrients carried from inland agricultural areas.

Eutrophication of freshwater ecosystems such as rivers and lakes also remains a key challenge (UNEP, 2012a). Estimates suggest that the number of lakes with hypoxia may increase globally by 20 % up to 2050 if existing legislative frameworks remain unchanged. Most of the projected increase may occur in Asia, Africa and Brazil (OECD, 2012).

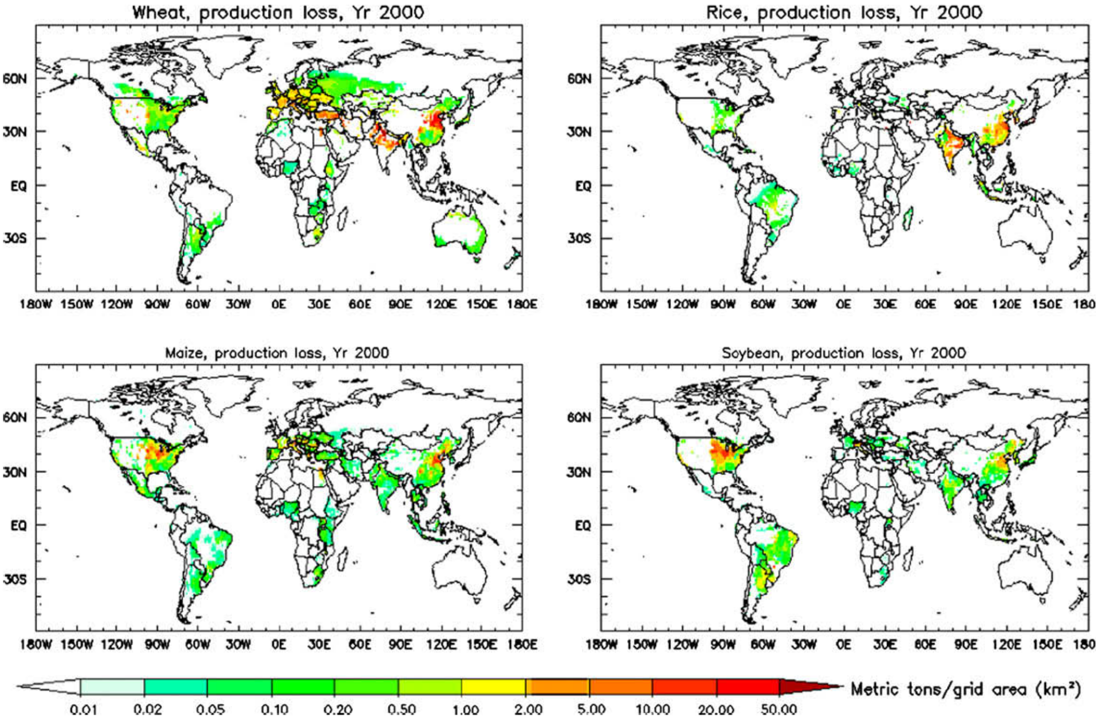
10.3.2 Agriculture and food provision

Like biodiversity, global agricultural production is mainly affected by the same two types of pollution and related processes: high concentrations of ground-level ozone and acidification primarily caused by sulphur and nitrogen deposition. Ground-level ozone is considered the most important air pollutant to vegetation (UNEP, 2012), on average causing larger economic damages than acidification (van Goethem et al., 2013).

Concentrations of ground-level ozone are unevenly distributed. In urban areas, periods of high 0_3 levels tend to be brief because O_3 reacts with other chemical pollutants, such as nitrogen oxides emitted by vehicles. In rural areas, elevated O_3 levels tend to last longer because substances that destroy O_3 are less prevalent. Furthermore, ozone is strongly phytotoxic, potentially causing a wide variety of damage to various ecosystems, most notably decreasing crop yields.

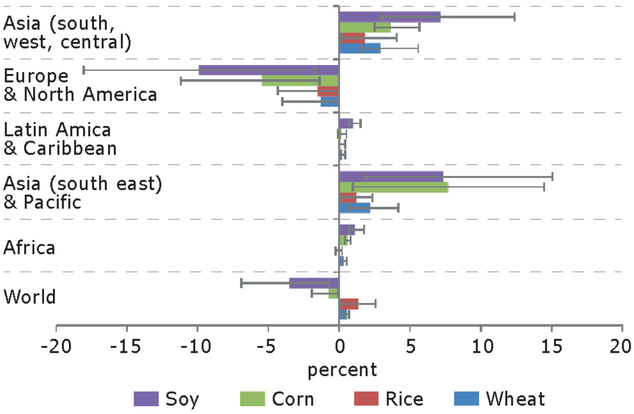
Global scale estimates based on concentration-response functions derived from chamber experiments suggest that relative yield losses (RYL) range between 7 % and 12 % for wheat, between 6 % and 16 % for soybean, between 3 % and 4 % for rice, and between 3 % and 5 % for maize, depending on the calculation approach (Van Dingenen et al., 2009). In terms of regional variations, Figure 10.12 highlights that high-production areas are associated with substantial production losses due to O_3. Depending on the crop, such areas are particularly situated in Europe, India, the mid-west United States, and eastern China. Assuming that current legislation remains unchanged, yield losses are projected to increase, particularly in Asia, and particularly for soybean and corn (Figure 10.13). In Europe and North America, yield loss is projected to fall, reflecting current emission reduction legislation (UNEP and WMO, 2011).

Figure 10.12 Modelled crop production loss due to O_3 for wheat, rice, maize and soybeans, 2000



Source: van Dingenen et al., 2009.

Figure 10.13 Differences in relative yield losses (RYL) between 2005 and 2030, for wheat, rice, maize and soybeans, for major world regions



Note: The 2030 scenario assumes the implementation of current legislation for the major world regions. Positive RYL values indicate an increase in crop yield loss in 2030 compared with 2005.

Source: UNEP and WMO, 2011.

Box 10.4 Key uncertainties regarding future loads of environmental pollution

As detailed in other GMTs, the key drivers of environmental pollution — population trends, economic growth, consumption patterns, technological change — are all subject to significant uncertainties. Rapid development of competitive alternative energy technologies, for example, could shift the incentives driving fossil fuel use and related pollution. Equally, a shift towards low meat diets could greatly reduce nitrogen inputs to agricultural production.

Experience suggests that future air pollution levels will depend greatly on the development and implementation of targets and agreements. In contrast to policies in other environmental areas, such as biodiversity, pollution abatement measures at the global and regional scales (e.g. the EU's National Emission Ceiling (NEC) Directive) have produced measurable results within comparatively short time horizons. The development and enforcement of abatement measures is therefore likely to have a major influence on whether or not the projected increases in pollution in Asia and elsewhere will become a reality. Changes in agricultural production systems (in particular in relation to nitrogen and phosphorus pollution) likewise appear to depend heavily on adequate policy development.

10.4 Challenges for Europe

The increasing scale of environmental pollution has created new governance challenges. Although policies aimed at reducing pollutant emissions on European territory have become increasingly effective, other world regions are likely to become more important in driving the absolute pollution burden in Europe and worldwide (UNEP, 2012a).

Trends in ambient concentrations of ground-level ozone and PM in Europe illustrate this challenge. European countries have significantly reduced anthropogenic emissions of ozone precursor gases since 1990. In general, however, ambient air measurements in urban and rural areas of Europe do not show any downward trends in ground-level ozone (EEA, 2013a). Similarly, sharp falls in emissions have not led to equally sharp falls in concentrations of PM in Europe (EEA, 2013b). These contrasting trends are at least partly explained by ample evidence of intercontinental transport of PM and precursor gases (EEA, 2012a). Indeed, for many European countries, less than 50 % of the observed fine particulate matter ($PM_{2.5}$) concentrations derive from their own emissions (EC, 2013).

The transboundary character of environmental pollution is also illustrated by the accumulation of persistent, bioaccumulative and toxic chemicals in the Arctic. Collectively, these trends suggest that Europe's capacity to manage environmental pollution and related impacts is constrained — and that the need for a global response to environmental pollution is likely to increase.

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