Planetary Health

Human Health in an Era of Global Environmental Change

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Contents

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Following a 15-year career in publishing, she joined the Royal United Services Institute (RUSI), a UK-based international policy think tank in 2007. Originally working as an editor within the National Security and Resilience Department, she moved into policy research and ran the Resilience and Emergency Management programme until 2017. Her portfolio covered risks on the UK National Risk Register from climate change, severe weather events, serious infectious disease and major industrial accidents. In 2013, her paper on the risks of antimicrobial resistance to business continuity was shortlisted for the Lloyds's Science of Risk Prize.

Alongside her work at RUSI, she lectured on the resilience module of the Geopolitics and Security master's programme at Royal Holloway, University of London, from 2013.

In 2017, Jennifer left RUSI to join the Oxford Martin School, University of Oxford, as public health policy adviser to the Rockefeller Foundation Economic Council on Planetary Health, a 2-year programme that ran from 2017 to 2019.

Since 2018, she has been working on two major projects at Royal Holloway, funded jointly by the Research Councils UK and the Indian Government Department of Biotechnology, examining the emergence and spread of antimicrobial resistance through the poultry food chain in India. As part of the Geopolitics, Development, Justice and Security (GDJS) group within Royal Holloway's Geography Department, she lectures on resilience, the governance of socio-ecological systems (SES) and climate change.

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Foreword

> The nation behaves well if it treats the natural resources as assets which it must turn over to the next generation increased; and not impaired in value.
>
> (Roosevelt, 1910)

Planetary health is a new and emerging field: one that is still finding its feet in academic and policy circles. It shares global health's focus on achieving health equity for all populations worldwide and one health's aims to integrate the health of humans, animals and the environment. It places a stronger focus than either, however, on the increasingly short time frame in which we may be able to address the environmental degradation that impacts on human health and the trade-offs that may be required to achieve this, for example in our ability to continue with high levels of energy use, meat consumption and consumer economies. Planetary health encourages us to clean up our act if we want future generations to live long and healthy lives.

Some of the environmental challenges the Earth faces are entirely natural – stories of famine, flood, plague and pestilence resonate through history. Others, however, are anthropogenic – caused or accelerated by human action such as fossil fuel consumption, land cultivation, global trade and international travel. Many factors impact on human health and the potential harm they can cause needs to be managed by individuals, populations and, in some cases, the entire human race. Human health and the health of the environment are inextricably linked.

But human exploitation of the environment and its natural resources has enabled incredible progress to take place over the past 10,000 years. The development of farming, the growth of cities and discoveries in medical science have led to a world in which living beyond 90 years of age is no longer uncommon in many nations – though by no means all: there are still far too many countries in which babies, children and adults die from preventable infections or malnutrition, and where diagnosis and treatment of cancers, heart disease and other later life conditions fall far short of what is possible. Furthermore, it is no longer the case that life is cut short by natural hazards that pose health risks only to the poverty-stricken: in all regions – including those that are affluent and developed – poor diets, sedentary lifestyles and air pollution from vehicle fumes are increasingly impacting on health. At a global level, climate change, plastic pollution and insecure food systems threaten the health of the human race and of the environment in which we live.

Planetary health addresses these challenges by encouraging students, scholars, policy makers and practitioners to look at the health of humans and of the environment not as separate issues, siloed from one another, but holistically so that the health of one can be improved by acting on the health of the other. This requires cross-disciplinary approaches that are unafraid to challenge the status quo and prepared to consider sometimes radical solutions.

This book aims to act as an introduction to planetary health: (i) its key concepts; (ii) the different ways in which challenges can be approached; (iii) the types of challenges encountered; and (iv) how solutions to these challenges are being found and implemented. The cross-cutting principles for planetary health are outlined in Box A. Through the use of case studies, it highlights how approaching human and environmental health holistically through a planetary health lens can provide actionable solutions that achieve better health for all.

Jennifer Cole
December 2018

Reference

Roosevelt, T. (1910) Speech before the Colorado Livestock Association, Denver, Colorado, 19 August 1910.

Box A. Cross-cutting principles for planetary health education[1]

Sara B. Stone, Samuel S. Myers, Christopher Golden and Amalia Almada

1 A planetary health lens
A planetary health lens enables understanding and appreciation of crucial linkages, cause–effect relationships, and feedback loops between environmental change and human health. This lens allows for the recognition and exploration of how human stewardship of the Earth is a primary determinant of future population health.

2 Urgency and scale
The field of planetary health is driven by the scale of environmental change, its effects on human health, and the urgency with which the global population must respond. Examining the complexity of interactions (e.g. geographical and temporal scale) that shape planetary health challenges will help to reveal potential solutions for sustainable human health outcomes.

3 Policy
Planetary health is intrinsically policy oriented. By quantifying the effect on human health of anthropogenic environmental changes and communicating this to stakeholders at many levels, collaborative work can be done across sectors to identify policies and practices, both local and global, to protect and improve the health of global populations. An appreciation for agencies at the individual and community level is key for a meaningful and context-specific translation of research into policy and action.

4 Organizing and movement building
The capacity to mobilize and manage resources and people power is key when considering solutions to challenges in planetary health. Organizing in the community and movement building in the political process are appreciated for their influence as bottom-up approaches to policy change both locally and globally.

5 Communication
Challenges in planetary health are complex, spanning different disciplines, sectors, geographical regions, cultures and scales; therefore, effective and meaningful communication across these arenas is needed, with a focus on translating planetary health science. Selecting the best suite of tools to convey the challenges and solutions of planetary health to diverse audiences, as well as an appreciation for listening as a part of effective communication, is vital.

6 Systems thinking and transdisciplinary collaborations
An understanding of planetary health necessitates engaging with many disciplines and stakeholders to understand and propose solutions to complex challenges. Systems thinking and knowledge integration is essential for collaboration across disciplines and the development of sustainable solutions to overcome existing gaps in research design and associated policy development.

7 Inequality and inequity
Understanding the differences between equality and equity in theory and practice, including concepts of marginalization, vulnerability, resilience, and who benefits and is harmed in a given scenario, is a core objective of planetary health theory. The effects of environmental change on human health are

Continued

Box A. Continued.

heterogeneous and mediated by factors such as geographical scale, temporal scale, socio-economic factors, and political and cultural context highlighting the importance of thinking critically about whose health is at stake and how it is measured.

8 Bias

Political, social and economic dynamics can drive the presentation and perceptions of environmental change and the resultant health effects. Vested interests of different stakeholders, both in support of and against the factors that affect the connection between environmental change and human health, must be recognized.

9 Governance

Governance – the high-level strategy used by a leader or leadership team in their processes of decision making and implementation – can turn capacity into action and generate capacity when it does not exist. Governance requires dealing with institutional issues, managing political interests and making leadership more effective. Challenges in planetary health can be created or aggravated by the failures of governing bodies to cooperate across populations, regions and boundaries, especially where effective cooperative mechanisms are not yet established.

10 Unintended consequences

Surprising and unexpected consequences of environmental change, both positive and negative, are inevitable. This represents a systemic uncertainty that requires a shift in government, corporate and community mindsets to allow for increased adaptive capacity, and an emphasis on programmes that increase socio-ecological competence, community resilience and sustainability.

11 Global citizenship and cultural identity

A global citizen is someone who sees themselves as part of the international community and whose actions help define the community's values and practices. Realizing cultural identities and recognizing one's inherent membership in both local and global communities, offers opportunities to help define the values and practices of the next generation to positively affect present and future communities.

12 Historical and current global values

An understanding of the past is necessary to solve the problems of the present. To grasp the necessity and urgency of planetary health, we need to be aware of the historical perspectives and milestones that have laid the foundation for the field, including those perspectives that have been historically marginalized or ignored. To identify opportunities for positive interventions, we must recognize patterns over time and appreciate current global context.

Note

1. A version of these principles first appeared as part of: Stone, S.B., Myers, S.S., Golden, C.D. and PHEB (Planetary Health Education Brainstorm) Group (2018) Cross-cutting principles for planetary health education. *The Lancet Planetary Health* 2(5), e192–e193.

Introduction to Planetary Health

1

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1.1 Introduction

Humans are not separate from the environments in which we live. We are integrated with them through the air we breathe, the water we drink, the food we eat and the waste we produce. Even within ourselves, the human body does not represent a single organism but a complex biological system (Bono-Lunn *et al.*, 2016). Many of the cells within us come from bacteria, viruses or other microorganisms with which we coexist, and which help or hinder our interaction with the wider, external environment (Rook *et al.*, 2017). We are an integral part of the wider biosphere of Earth.

The proper functioning, resilience and diversity of Earth's biosphere determines the health of the planet and those who live on it, but this is now under severe stress (Steffen *et al.*, 2006). Over the past 10,000 years, since the beginning of agriculture and the emergence of the first cities, humans have altered the environment to benefit our own species without due consideration for the impact this has on others or on the Earth itself. We have removed finite resources such as iron, coal, oil and gas (Geels *et al.*, 2017; Sovacool, 2016). We have polluted air, water and land and have depleted potentially sustainable resources such as forests, soil micronutrients and marine life at rates that nature cannot replace. The impact of this on the environment is well documented (MEA, 2005; Landrigan *et al.*, 2018). The way in which human health is changing, thanks to advances in sanitation and medical science, is also well understood – smallpox has been eradicated completely (Henderson, 2017), rubella has been eradicated from the Americas, and we are on the brink of seeing global success in polio eradication (Cochi *et al.*, 2016). But as the risk from infection decreases, rates of heart disease and cancer are rising (Horton and Sargent, 2018) – driven by changes to land use, energy production, air quality, longer life and the lifestyle choices we make.

1.2 Human Health and the Environment

Exactly how the environment impacts human health is complicated, however, particularly at the global level. On average, we are living longer than ever before:

human life expectancy has risen from 30–40 years before the 19th century to more than 80 years in some parts of the world today, with a global average life expectancy at birth of 71.4 years in 2015 (WHO, 2015). In the 19th century, only 50% of children survived to their fifth birthday, whereas in most developed countries today, child mortality is a fraction of 1%. Between one in 100 and one in 200 births resulted in the mother's death, compared with just two to three in every 100,000 in some countries today. In this respect, the Earth of the 21st century is a healthier environment for humans than it ever was in the past.

This is not only related to the food security agriculture can offer and the services and more stable environment of cities, however: medical science also plays an important part. Many previously fatal conditions, such as cancer, diabetes and human immunodeficiency virus (HIV) infection can now be managed with medical care.

We are becoming complacent about the state of the natural environment, however. Progress and development provide clean water and sanitation to urban populations, wiping away diarrhoeal disease and infection, but they also pollute that same population's air through the use of carbon fuels, uncontrolled vehicle emissions and industrial chemicals (Lelieveld *et al.*, 2015). Moreover, access to this progress is extremely uneven: in 2016, one in eight people worldwide did not have access to electricity, rising to nearly one in four in rural areas (World Bank Data, 2018).

Reports such as *Safeguarding Human Health in the Anthropocene Epoch: Report of The Rockefeller Foundation–Lancet Commission on Planetary Health* (Whitmee *et al.*, 2015; Haines, 2016), the Global Burden of Disease (GBD) study (GBD collaborators, 2016) and the World Health Organization's *Preventing Disease through Unhealthy Environments* (Prüss-Üstün and Neira, 2016) estimate that in 2015, as many as 12.6 million deaths globally – 23% of deaths worldwide – were attributable to environmental factors that could be eliminated or avoided. Out of 133 diseases or injuries considered in GBD, 101 have significant links with the environment (Prüss-Üstün and Neira, 2016).

Scientific and medical progress has given us the ability to offset ill health with treatment – if we can afford to pay, but many cannot. Vast disparities in health between different countries are tied closely to their level of economic development, affecting life expectancy at birth and the incidence and type of ill health that impacts their populations throughout life (OECD, 2017). Such disparities are even apparent within countries, based on socio-economic status, ethnic group and gender (Hotez *et al.*, 2016). Exposure to environmental risk factors such as air pollution and contaminated water supply is often much higher in low- and middle-income countries than in high-income ones. If we placed more value on the environment, and the impact it can have on health, we may be more inclined to protect it – and the health of those who live in it into the bargain.

1.3 Human Health and Environmental Change

Whereas the academic fields of global health and one health consider the impact of the environment on the health of humans and animals today, planetary health is concerned not only with the current state of the Earth but also with environmental trends and the impact they may have on future generations. Environmental *change* is as important as the prevailing environmental *conditions*.

Global environmental change is closely associated with the forces of the Great Acceleration (Steffen *et al*., 2007) (see Chapter 2, this volume), a profound transformation in the relationship between humans and the natural world that began in the middle of the 20th century and which has influenced all components of the global environment since: the oceans, the atmosphere and land. There is increasing evidence that global environmental change harms human health through a variety of direct and indirect pathways leading from these accelerations. Major adaptations to the drivers of these trends, such as a move towards the use of cleaner energy and the development of less damaging agricultural practices, are needed to ensure that the environment is sustained for future generations.

For public health experts, environmentalists and policy makers to support such adaptations, a strong understanding is required of the relationship between human health and the environment, how it has changed over time, how it is likely to change in future (Fig. 1.1), and how human culture and psychology influences the problem space as well as the solutions. This book aims to provide a starting point towards that end, by helping readers to understand how the conceptual underpinning of the Great Acceleration helps us to understand how environmental change impacts on humanity and to recognize the urgency with which we need to act.

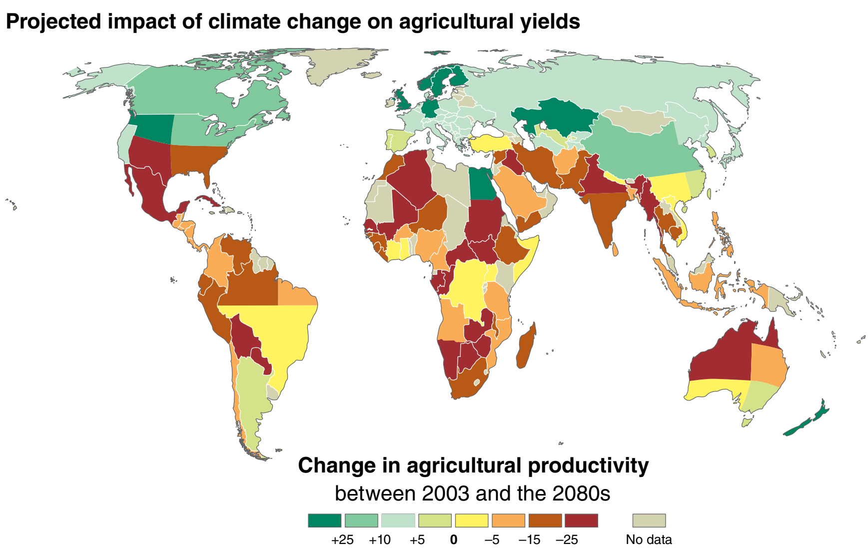

Fig. 1.1. Which parts of the Earth are most able to grow food is likely to change in coming decades as the climate changes. This will require agricultural systems, geopolitical alliances, trade agreements, labour markets and diets to adapt to the new conditions. (From Cline, 2007.)

1.4 A Systems Approach to Planetary Health

A particularly valuable aspect of the Great Acceleration framing is that it immediately places both the changes and the drivers of change within two parallel systems – the Earth system and the socio-economic system – that influence, and are influenced by, one another. The Earth system is influenced by chemical flows such as nitrogen and phosphorus into agricultural land, the atmosphere and water courses. These flows in turn are driven by socio-economic changes in farming practices and urbanization. Increases in the concentration of methane, carbon dioxide (CO_2) and nitrous oxide (N_2O) into the atmosphere are caused by increases in global transport, international tourism and population numbers. Together, Earth systems and socio-economic systems form a single, socio-ecological system (SES) (Ostrom, 2009), the understanding of which provides a framework for how the natural world and the actors (individuals, groups and institutions) who influence it fit together. The SES concept conceptualizes the integration of humans *in* nature, rather than of humans *and* nature. A planetary health approach should consider how multiple systems (for example, water systems for both irrigation and sanitation), fit together and also intersect with other systems (for example energy systems), that can complement one another (Fig. 1.2).

The SES is a complex adaptive system (CAS) (SRC, 2018), in which local actors interact with others to instigate the (usually gradual) emergence of small changes that slowly accumulate into large changes. The system thus displays 'path dependency': an event in its past determines its future development.

Adaptation and transformation

Changes in the system can be 'adaptations' or 'transformations' (Barnes *et al.*, 2017). Adaptations are small changes that enable the system to adjust without fundamentally changing: for example, gradual coastal erosion over many decades may slowly move a community further inland as new structures are built on higher ground, but this is managed smoothly and has little obvious effect on the community or its way of living. Transformations are more fundamental changes that happen when the existing ecological, economic or social conditions make the existing system untenable. For example, severe coastal flooding may devastate a coastal town to such an extent that the community disperses; fishermen may lose their livelihoods and seek different employment elsewhere. In retrospect, a series of adaptations may look like a transformation if compared between two fixed points in time, but if the end point has been arrived at through a continuous series of small changes, the process is likely to have been much less disruptive for those living through it.

Adaptation to ecological and environmental changes enables the maintenance of existing socio-economic conditions and preserves the health and well-being of the population. The ability to adapt is, however, dependent on social capital, collaboration and cooperation. Adaptation can happen from the ground up, with

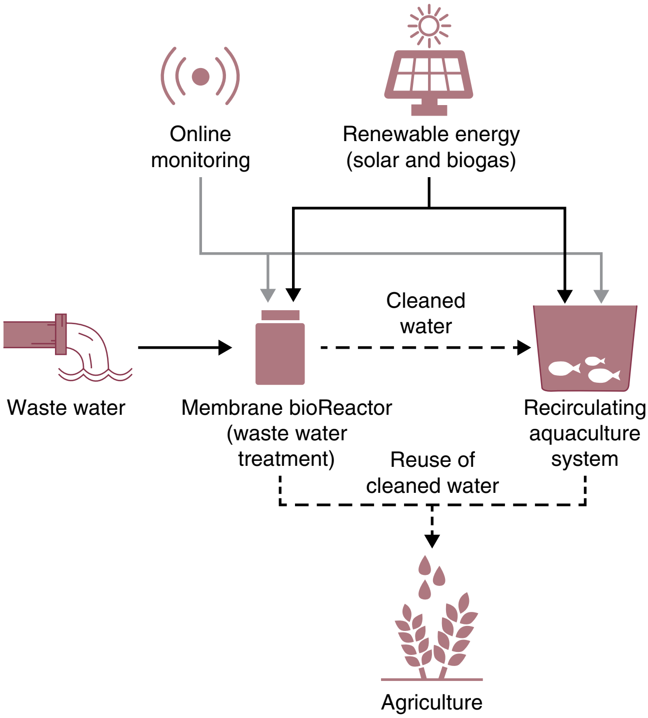

Fig. 1.2. Thinking of sanitation as a system that interacts with energy systems and agriculture as well as water can help to ensure the full benefits of changing current practices are captured. (From Mancuso *et al*., 2017 – VicInAqua, Horizon2020.)

little need for formal governance, or may be agreed at a more strategic level and implemented downwards through institutional rules and regulations. It tends to have low(er) financial and political costs and few(er) disadvantages to the people who are adapting.

Transformation, on the other hand, is more likely to be abrupt and to need more strategic direction (such as international or national governance). This usually invokes high(er) costs in the short term, though there may be much larger longer-term advantages. Transformation can enable a system to bounce forward into a better state, rather than bounce back to the same vulnerable conditions it was in before. It is worth bearing this distinction in mind when considering planetary health, and also the different methods by which adaptive and transformative change might be managed. Humans are the most powerful actors in SESs: we have the power to exert or resist the pressures that will require adaptation or transformation and can dampen or strengthen our actions (Kittinger *et al.*, 2013) within the constraints of the environment and its resources. In this way we can instigate, mitigate or avoid tipping points beyond which transformation is inevitable.

Humans may choose to deliberately push the system, or a component of the system, towards a transformation that can be managed smoothly, in order to avoid a different transformation that might be more difficult. For example, a transformation within the socio-economic system towards clean energy use is likely to be more easily managed than an environmental transformation resulting from an average global temperature rise of more than 2°C above pre-industrial levels.

Identifying precursors for adaptation and transformation

Planetary health solutions are likely to come from diverse directions, including sociology, economics, political science, technology and law (Cole and Bickersteth, 2018). Each of these has its own internal systems, and researchers should aim to determine how best to identify preconditions or enablers for adaptation and transformation of and within these systems. Population-wide attitudes may gradually shift towards a more environmental outlook, for example enabling a transformative policy that would not have been adopted at one point in time to be attractive to the government some time later. Key questions to ask include: (i) How best can we prepare for and manage both adaptation and transformation?; (ii) How do social structures relate to ecological structures and to the specific environmental problem at hand?; and (iii) How does this affect the narratives, social movements, governance structures, economic tools and financing mechanisms through which such issues might be addressed in future? It is also important to consider the political ecology of the system in which the adaptation needs to take place. A corrupt government may, for example, give subsidies to oil companies ahead of investing in a clean energy transition – the political system may need to be adapted or transformed before a similar change can take place in the technological one.

Adaptation across any system, and particularly one as large and complex as the SES of Earth, is a continual process: it may not have a clear start or end point. How decisions are made and enacted in this context, particularly under the stress of imminent environmental change, is an area ripe for further research. Longitudinal analysis, with inputs from behavioural and evolutional psychology, network and systems science will be required as well as those from human health and environmental science.

1.5 Conclusions

Planetary health is a challenging approach that draws in many diverse fields and disciplines. This favours a systems approach – such a conceptual framework is already well established in ecology, environmental science, sociology and governance studies. It provides a way to understand equilibrium, adaptation and transformation, the drivers of each state and the governance that can maintain the status quo or manage the transition to a 'new normal'. It provides a framework for when stress should be absorbed, and highlights that not all stress is negative – some stresses can be forces for good, preventing stagnation and nudging the system towards action.

The following chapters of this textbook will introduce four approaches (evolutionary biology, transhumanism, natural capital and one Earth) to how pressures on the system might be identified and potential adaptations and transformations managed. It will introduce key concepts that can help to conceptualize and understand SESs and the impact they have on human and environmental health. These are not necessarily the only concepts, nor the only approaches that have value, but they aim to provide a starting point from which newcomers to the field can explore, understand, influence and hopefully work to improve planetary health.

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2

Key Concepts in Planetary Health

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2.1 Introduction

The field of planetary health is cross-disciplinary, drawing on knowledge, literature and methodologies from global health, public health, environmental science, economics, ecology, anthropology, geography, geology, psychology, medicine, resilience, organizational theory and many others. A number of key concepts drawn from across these fields underpin ideas on and approaches to planetary health. This chapter will briefly introduce the main concepts that will be returned to throughout the chapters of this book through three key themes: (i) how humanity is changing the Earth; (ii) where Earth's natural limits may lie; and (iii) how we may need to re-evaluate our relationship with nature to ensure a secure future for humanity.

2.2 Humanity is Changing the Earth

The Anthropocene

The 'Anthropocene' refers to a period of time during which human activity has had more of an impact on the Earth than natural events. Over the course of history, changes in temperature, climate, ecosystems and species living on the Earth have occurred naturally – fluctuating between ice ages and warmer periods, for example. Our environment is now more heavily influenced by human activity, however (Gaffney and Steffen, 2017). Burning fossil fuels releases large amounts of CO_2 into the atmosphere and causes global warming. Wild forests and grasslands are cultivated to grow crops and graze food animals. The ozone layer has been severely damaged by chlorofluorocarbons (CFCs) from refrigerators and aerosols. These 'anthropogenic' changes are so significant that some scientists argue that the period – or even the era – in which they have occurred should be considered separate from previous ones (Crutzen, 2006; Glikson, 2013).

(a) **The Great Acceleration: Earth System Trends**

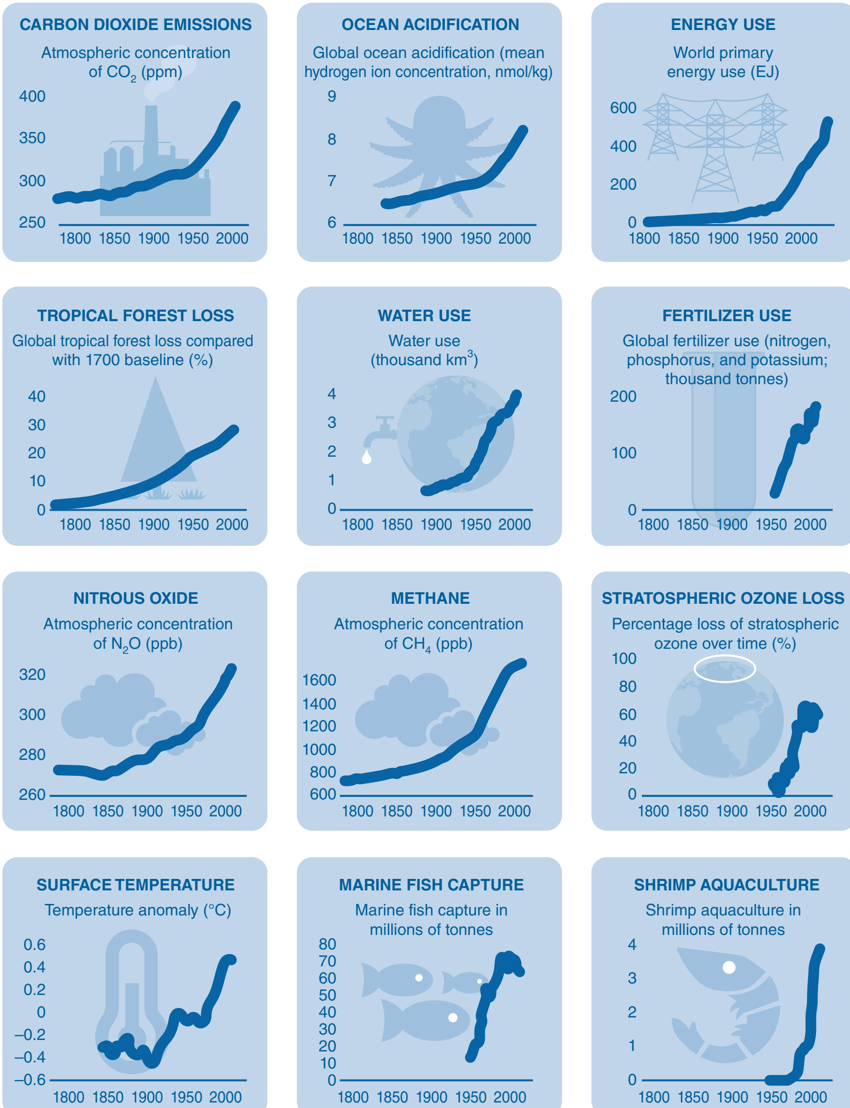

Fig. 2.1. The concurrent increase in a number of Earth system (a) and socio-economic (b) trends shows the interrelated impacts of human activity on the planet, at a global level, over recent time. Most trends started at the beginning of the Industrial Revolution in Europe but have accelerated dramatically since the mid-20th century. This impact has been particularly dramatic since 1950. Many trends, including domestication of land, population, use of transportation and biosphere degradation are now accelerating at a pace that cannot be sustained without major systemic change. (From Steffen *et al*., 2004.)

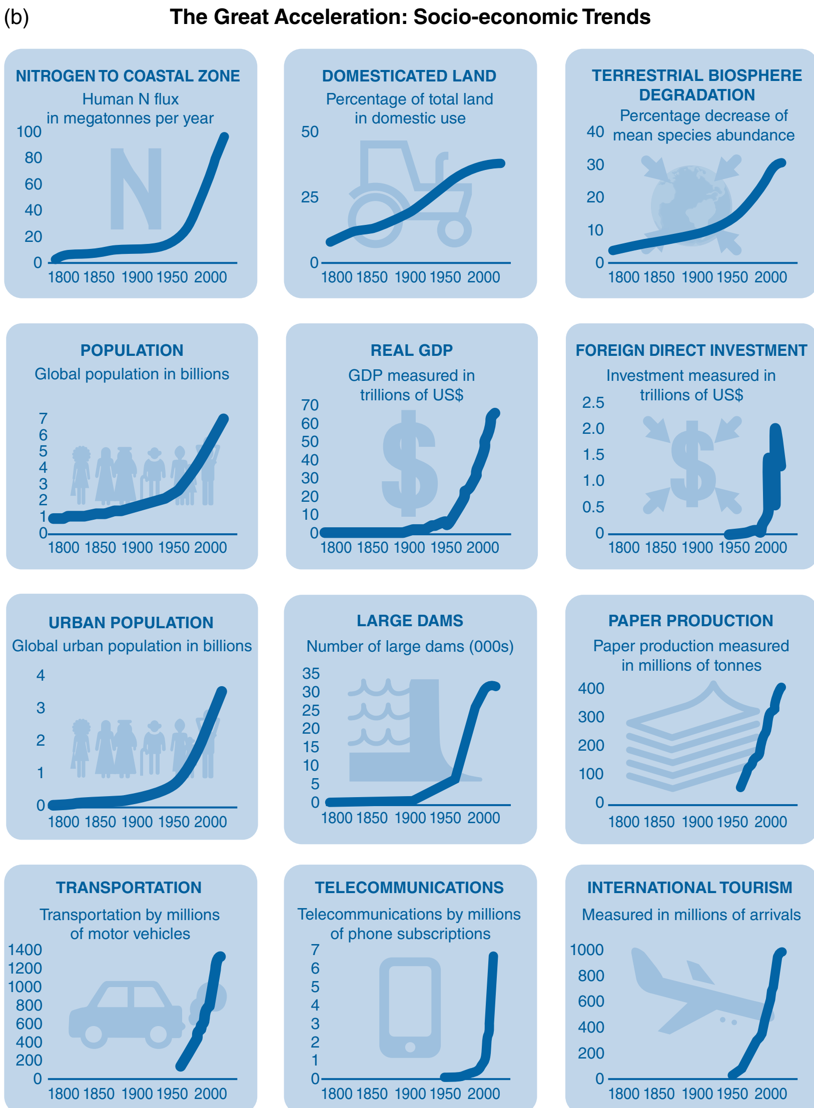

Fig. 2.1. Continued.

In May 2019, the Anthropocene Working Group of the Subcommission on Quaternary Stratigraphy, voted that the Anthropocene should be formally recognized as distinct from the Holocene (AWG, 2019), the currently recognized time period in which we live, part of the Quaternary Period of the Cenozonic Era; a subsequent vote will be required to determine when exactly it should begin (and thus when the Holocene ends). The Holocene started *c.*11,700 years ago with the end of the last ice age, and can be subdivided into two further periods, the

Hypsithermal and Neoglacial periods. The boundaries of these periods roughly align with the beginning of the Stone Age and Bronze Age. The Holocene also sees the emergence of agriculture, human settlements and the first evidence of considerable human impact on the environment – human farming activity, which accelerated the desertification of the Sahara in Africa at the end of the African Humid Period (Wright, 2017). Some authors argue this is a reason for dating the beginning of the Anthropocene to this time, while others argue for 1750 (the invention of the steam engine and the beginning of the Industrial Revolution) or the 1950s (the exponential increase of the Great Acceleration curves). The Anthropocene Working Group strongly favours, and has proposed for adoption, the mid-20th century as the starting point for the Anthropocene.

The Great Acceleration

The Great Acceleration refers specifically to the period from the middle of the 20th century to the present day, at the start of which the rate of environmental change caused by anthropogenic factors – including atmospheric concentrations of CO_2, nitrous oxide (N_2O), methane and ozone; ocean acidification; tropical forest loss, and the surface temperature of the Earth – began to increase exponentially, and above levels that would have been observed without human intervention. Alongside these 'Earth system' trends, socio-economic trends such as overall population numbers and the percentage of the population living in cities, wealth (measured as gross domestic product (GDP)), and number of motor vehicles, have also risen quickly, giving rise to the term the 'Great Acceleration'.

Many of these trends cannot continue indefinitely without irreparably altering parts of the Earth's natural systems to a point where the planet, or large parts of it, may become inhospitable to human life – for example, unable to produce enough food for the population, or too hot, too short of water, or flooded. The graphs showing these trajectories, which have come to be known as 'the Great Acceleration graphs' (Fig. 2.1) were designed and constructed as part of the International Geosphere–Biosphere Programme (IGBP) conceived by Paul Crutzen in 2000, first published in 2004 (Steffen *et al.*, 2015a) and influenced the introduction of a new academic journal, *The Anthropocene Review*, in 2007 (Steffen *et al.*, 2007). The upward trajectories of the Great Acceleration cannot continue indefinitely if the future environment of Earth is to remain comfortably habitable for most of its inhabitants.

2.3 Beyond Earth's Natural Limits

The Limits to Growth

The term Great Acceleration was coined in the early years of the 21st century but concerns over the influence of humans on the Earth is not a modern concept. Ancient texts displaying fears of Earth's perceived overpopulation date back 4000 years (Kilmer, 1972); a desire to depopulate the planet is one of the reasons given in *The*

Illiad for the Greek gods beginning the Trojan War (Reeves, 1966). In 1798, Thomas Robert Malthus observed that as living standards improved and the population increased, resources became more limited, but that rather than preserving resources by attempting to limit the population, humankind showed no such constraint (Malthus, 1826). This concept is known as the 'Malthusian trap'. Evolutionary biologists have even proposed that the human race is 'hard-wired' to reproduce more offspring than it needs, even in low resource settings (Hill and Reeve, 2004).

The Limits to Growth (Meadows *et al.*, 1972), a 1972 report commissioned by the Club of Rome,[1] posited that problems facing the human race, including environmental degradation, poverty, criminality and ill health, cannot be addressed in isolation. All are interrelated and need to be addressed holistically. Equally importantly, it suggests that economic growth cannot continue indefinitely if it depends on resources that are being depleted.

A second report, published in 1991, suggested that to act collectively, humankind would need a common enemy: framing pollution and environmental damage as this enemy may improve the chances of collective action. Evolutionary anthropologist Michael Tomasello's work points to a common intentionality – a shared sense of 'we' – as a driver of human cooperation (Tomasello, 2009). *Our Common Future* (Brundtland, 1987), the 1987 report of the World Commission on Environment and Development, further frames the need for collective action on a global scale. If humanity cannot unite behind the common enemy of environmental harm, many Earth systems face collapse by around 2050.

Planetary boundaries

The idea of Earth's system collapse set out by the Club of Rome underpins the 'planetary boundaries' concept proposed in 2009 (Rockström *et al.*, 2009). This sets out thresholds for nine Earth-system processes which must not be transgressed if the human race is to remain in a 'safe operating space for humanity' (Fig. 2.2). Breaches could result in catastrophic and irreversible damage to Earth as a habitable space for its human population. An example of one planetary boundary is stratospheric ozone depletion – the loss of the ozone layer protecting the Earth's surface from ultraviolet radiation that causes skin cancer and cataracts. Another is ocean acidification. The boundaries were developed with the help of scientific evidence, but to a large extent they were arbitrary values, highlighting knowledge gaps as much as robust evidence, and are the subject of substantial uncertainty: no one knows for sure what will happen until they are crossed, but by that time it may be too late.

They do, however, provide a useful framework within which to consider the impact that human activities are having on the planet, and to think about how we may scale back or adapt these practices to be less damaging, either by reducing the activity that brings us closer to the threshold being crossed, or by finding a way to undertake the same activity in a way that has less environmental impact (Steffen *et al.*, 2015b). For instance, we could reduce greenhouse gas emissions by using less energy (but this would offset the benefits of electricity, such as heat and light

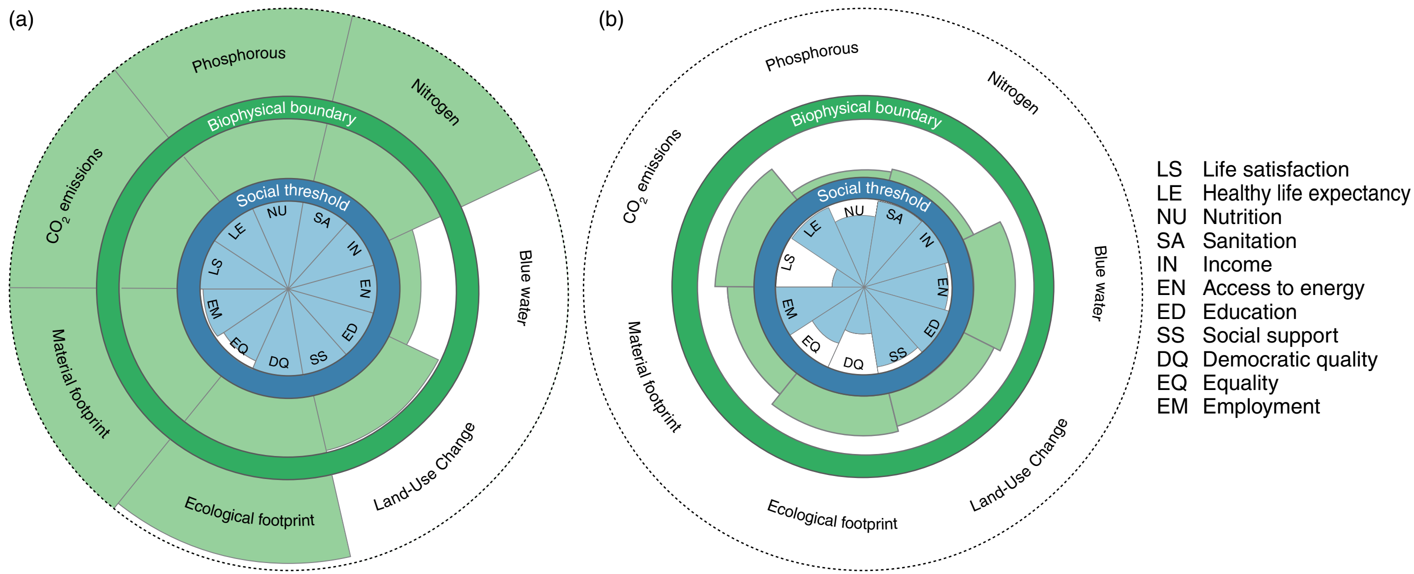

Fig. 2.2. Increasingly, attention is being paid to how humanity can achieve social targets linked to well-being and prosperity, such as universal access to improved sanitation, education and clean energy, while not inflicting permanent damage on the environment. Projects such as Leeds University's 'A Good Life for all within Planetary Boundaries' show that most developed countries (e.g. UK, shown left) come close to meeting social thresholds, but at the expense of biogeophysical ones. Developing countries, such as Sri Lanka (shown right), stay within planetary boundaries but often fall short on social targets. (From O'Neill *et al.*, 2018; used with permission.)

in winter, refrigeration and air conditioning in summer, both of which improve health) or by finding ways to create the same amount of energy without releasing greenhouse gases – for instance by moving from coal-fired electricity generators to solar power, or from diesel-fuelled cars to electric vehicles.

An important part of the planetary health approach is considering advantages, disadvantages, and trade-offs of every option, and how these interact and influence one another.

Global footprints

A useful way to conceptualize humanity's individual and collective impact on the Earth is through the idea of 'global footprints' – which may be measured by carbon footprints (Wiedmann and Minx, 2008) (the amount of carbon used), ecological footprints (Global Footprint Network, 2012; Rees, 2018), which measure the total amount of ecological harm caused, or across a number of different footprints. Such footprints measure the human demand on nature, through accounting for supply versus demand: can the Earth supply what the human race is demanding at a rate that it can be replaced, or will the resource (e.g. fuel, freshwater, forests) eventually be used up? The more people there are, the smaller each one's footprint needs to be, so as population increases, consumption either needs to go down, or the resources used need to be managed in a more sustainable way. The alternative is to have fewer people, each of whom could then 'afford' a larger footprint.

At present, people living in different regions of the world have very different sized footprints. Based on the size of footprint the Earth could sustain, if every person alive had an equal one, the average resident of Qatar has a footprint ten times the sustainable level, and most European countries have a footprint at least six times too high. Fewer than one in ten countries worldwide have a footprint less than 1.0, and most of these have populations in extreme poverty.

This cannot be sustained indefinitely, and planetary health must find a way to address this by promoting more frugal use of resources, replenishment of natural resources where they can be renewed, and by recycling resources so that as little as possible is lost. Human waste, for example, can be reused as natural fertilizer; paper use is less of a problem if trees are replanted to replace those cut down; clothes can be passed on, sold second-hand or the fibre recycled. A planetary health lens helps to see the need for economic development *and* sustainability: they are inseparable and interconnected.

Sustainable Development Goals

The need to consider trade-offs between one course of action and another is extremely important to planetary health because of its incorporation of concepts around equity, equality and standards of living. Human health (measured by the number of years we live) and our quality of life (measured by the quality of our housing, education, access to sanitation, electricity, job opportunities and democracy among others) has improved considerably across the same period that the environment has been degraded for many – but not all – of the world's population. To stop this progress now, for the sake of the environment, would condemn millions to lives of inescapable poverty, unable to access the benefits that come with electricity, road and transport infrastructure, modern farming practices, or the health systems, secure food supply and sanitation systems that need a strong and stable economy to support them.

For this reason, considerations of planetary health also need to bear in mind the aims and targets of the Sustainable Development Goals (SDGs) (Sachs, 2012) set by the United Nations in 2015 to 'eradicate poverty in all its forms' by 2030 (Fig. 2.3). Importantly, the SDGs acknowledge that the targets must be achieved in a way that does the least damage possible to the environment. For instance, Goal 7 – Affordable and Clean Energy – requires the share of renewable energy in the global energy mix to be increased, not just the proportion of the global population with access to electricity. Goal 12 – Responsible Consumption and Production – requires people to be made aware of the impacts made by their lifestyle choices. Goal 14 – Life Below Water – requires regulation to control overfishing and a reduction in fishing subsidies, which could be seen to be in competition with Goal 2 – Zero Hunger. Finding a balance between meeting the targets of the SDGs while remaining within planetary boundaries is a driving force of the planetary health approach.

2.4 Re-evaluating Humanity's Relationship with Nature

Gaia theory

In the 1970s (at around the same time as the Club of Rome published *The Limits to Growth*), atmospheric chemist James Lovelock proposed the Gaia hypothesis (Lovelock, 1972) – that Earth can be seen as a single living entity or biosphere, as conditions in which life can flourish are maintained by the planet's biota. The theory was expanded by microbiologist Lynn Margulis (Lovelock and Margulis, 1974). The name Gaia is from the Greek goddess of the Earth, similar in concept to Mother Nature – though Lovelock's approach to his theory was purely scientific. The root of the goddess's name, gea, also gives us the geo in geology and geophysics (Rolston, 1998).

Gaia theory links geophysical cycles (many of which are key to the planetary boundaries concept discussed above) with the biological cycles of living organisms. The homeostasis (steady state) of the Earth's environment, including the composition of atmospheric gases, the pH (acidity or alkalinity) of the oceans, and the climate are maintained by and for the existence of life forms on the planet, just as an individual organism maintains its own body temperature, through an active, adaptive control mechanism (humans maintain a body temperature of around 37°C regardless of the external temperature of the environment).

Fig. 2.3. The Sustainable Development Goals (SDGs) of the United Nations.

Within the wider environment, humans take in free energy, in the form of the chemical potential difference between food and oxygen (which is taken into the human body as fuel) and excrete waste chemicals and heat to the atmosphere. The boundary between the 'inside' of the human body and the non-human 'outside' is the skin. A plant takes in energy in the form of light from the sun and produces oxygen (O_2) – which enables humans to breathe – and grows, producing the fuel (food) which humans and other animals need to survive. As humans cannot create energy direct from sunlight, the true 'boundary' of human life, therefore, is not the skin but the plants we depend on for fuel. In turn the 'boundary' of plant life is the atmosphere that contains the CO_2 they need to make use of the sunlight.

By extension, Gaia's boundary, or 'skin', is the edge of the atmosphere and it affords the Earth a different steady state than would persist if there were no life present. Earth, and the entirety of life on it, forms a self-regulating system on a planetwide scale. This strongly influenced the development of Earth systems science (Mackenzie and Mackenzie, 1998), which joined together the study of the geosphere and the biosphere to consider Earth as a single dynamic entity. It is also important to biodiversity (Rushton, 2002) as it stresses the importance of the interconnectedness of all life forms and thus warns of the danger of losing some species of plants and animals, whose full value to the ecosystem we may not yet recognize.

The theory has been championed outside of science by many environmental groups and this has led to some scientists to be sceptical of its value (Lenton and Wilkinson, 2003) while others have attempted to advance it (Charlson *et al.*, 1987; Ayers and Cainey, 2008; Ward, 2009). It has certainly inspired a more philosophical and theological consideration of environmental challenges, including the importance of cooperation, love and respect for all living things (Midgley, 2003), which has inspired ecological and spiritual movements to think more holistically about all of Earth's inhabitants. In 2018, sociologist Bruno Latour and global health expert Tim Lenton expanded on the original theory in Gaia 2.0 (Lenton and Latour, 2018), proposing that the need for humanity to self-regulate its activities through mitigating technologies and behaviours constitutes a transformative change and favours sustainability.

Deep time

Deep time first emerged as a geological concept that acknowledges the extremely long history of Earth – the planet is more than 4.5 billion years old. Against this, the emergence of *Homo sapiens* (between 150,000 and 300,000 years ago) and of human civilization (approximately 10,000 years ago) is only a tiny fraction of the most recent history. The concept may have inspired Charles Darwin to begin thinking of a 'deep time' origin for humanity, and of human evolution (Zen, 2001).

This idea of a long history is considered important in Earth system science as it can engage researchers in a deeper understanding of the nature of scientific investigation, evolution and of humanity's place in the universe (Mayer, 1991), with important influences on cultural, educational and economic frameworks (Cervato and Frodeman, 2012). The academic concept of deep time has been popularized in books such as *Time's Arrow, Time's Cycle* (Gould, 1987). Its philosophical implications have been explored in theology (Swimme and Berry, 1992; Berry, 2009) as well as science, as a way to encourage humanity to contemplate our place in the universe and to see ourselves as one factor in the history of Earth but not the dominating one – nature's servant rather than its master. This in turn has influenced the field of 'deep ecology' (De Jonge, 2017), which values living organisms as and of themselves, not just in terms of the services (food, work animals, etc.) they provide to humans, and urges us to respect and preserve the Earth. This is often described as taking an ecocentric (Eckersley, 1992) approach to environmentalism, rather than one that is more anthropocentric (Callicott, 1984), favouring humans over the environment. Such a framing favours green movements, simple living and population control to ensure that humans do as little damage to their environment as possible.

Natural capital

Another way to address the imbalance between current use of global environmental resources and the rate of consumption the Earth can replace is through the concept of natural capital, and natural capital accounting (Daly, 1990). Earth has natural 'capital' – or wealth – comprising natural resources such as air, water, plants and animals, minerals and land. Some of these provide goods (e.g. food), services such as the removal of CO_2 from the atmosphere or cultural enrichment as shared community spaces.

If we take from our natural capital without putting the equivalent value back in, our capital will be diminished. Traditional economics tends to ignore the true value of natural stocks – for instance, the value of a forest for the service it provides in ensuring clean air – in favour of financial values (e.g. the value of the timber once the forest has been cut down) and this undervalues nature. Incorporating natural capital values into overall economic assessments would enable the true value of ecosystem goods and services to be captured and may show that depleting them will be costlier in the long run than replenishing them or avoiding their extraction in the first place. This has led to an internationally agreed System of Environmental-Economic Accounting (SEEA) (United Nations Statistics Division, 2018) that includes definitions, classifications, accounting rules and tables for producing internationally comparable statistics on the environment and its relationship with the economy. This can help to assign a value to such natural assets and ensure they are fully considered in cost–benefit analyses and policy decisions.

2.5 Conclusions

The aim of this chapter has been to outline the key concepts in planetary health and to give those new to the field pointers to further information and study. It has sought to show the breadth of knowledge – from atmospheric physics, to evolutionary philosophy, from microbiology to cultural psychology – needed to build a full understanding of the biological and geochemical systems on which Earth depends and which are under threat in the Anthropocene. The following chapters will provide more information on how these concepts are incorporated into the dominant conceptual frameworks emerging in the field and the problem spaces they can help to conceptualize, before outlining examples of how planetary health conceptual frameworks can be applied to the challenges arising from global environmental change.

Note

1. The Club of Rome is a group of United Nations bureaucrats, politicians, government officials, scientists, economists, business leaders and former heads of state from around the world.

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3

The Evolutionary Biology Approach: a Natural Baseline for Human Health

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3.1 Introduction

Human populations have profoundly reshaped the natural environment over the recent past, but our genetic profile still reflects adaptations to earlier and very different ecological circumstances (Greaves, 2015). This has far-reaching consequences for health over the course of our lives. A deeper understanding of human evolutionary biology, and of the differences between the modern world and the environmental conditions we evolved to live in, may provide pointers to how we can experience better health and sustain healthier environments.

Since the emergence of *Homo sapiens*, which may be as long as 300,000 years ago, our development has been marked by social evolution alongside biological adaptations. Humans have used and mastered fire, domesticated animals, cultivated land, harnessed energy far beyond that needed for our metabolic processes, and have developed language, religion, writing and science. Our basic anatomy and physiology changed little across that time (Stringer, 2016), however, and hardly at all in the last past 40,000 years.

The 10,000 years since the beginning of the Holocene, the introduction of agriculture and the emergence of cities is the blink of an eye to geological time. Biological evolution cannot keep pace with the environmental change we have instigated: a theory known as the adaptive lag hypothesis (Laland and Brown, 2006). Patterns of nutrition, activity, fertility and immunology (Wells *et al.*, 2017) that affect our physiology, health and well-being have drifted away from the 'natural baseline' for which we are biologically designed. And it is not only human health that is affected this way: when we artificially and rapidly manipulate the lifestyle and bodies of domesticated animals, including perpetual egg laying in battery hens and the breeding of pedigree dogs, cancer rates shoot up in the tissues most affected – ovaries in chickens and long bones in large breeds of dog (Greaves, 2015).

3.2 Establishing a Natural Baseline

The lifestyles of extant hunter-gatherer populations (the best indication we have of the life courses of humans living a 'natural' existence) are characterized by moderate physical activity, sustained into old age. Calorific intake of around 2500 calories/day for a man and 1800 for a woman (Black *et al.*, 1996) is fuelled from food that is cooked but not highly processed, and which contains low levels of fat, sugar and processed carbohydrates.

Such populations experience a natural age span of around 68–78 years (Gurven and Kaplan, 2007), with a fertility rate of eight to ten births per mother and approximately 2.5–3 year intervals between each birth. Very few hunter-gatherers (even those that live past 90 years of age, as some do) develop high blood pressure, cardiovascular disease, diabetes or cancer.

This presents a somewhat idealized view, however. While we 'can' live to this age, it is a relatively recent development that most people do. Many hunter-gatherers die from infections (around 70%, mostly in early childhood and later age) and 20% from accidents; the high natural birth rate is an evolutionary adaptation to environments in which many children do not survive to reproductive age, and many women to not survive from first menstruation to menopause. Such societies are also at risk of food insecurity. The World Health Organization classifies infection, malnutrition and childbirth complications as Group I diseases, associated with communities living in extreme poverty, with low levels of development.

3.3 Infection and Illness

Pathogens are abundant in the natural environment. In response, our immune system has evolved to require some exposure to infection in order to recognize, balance and shape its subsequent regulation and response (Boehm, 2011). Microorganisms with which humans have coevolved have been virtually eliminated from urban and home environments in the developed world; however, without exposure, infants may not be able to learn how to recognize dangerous pathogens, ignore harmless ones and react appropriately (Strachan, 1989). Adults in low-income rural environments are more able to shut off the immune response when it is not needed than those in high-income environments: remaining in an unnatural state of permanent readiness, as it does in many urban populations, can lead to increased risk of disrupted immunoregulation and inflammatory responses, cardiovascular disease and depression (Rook, 2013; Lambrecht and Hammad, 2017). This might explain the rapid increase in allergies and chronic inflammatory disorders in high-income countries in recent years (Rook, 2013). Delivery by Caesarian section and overuse of antibiotics in early childhood can also significantly disrupt the immune response (Gluckman *et al.*, 2008).

This is not to say that we should eschew modern, more sanitary and hygienic environments, nor shy away from medical advances including vaccination, antiviral drugs and antibiotics. These clearly confer a survival advantage overall (including to some cancers associated with endemic, early and persistent or chronic infection), but we do need to be mindful of some concurrent disadvantages to excessive cleanliness.

3.4 Evolution and Energy Requirements

Evolution – like planetary health in general – requires trade-offs. Strong immune function is metabolically costly and can divert available energy away from growth, for example.

The most recent changes in human evolution are linked to the energy requirements of growing and maintaining our bodies (particularly our large brains, which require twice as much of the available metabolic energy as those of chimpanzees), to undertake physical activity such as running and walking, as well as to fight off infections. The energy available to us from food has been greatly affected by how we have obtained and prepared it throughout history (see Box 3.1), and our relationship with food production and consumption will be returned to throughout this book, particularly in Chapters 11 (on agriculture) and 19 (on livestock).

Physiological adaptations that occurred concurrently with the appearance of such foods in the human diet include increases in body and brain size, reductions in tooth and gut size, and altered gene expression in the liver. Humans may now be unable to extract sufficient nutrition without cooking most of the food we eat, as raw plants are too fibre-rich and raw meat too tough for easy chewing and digestion.

The ability to digest lactose, on the other hand (and thus to include dairy products in the diet), is more recent and has evolved within the last 7000 years – since the introduction of agriculture and farming, though not in all human populations. Globally, lactose intolerance is still relatively high and we have not (yet) fully adapted to the high fat content consistent with the substitution of animal husbandry for hunted meat, or to the processed, high glycaemic index (GI) of fried foods and processed grains and sugars. The type of processed foods that can make up over 70% of the American diet today were virtually absent from the diet of our ancestors.

Box 3.1. Cooked food, nutrition and human evolution

The fuel source we use for metabolic processes is food (Malhi, 2014), but what sort of food, how much we can get and how it is prepared – in particular whether or not it is cooked – affects how much energy we can obtain from it and how quickly. Calorie-dense foods such as meat (which provides a small proportion of the diet of hunter-gatherers compared with those living in even pre-industrial settlements), grains and tubers (which have been part of the human diet for at least 100,000 years) all provide more energy per gramme when cooked (Carmody *et al*., 2016).

As diet changed, early farmers suffered from more cavities, infectious disease, iron deficiency and developmental delays; they were also shorter. This represents an evolutionary discordance. Food we evolved to crave when it was in short supply is good in keeping humans alive until around the age of 45, but not so good for ensuring good health over longer lifespans. The efficiency we developed for helping our bodies to obtain and digest extra calories now means we often consume too many, making us fat and increasing the risk of obesity (Caballero, 2007), an unnatural, unhealthy state associated with low fertility, stroke, cardiovascular disease and increased cancer risk.

3.5 Hormone Exposure

The hormones we are exposed to throughout our modern lives present another evolutionary discordance. The processes that enable insulin to allocate energy across competing physiological functions may have been extremely beneficial when fuel (food) was in short supply (Wells *et al.*, 2017) but increase the risk of diabetes, thus becoming a biological liability, when there is an abundance of food. The hormone cortisol enables humans to deal with stress, but increases blood pressure, reduces immune function and accelerates ageing (Godfrey *et al.*, 2010), trading off short-term benefits against long-term health. Exposure to high levels of the female reproductive hormone oestrogen across the life course (modern urban women have around four times as many menstrual cycles throughout their life as hunter-gatherer women, who spend much of their adult lives pregnant or breastfeeding) lowers the risk of osteoporosis and cardiovascular disease in later life but increases the risk of breast cancer (Jasienska *et al.*, 2017).

3.6 Conclusions

The human race has made unprecedented cultural advances over the past ten centuries, but neither our bodies nor our minds may be ideally geared to the modern environment. We seem to be biologically programmed to maximize our reproductive potential and to exploit our environment without concern for the available resources. Our evolutionary biology has intertwined our ability to develop physiological adaptations with biological ones: the introduction of meat, which is more likely to carry harmful pathogens (incurring a high immunological cost) and is tough to chew and digest, was offset by the social development of cooking (Carmody *et al.*, 2016). But the benefits of food security and more efficient energy-per-gramme extraction have been offset by urban, sedentary lifestyles that encourage obesity and increase the risk of chronic disease in later life. Lifetime risk of cancer is now 50% in many Western societies, which may be explained by ‘tissue ecosystem pressures’ and the trade-off between the mutability of human genes and our long post-reproductive life into old age. Lifestyle-associated factors increase cancer risk 100-fold and the overall cancer impact of diet on the human race may be second only to that of smoking in developed societies (Greaves, 2015).

Human progress away from hunter-gatherer existences towards modern urban societies has brought many advantages, however, and we do not want to give these up. The challenge for planetary health is to determine if we can maintain modern standards of living – and provide food security, electricity, freedom from childhood mortality and better housing conditions to the developing world – without increasing the risk of non-communicable diseases linked to poor diet, insufficient energy expenditure and excessive hormone exposure. Modern medicine has enabled us to treat, cure and live with many chronic conditions (Greaves, 2015) but we should also be more concerned about how we might prevent them.

A stronger understanding of evolutionary biology may help to explain disease emergence and variability (particularly with regard to non-communicable diseases) in individuals and populations. Evolutionary psychology – though it has not been covered here – can also help to explain the 'choice' of undertaking risky lifestyle activities such as smoking and poor diet that offer immediate gratification but long-term health challenges. These academic fields, combined with a strong understanding of the ecological and environmental conditions under which humans have evolved, may help us to maintain good health in the modern world.

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4

The Natural Capital Approach: Opportunities and Challenges

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4.1 The Value of Nature

When eating a sandwich, do you ever consider what the ingredients are – the flour that made the bread, the seasoning that gave the flavour, the mayonnaise that held it all together? But what about the sunlight that allowed the grains for that flour to grow? The water that quenched the roots and cleaned the salad? What about all the CO_2 floating in the atmosphere courtesy of the fossil fuels burnt to make the energy to bake the bread and to bring all the ingredients and packaging together? If you are a meat eater, what about the loss of forest cover to clear the land to feed and graze livestock, and the selective pressure leading to antibiotic resistance caused by the antibiotics used as growth promoters? What about the plastic packaging that ended up in landfill or the world's oceans?

Your sandwich would not have been possible without the Earth's stocks of natural assets: its forests, rivers, land, minerals and oceans, and the natural processes that sustain them. Because these stocks of natural assets produce value to humans, they are sometimes called 'natural capital', and the flows of services they produce are called 'ecosystem services'. The combined capacity of all the natural assets used to supply ecosystem services in a given area constitutes that area's natural capital.

However, only a subset of all ecosystem services – those that reach markets, such as fish extracted from rivers and oceans, timber from forests, extracted minerals, gas and oil – enter into standard measures of economic activity. Gross domestic product (GDP) values only activities with prices attached to them. The harm done by boosting economic growth while degrading natural and human assets (e.g. harming humans through polluting their environments) does not show up in standard GDP numbers. In fact, health expenditure to fix the damage is *even* measured as a positive contribution to GDP and thus to how successful a country is considered to be.

The concept of 'natural capital', which seeks to highlight the true value of the natural environment, was first introduced by E.F. Schumacker (Schumacker, 1973) and popularized in the book *Blueprint for a Green Economy* (Pearce *et al*., 1989). The United Nations Convention on Biological Diversity (United Nations, 1992) and the Millennium Ecosystem Assessment (MEA, 2005) highlighted how loss of biodiversity, pollution, climate change and unsustainable land use were diminishing the ability of ecosystems to provide services essential to human health and well-being.

4.2 Natural Capital and Sustainability

Natural capital is an extension of the economic notion of capital, which refers to resources that enable more resources to be produced. In standard economic production functions, different types of capital – in particular financial, manufactured and human – are combined in varying proportions to produce goods and services for the benefit of humankind. The end results, on entering markets, generate the prices that get used to value the capital. Natural capital upsets this standard economic presupposition. Sustainable planetary systems maintain, and pass on to future generations, sustainable stocks of natural capital; unsustainable planetary systems do not. Perhaps the rise and fall of the value of natural capital stocks (if only we can calculate it) could be used as a barometer of the health of the planet.

There is a twist, however. Similar to the situation with other types of capital, nearly all the benefits that humankind derives from natural capital are coproduced by using it in combinations with other types of capital. If all types of capital are substitutable (i.e. if one can be used instead of another in certain situations), sustainability would simply require that the summed-up value of all capital, of whatever type, is non-declining across human generations. Natural capital could be run down so long as other types of capital were built up to offset the loss (this is termed ‘weak sustainability’). Indeed, since about the 1950s, humans have been running down natural capital stocks while building up stocks of other types of capital as if this was the case. However, in a world of planetary boundaries, this logic increasingly falters. If some types of natural capital are substitutable only within a ‘safe operating space for humanity’ – that is within certain planetary boundaries (Rockström *et al*., 2009) – the value of all capital needs to be non-declining across generations and ‘critical’ natural capital must not be depleted beyond planetary boundaries (this is sometimes termed ‘strong sustainability’). Such logic may apply at local scales. Tropical forest, once destroyed, is not easily replaced: it is gone for good, and forest cover, unlike other types of capital, cannot simply be moved to fill the gaps.

If you become addicted to consumption, spend beyond your means, run up debt and run down your financial capital, you may end up bankrupt. Similarly, if natural capital stocks are run down too quickly without a chance to recover, eventually there will be ecosystem bankruptcy. Unlike in cases of personal bankruptcy, nature may not get to wipe the slate clean and start again: an extinct species is gone forever. Entire regions may become permanent deserts.

One role of planetary health economics is to derive the models of investment and economic growth that determine the safest mix of different types of capital, allowing for planetary boundaries. Price signals and discount rates can be determined according to how close natural capital stocks are to planetary boundaries, annuity values can be placed on assets that are sustained into perpetuity, and option-price logic can determine when, and how quickly, to invest (or not).

Herein, however, lies a dilemma. Stocks of natural capital are not in permanently fixed supply – they can be improved or degraded by human actions over time – and their 'replenishment' needs investment and sacrifice. Yet no mechanisms similar to those for other types of capital exist to achieve this end.

A big goal of the natural capital approach is to put natural capital on an equal footing to financial, manufactured, human and social capital within systems of national (and international) accounting. However, while the value of other types of capital depends on consumer preferences, the value of natural capital depends, to a larger extent, on an understanding of the science of *exactly* what such capital is providing. For example, in the case of a tree: (i) the conversion of CO_2 to oxygen; (ii) shade from excessive heat; (iii) filtration of air and noise pollution from a nearby road; (iv) strong roots that prevent soil erosion; (v) nesting space for wildlife; (vi) fruit, nuts and sap; and (vii) wood and/or carbon storage. All this has to be somehow valued, both in isolation and against what providing that service might otherwise cost (if, indeed, there is another way to provide it).

4.3 Systems, Geography and Time

Much natural capital has unique, even irreplaceable, features. Natural systems tend to be highly adaptable and multifunctional (they do many things at the same time efficiently; Foley *et al.*, 2005). Natural landscapes with more biodiversity, and so more genetic variability, are more resilient, for example, to climate change. As this resilience declines, some regions become more prone to extreme events such as floods and droughts, potentially leading to human starvation, conflict over resource scarcity, and population displacement. But it is difficult to capture this value. For a natural capital approach to be useful for planetary health, we really need to know how the complexity and connectivity of natural systems affect the value of the stock of natural capital. We are in the early days of exploring the multiple pathways through which climate change modification can affect the values of natural assets.

The natural capital approach is people-, not nature- or ecosystem-centred: anthropocentric rather than ecocentric. To count as natural capital, an aspect of nature must be able to create services that humans value. The value of geographically specific forms of natural assets varies according to where they are, and which groups of humans benefit from them. Pollinators in the orchards of California have higher natural capital value than in the Australian outback. A tree in the middle of nowhere has less natural capital value than a tree in a city. Rising sea levels are more harmful if more people live on low-lying lands. Natural capital values are also not determined once for all, but need to update over time, and involve predicting future developments that are hard to quantify. Capturing all of these effects is challenging.

4.4 The Valuation Problem

Valuation of natural capital is unavoidable, however; resource-constrained policy makers have to trade one policy option – involving impacts on natural capital – against another. There is no disagreement over the basic notion of natural capital, but great disagreement over how to value ecosystem services and natural capital.

First off, many forms of natural capital, and their ecosystem services, have no prices. Using wages and incomes to price the human-affecting impacts of changes in natural capital stocks makes valuation some function of the prevailing economic system that shapes human preferences and prices. If assets are non-substitutable near planetary boundaries, however, valuation based on such marginal prices is wrong as such assets should not be depleted so far.

There are missing values (in particular related to the benefits of biodiversity) and unobtainable values (what price do you put on human health?). There is a danger of bias to relatively easier-to-measure forms of natural capital (e.g. timber, rather than forest cover) and of quantity over quality. As a consequence, it will be necessary to run parallel, monetary and non-monetary, approaches to value.

This does not necessarily set up a conflict. Monetary measures (even if highly imperfect) are needed to change business practices, and to get governments to adjust policy. Non-monetary measures, such as the number of deaths from pollution, might be helpful for equity judgements.

4.5 Urgency and Terms of Office: the Political Dilemma

Currently, much valuation is done over very short time horizons. Longer horizons raise the issue of time discounting, which is a fairly standard investment practice. As a first principle, the discount rate should be set empirically, based on people's preferences; since societies live for horizons much longer than the individuals within them, societal discount rates are typically much lower than private discount rates, which at least tends to enhance the value of natural capital. Second, discounting needs to be done subject to the 'strong sustainability' constraint. If a chosen discount rate risks the subsequent breach of a planetary boundary, the discount rate needs to be adjusted to reflect the state of planetary systems (in particular of how close those boundaries are).

Most fundamental of all, the natural capital approach does not avoid the unresolved issue that prices are often very poor guides to intrinsic value (clean water in the UK is cheap to the consumer, but of massive value: much of the full value of clean water – and maintaining the infrastructure that disinfects, pipes and delivers it – is borne by the public purse, not by the individual consumer).

4.6 Natural Capital and Human Health

The natural capital approach has recently been promoted as a framework for bringing health and environment together. Human health depends on natural systems in multiple ways, both direct and indirect. In theory, if we can calculate the consequences of human actions (such as climate change) on the ability of a natural asset to generate ecosystem services, and calculate also the impact on human health, we can use this information to calculate the change in value of individual ecosystem assets and the total stock of natural capital. We can start to operationalize natural capital valuation as a barometer of planetary health. This presents us with a range of further challenges.

The first is the lack of commensurability across different kinds of metrics of health impact, which come in such a diversity of units that putting them into a common unit to derive natural capital values is not easily done.

The second is the standard difficulty (common also to cost-effectiveness analysis) that one can't easily aggregate local valuations, particularly if based on local cost conditions (which may, nevertheless, be useful for making local decisions involving local trade-offs) to the global level.

The third, thought through the multi-capital lens above, is that total health impact is the result of all pathways for health to be affected through combinations of all types of capital and not just natural capital, with health also treated as an input in production and not just as an output in its own right. Natural capital itself impacts on health through multiple pathways and has impacts beyond human health too. How do we capture all of these impacts?

One solution would be to give stocks of human health and well-being greater roles in the ultimate measure of value. Measuring stocks of human health and well-being that put positive value on good health lived and not just poor health avoided, such as disability-adjusted life years (DALYs) and quality-adjusted life years (QALYS) (Gold *et al.*, 2002), and understanding the addition that ecosystem services make to these metrics might support the role of natural capital in tracking planetary health – adjusted for population dynamics, possibly using scenarios over time that incorporate epidemiological and demographic transitions. Perhaps, as a welcome side effect, this will improve the welfare and equity credentials of the natural capital approach.

GDP is not a measure of welfare. The prices used to measure GDP are driven by the distribution of wealth, income and economic power. Shifting focus onto natural capital does not take this problem away. The natural capital approach does not eliminate the need for an ethical decision-making framework; *who* gets benefit from natural capital, where, and when. Equity-driven valuation of natural capital might, for example, need prices to be based on very different distributions of income and wealth, prices that are further different from current market prices because they better capture the true underlying state of the planet's health. A societally acceptable ethical framework (Foster *et al.*, 2019) may need to be adopted before natural capital values can be derived.

Because the natural capital approach is based on human preferences, it implicitly asserts that some sorts of damage or protection are less worthy of value than other sorts. The value of natural assets can even fall to zero if human interests are not involved. The inherent value of natural capital cannot just be anthropocentric.

4.7 Conclusions

Making natural capital more visible will help to protect it, but changing human behaviour needs emotional engagement beyond just science and statistics. Some companies are waking up to the benefits of taking natural capital into consideration in their decision making – insurance firms, in particular, have explored natural capital tools. It would be naïve, however, to think that embedding natural capital in the business landscape will solve all the problems. Utility companies, banks and many corporate organizations required to sacrifice profit for more capital often find ways to get around requirements they do not see as in their interests (utilities companies thereby destroy their regulatory mechanisms; banks cause crashes). Environmental regulation, taxation and public investment will still be needed to support natural capital.

Nevertheless, natural capital thinking has helped companies, finance ministries and public agencies think about the wider impact of the decisions they make. The language of natural capital has given the natural environment a voice in settings where otherwise it would have not gained entry.

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5

The One Earth Approach: Planetary Health in an Era of Limits

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5.1 Introduction

At heart, the concept of planetary health involves the recognition of complex, recursive systems, in which the health of any particular 'unit' of interest – such as a person or a population of people, or a community of species – cannot be understood without reference to the health of neighbouring 'units' (e.g. other people, other species) or larger scale units which encompass the person or population of interest. Thus, human nutrition depends upon healthy soils and ecosystems, and is threatened by erosion or declining biodiversity. This focus on nested systems and subsystems recognizes that health is fundamentally a function of networks and interdependence, and that even the identity of seemingly straightforward entities such as an 'individual person' is complicated by this pattern of complex interdependence. For instance, it turns out that human health is indivisible from the complex ecosystem of nominally independent gut fauna, which in turn communicate with and develop in tandem with wider food systems and influence our relationship with soil.

In a very serious way, this begs the question: 'What *is* a human being?' Is it just the coalition of cells that share common DNA? Or the higher level coalitions of human + gut fauna? From a systems perspective, boundaries are always complex in this way.

This epistemological instability with regard to the basic units of analysis has two notable consequences. First, any comprehensive approach to planetary health necessarily has to juggle multiple, very different *time horizons* – from the nanocycles of biochemical metabolism, to the reproduction and gradual evolution of the ecological life support systems of the biosphere over millions of years. Secondly, a 'planetary' approach ultimately must refer to an *integrated and zero-sum metabolism*. Our one Earth has one flow of materials, one flow of energy and clears one set of accounts. On a finite planet, human health is dependent on the integrity of the pulsing and fractal web of nested systems that characterizes the biosphere. When the impact of human activities threatens this integrity by surpassing planetary boundaries (Rockström *et al.*, 2009) and/or overshooting the ecological limits to growth (Meadows *et al.*, 2004), the long-term prospects for human health are increasingly uncertain (Zywert, 2017).

5.2 Kinship with Creation

In 1949 in his celebrated essay 'The Land Ethic', Aldo Leopold expressed the hope that as the ontological truth of evolutionary-ecological science percolated into popular culture, there would emerge a deep-seated and perhaps quasi-spiritual recognition of our literal genetic and ecological kinship with the rest of creation. The resulting 'land ethic' would, he argued, provide the basis for ecological conscience formation and the internalization of behavioural restraints in our individual and societal treatment of nature (Quilley, 2009). As he anticipated, the scientific worldview is indeed now pervasive. From kindergarten onwards, students are taught a scientific catechism of ecological community and connectedness. Scientists have developed an increasingly sophisticated language to model the complexity of systems ecology. Since 1970, thousands of faculties have trained hundreds of thousands of students in sustainability science. And since the 1980s a succession of global conferences, treaties and protocols have fleshed out an agenda that aims to reconcile ecological integrity with much-needed social equity and development, and in turn sustainable economic growth.

Despite this enormous investment in education, policy making and technical change, there has been no actual paradigmatic transformation in behaviour, societal organization or the structure of political economy, however. Capitalist modernization proceeds apace – pulling millions of people out of poverty while at the same time degrading the life support systems of the biosphere.

5.3 The Challenge of Wicked Dilemmas

The reasons for this pattern of failure are complex. But from a sociological perspective they hinge on a series of 'wicked dilemmas' – paradoxical concomitants of modernity that were identified very clearly by those 19th-century sociologists who first tried to understand the nature of the modern world. Essentially, both the nation-state and the market economy require that individuals are extracted or 'disembedded' from local, place-bound and family-centred communities of reciprocation and mutual obligation (Polanyi and MacIver, 1944). In the 'society of individuals' (Elias, 2010) people relate to power and authority as individual citizens and to the economy as rational, transacting (individual) consumers or workers (the *Homo economicus* of micro-economic theory). At the same time, the active creation of unified markets, with single currencies operating in clearly demarcated national territories had the effect of making everything 'fungible' (i.e. through the 'cold calculus' of the market, artefacts and processes with seemingly incommensurable qualities could be compared, measured and traded through increasingly universal units of value). Having disembedded the economy from wider institutions of culture, religion and family, economic logic began to corrode and transform these domains.

In short, the process of modernization creates a world of mobile, disembedded, rational-acting individuals who operate in relation to a fundamentally material, one-dimensional and 'dead' world. Residual attachments to family aside, such individuals experience a minimal attachment to place and the particularities of landscape or social-ecological community. Their safety and security is guaranteed not through attachment to such local survival units but as a function of the institutions of the nation state and the market (see Fig. 5.1).

This disenchanted world, dominated by a rationalized scientific worldview and in which people are highly individualized, is new. And it has very specific implications for ecological conscience formation, environmental rationality and the ways in which individuals are able to perceive the complex pattern of relationships upon which they, and planetary health, depend.

Specifically, the dead, material world consolidates a very mechanistic and Cartesian understanding of individual consciousness as both unique and separate, engendered by very specific neurochemical processes locked in individual brains – and tragically trapped in and destined to die with that vessel. Undermining wider structures of meaning and signification associated with traditional religious worldviews, origin myths and cosmologies, this brutal materialism engenders a large measure of 'ontological insecurity' – a form of neurotic anxiety particularly about death, that is greatly heightened in modern societies (Giddens, 1990). In social psychology, 'terror management theory' inspired by the work of Ernest Becker, has shown that death anxiety remains a ubiquitous driver of both culture and individual behaviour.

5.4 The Challenges of Modernization and Sustainability

In modern societies, this is channelled into cycles of mindless and passive consumption (Dickinson, 2009). What seems very clear is that these mobile and ontologically unhinged individuals that have become the *raison d' étre* of modernity and processes of modernization are prone systematically to discount the future. Certainly, this orientation is tempered by people having children – and children remain what Becker (1973) called a powerful form of 'immortality project' that serves to partially insulate parents against the ubiquitous fear of mortality. But the failure of the environmental project thus far and the difficulty of internalizing the otherwise self-evident insights of planetary health into personal behaviour and political commitments, suggest that there is a real problem. A paradigmatic sustainability transition won't be effected simply by changes in education, or technology or even better governance – however radical or far-reaching.

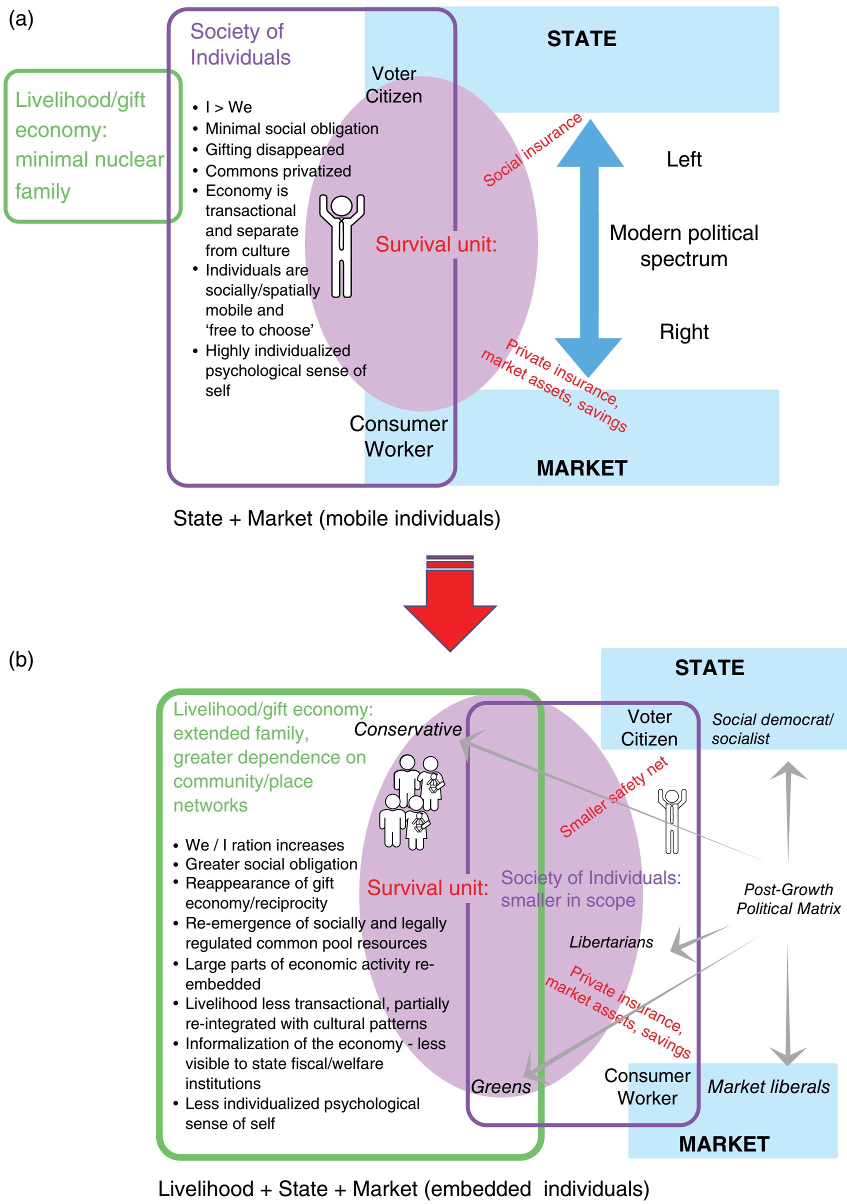

Fig. 5.1. The process of re-embedding and degrowth.

Here, we have a paradox. Science has greatly enhanced our capacity to model natural phenomena including disease, health and ecological integrity. But at the same time the process of market and scientific rationalization undermines both the onto-logical frameworks and the place- and community-bound cultural resources that might drive the emergence of new societal and behavioural restraints, taboos and processes of self-regulation that could effectuate planetary health. The problem of planetary health and a paradigmatic shift towards a more sustainable culture may therefore depend on whether it is possible to mobilize and consolidate a kind of creative cognitive dissonance. Is it possible to sustain a scientific worldview while at the same time recovering an ontological frame of reference that links the ancient past and deep future, that foregrounds the horizontal, interdependent pattern of reciprocation between species (ecological kinship) and, on consequence, makes it very difficult for both individuals and societies to discount the future? Is it possible to ingrain a deep-rooted sense of self that is expansive and less hermetically contained by that Cartesian insistence on individual brains? Is it possible to re-embed the powerful but corrosive rationality of both the market and science into cultural narratives that project self both forward and backward in time, and laterally to encompass non-human entities and systems? In other words, can a triune land–ancestor–descendent ethic be reconciled with progressive modernity? Contra Leopold, it seems likely that such a scenario requires some kind of re-enchantment and a spiritual/extra-scientific frame of reference.

5.5 Health as an Integrated Component of the Ecosystem

From a planetary health perspective, what is needed are societal and economic arrangements (including culture) that make it possible for individuals routinely to experience health and well-being as a function of the integrity of wider familial and community relationships as well as that of local and global ecosystems. How might this happen? Elsewhere we have theorized the contours of such an alternative modernity (Quilley, 2017; Zywert and Quilley, 2018), arguing that this would involve the rebalancing of the institutions and political economy of state and market with a renewed emphasis on informal processes of reciprocation, care and mutual aid based upon family and place-bound community.

The other dimension relates to the fabric or architecture of everyday spirituality (i.e. stories, mythologies enacted through mundane rituals which capture and constantly bring into existence that triune combination of land–ancestor–descendant ethic). One very promising approach is that of Seligman and Weller (2008), who explore the ways in which ritual (like play) functions to reconcile without resolving different and incompatible realities. In many ways, this is precisely the problem of ecological conscience formation – the tension between the scientific world view and the corrosive logic of markets on the one hand, and ethico-moral and ontological commitments to an ineffable reality much greater than any individual and stretching both backward and forward in time, on the other. Lived and experienced in the mundane interstices of everyday life, such a worldview might better allow individuals to balance their own immediate real-time physical and economic interests with these wider commitments – and so better accommodate the experience and prospect of death, disease and ill health (including as these relate to family and children) with the idea of a meaningful life. At the level of institutions and policy, the widespread recovery of such frameworks might make it easier to navigate and negotiate what are likely to become very difficult, traumatic and conflictual zero-sum resource constraints.

5.6 A Land–ancestor–descendant Ethic for Planetary Health

If we are rational Cartesian brains locked into short-lived bodies in a dead world and primed by an evolved propensity for cynical game-theoretical rational choice, then the future must be bleak. There is little to restrain the present from eating the future, the strong the weak, and humanity the rest of nature. In such a context, the concept of planetary health is likely to be stillborn. But if, on the other hand, we can both internalize and socialize some sense of a spiritual reality in which the past and the future are always implicit in the present and in which entities – be they cells, organisms, communities, species, cities, nation-states – exist in networked, interdependent relations, then it is at least possible that we can begin to work towards planetary health by enacting ways of living in which our interests as individuals are always tempered gently but firmly by our wider engagement and dependence on this beautiful, ever-changing and infinitely complex pattern that is our evolving biosphere.

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6

The Transhuman Approach: Technoscience and Nature

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6.1 Introduction

What are the futures in which you see yourself living? For some, images of the effects of water stress, rising sea levels and novel extreme weather events come to mind. Others may think of the continued blurring of technoscience and society. Most likely is a blend of these two possibilities among others. Whereas the former can be referred to as the world in the context of climate change, the latter can be seen as an expression of transhumanist thought, with both playing key roles in the production of the future. So, what is transhumanism, and why is it relevant to planetary health? Max More, one of the leaders of movement, provides the following definition:

> Transhumanism is both a reason-based philosophy and a cultural movement that affirms the possibility and desirability of fundamentally improving the human condition by means of science and technology. Transhumanists seek the continuation and acceleration of the evolution of intelligent life beyond its currently human form and human limitations by means of science and technology, guided by life-promoting principles and values.
>
> (More, 2011, p. 137)

In a later text, More and Vita-More (2013) clarify what they mean by life promoting: the elimination of ageing and enhancement of intellectual, physical and psychological human capacities. Such views can also be found in the writings of Nick Bostrom, Ray Kurzweil and Gregory Stock among others. The possibilities transhumanism presents are undoubtedly attractive and, although not explicitly transhumanist texts, echoes can be traced through the likes of Yuval Noah Harari's *Homo Deus* (2016), Max Tegmark's *Life 3.0* (2017) and Martin Rees's *On the Future: Prospects for Humanity* (2018), as well as multiple texts on the fourth industrial revolution.

Transhumanist ideas have also permeated the world of pop culture technoscience. SF (Science fiction, speculative futures – see Haraway, 2016) such as *Blade Runner*, *Altered Carbon* and *Westworld* each draw on transhumanist ideas. Ideas regarding the social function of technoscience are so strong that arguing that this will only increase in the future can result in one being referred to as a Luddite. The future seems fiercely locked down.

In the face of this seemingly predetermined future, what does transhumanism offer to planetary health, and what is the appropriate response from the planetary health community to transhumanism, especially when both fields claim to hold the best hope for humanity's future?

6.2 Areas of Synergy and Opportunities

There are three ways in which planetary health and transhumanism might aim to work together. First, transhumanism is eager to see the datafication of the world. Planetary health could use such data to better understand anthropogenic environmental changes and the effects on human health that might occur as a result of these changes. Working with transhumanism could lead planetary health towards producing up-to-date policies based on continuous, real-time data.

Second, transhumanism's concerns with the reduction of existential risk (Bostrom, 2011) align with planetary health's aims to reduce the potential drivers of ill health. This is related to the previous point, as it concerns the monitoring of microbes, pollutants and atmospheric gases in the environment, and the incidence of ill health among both human and non-human populations.

Finally, transhumanism offers the potential for humans to be affected in novel ways by, for example, bodily implants or gene manipulation. These new sensitivities might allow for new forms of ethics, beneficial to planetary health's imperative to consider more carefully non-human realms of life. Such are some potential areas of collaboration.

6.3 Potential Challenges and Conflicts

The rest of this chapter concerns itself with areas of conflict between planetary health and transhumanism. First, it is necessary to consider whom transhumanism speaks for. Second, the chapter will examine the potential environmental costs of transhumanism. In its conclusion, this chapter will reflect on how transhumanism and planetary health might work best together for the benefit of humanity's future, a goal to which both lay claim. While the critique of transhumanism's effect on ontological approaches to being/becoming human is pertinent, such critiques are better expanded upon elsewhere than can be done here in the space available (see Hansell and Grassie, 2011).

6.4 Two Critiques of Transhumanism from the Perspective of Planetary Health

Whom does transhumanism benefit?

The transhumanist narrative is born of Anglo-American academic institutions, with extensions into neo-liberal groups that envision the free market as the key to progressively greater human existence. As a whole, transhumanist movements tend to be based in the Global North. With this in mind, there are several questions that are imperative to planetary health that must be asked of transhumanism.

First, is transhumanism normative? In transhumanist writings, the subject to be improved upon is, invariably, the human body. Transhumanists describe it as an imperfect machine: not necessarily bad, but with room for improvement. The target here is not only to rid humanity of various genetic disorders, but also to improve it as a species, inserting 'better' genes to improve mental and physical health. Implicitly, this seeks some kind of human ideal, the production of a maximized biological state, continually improved upon through technological enhancement.

At stake here is human genetic diversity. Such is the complexity of human genetics that it is difficult to know what some genes do, let alone gene–gene interactions and gene expression. We cannot be sure how genetic modifications may influence our ability to cope with the environmental stresses of the Anthropocene, particularly future ones. Deep, embodied abilities to cope may be crucial to surviving the next century (Gunaratnam and Clark, 2012). Understanding these abilities and their associated genetics may be more important than altering them unknowingly.

As genetic modification could lead to the reduction of genetic diversity, this approach also increases the risk of a more serious impact from future pandemics. Though transhumanists may counter this by reminding us of the possibility of planetary monitoring systems, humanity could be left in a weaker position with genetic modification, should these systems fail, than without it.

Class and race in transhumanism

Second to this seeking of bodily normativity, yet no less important, are issues of class and race. These issues should not be read as intentional, but lack of intent does not remove the need to consider them. For all that transhumanists state they seek to improve conditions for all, the means of transferring these improved conditions remains tied to the market. Who, therefore, is more likely to become posthuman? An African flower farmer or a Silicon Valley entrepreneur? A Brazilian factory worker or a Japanese billionaire? These examples are, admittedly, leading. The point, however, should be clear.

Transhumanism risks widening the inequality gap between those at the top of the global economy and those at the bottom to such an extent that, at its extreme, transhumanism's excesses risks turning this into a difference between the current *Homo sapiens sapiens* and a new subspecies descended from economic elites. If planetary health is to emphasize equity, true global perspectives, and the importance of indigenous and non-human perspectives, it cannot align itself with this transhumanism.

6.5 What is the Ecological Cost of Transhumanism?

Transhumanist writings consistently fail to address how such future technologies will be created. There is a persistent lack of clarity about the resource cost of transhumanism. Currently, rare earth elements (REE), specialized plastics and silicon-based materials are dominant in contemporary technological innovation that is of interest to transhumanists.

This section will first consider contemporary ecological trade-offs involved in the production of novel technologies as an analogue for transhuman ecological costs. Second, one counterbalance to these ecological costs – Half-Earth Theory – will be examined, with the challenges of this argument drawn out.

If current trends in resource use in innovation continue, we can predict that the use of REE, specialized plastics and silicon-based materials will also increase. There is not enough space here to consider each of these in turn. As such, REE will be focused upon. Research on the health and environmental effects of these metals at various stages of their production – be it resource extraction, purification or the disposal of waste production – is mostly based on occupational health assessments. Nonetheless, there is a constant theme of this research – although it is often based on the elements cerium (Ce), lanthanum (La) and gadolinium (Gd) – that while at low levels REE can have beneficial effects, continued accumulation of REE over time is associated with tissue-specific damage to the heart, lungs and brain (Pagano *et al.*, 2015). A 2017 report on e-waste (i.e. the disposal of electronic goods) found that only 20% of all e-waste was properly recycled (Baldé *et al.*, 2017). Improper disposal of these products can further increase the detrimental effects on populations and ecosystems. Can planetary health viably align itself with a movement that is notably silent in its discussions of resource use (Hayles, 2011)?

Box 6.1. The Half-Earth Theory

One way of balancing out the ecological costs that may be favoured by the transhumanist community is the conservation strategy of Half-Earth Theory (Wilson, 2016). Developed by the evolutionary biologist E.O. Wilson, this is the idea that if half of the Earth's surface is conserved, then the biodiversity potential of the Earth will be saved from the effects of anthropogenic environmental degradation by targeting biodiversity hotspots and ensuring the possibility of the safe passage through environments for migrating species.

Box 6.1 outlines Half-Earth Theory. In principle, this idea sounds like something that could work. However, with regards to the potential environmental effects of transhumanism, the Half-Earth project forgets about the dynamic movement of both the atmosphere and the oceans. The former of these is more relevant to the deposition of REE around the Earth, while the latter is more relevant to that of plastics.

6.6 Conclusions

Perhaps, for the reasons mentioned above, transhumanism does deserve the title of the 'most dangerous idea of the world' (Fukuyama, 2004). As previously discussed both here and in other critiques of the transhumanist project, human equity and humility about human nature are potential victims of this movement, and environmental concerns have also been brought to light here. For planetary health, the obvious reaction might be to cut any ties with this movement and see it as an enemy, equipped with a competing vision of the future.

Such a perspective would be an overreaction, however. It should not be an either/or with planetary health and transhumanism, but a both/and. In other words, it is a case of asking: 'What kind of transhumanism for what kind of planetary health?'. There are legitimate reasons for working with transhumanism, but there are also legitimate concerns over its excesses. For all that transhumanists claim that life-extending technologies, among others, are close to fruition, is it really better to invest in technologies to improve the length of the lives of a few than the quality of life of many while finding solutions for society in the Anthropocene?

Planetary health cannot just ignore transhumanism, however. Its influence on popular culture is such that the future and transhumanist themes are irrevocably entangled with each other. As such, planetary health must attempt to bring transhumanism into its discussion. There is not enough time to compete for resources. Rather, transhumanism and planetary health must cooperate, not only so that both may work to improve the condition of the planet, but so that such improvements can be done in a manner according to the critical rationalism both movements admire.

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7 Trends in Human Health

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7.1 Human Health and the Natural Environment

Human health has changed throughout history as environmental conditions have changed. Causes of ill health and vulnerability to these risk factors combine and intersect in a complex and place-specific manner (Smith *et al.*, 2014). This can make the exact cause hard to determine, though there is no doubt that environmental factors play an important role (Prüss-Üstün and Neira, 2016).

In pre-Industrial Revolution Europe, roughly 25% of infants died before their first birthday and 40–50% of the population died before the age of 10. At the end of the 17th century, only 20% of people living in Amsterdam were over 50 (Phillips, 2008), whereas in 2017 the figure was closer to 40%. Children born in developing countries today, however, can expect to live for more than 80 years (WHO, 2015), and living until 90 is no longer uncommon. In other countries, however – particularly those in sub-Saharan Africa – the average life expectancy is barely over 50 years (Fig. 7.1).

Global average under-5 mortality dropped from 21.4% of live births in 1950–1955 to 5.9% in 2005–2010 and to 4.1% in 2015, but again there is a wide range – from 0.2% in Iceland to 13.3% in Somalia (World Bank Data, 2017). Something has changed in the last 350 years, clearly, but it has not changed everywhere.

7.2 Regional Inequalities in Health

While the extent of the change has been most dramatic in Western Europe, North America, Australia and Japan, many central African countries today bear an uncomfortable similarity with 17th-century Europe. What is different about the environments we lived in 350 years ago and those that some of us live in today? And what is different about the environments in which the average person today lives to be nearly 90, and those in which the majority would count themselves lucky to reach 50? Countries with a low life expectancy also tend to be those with high rates of neonatal

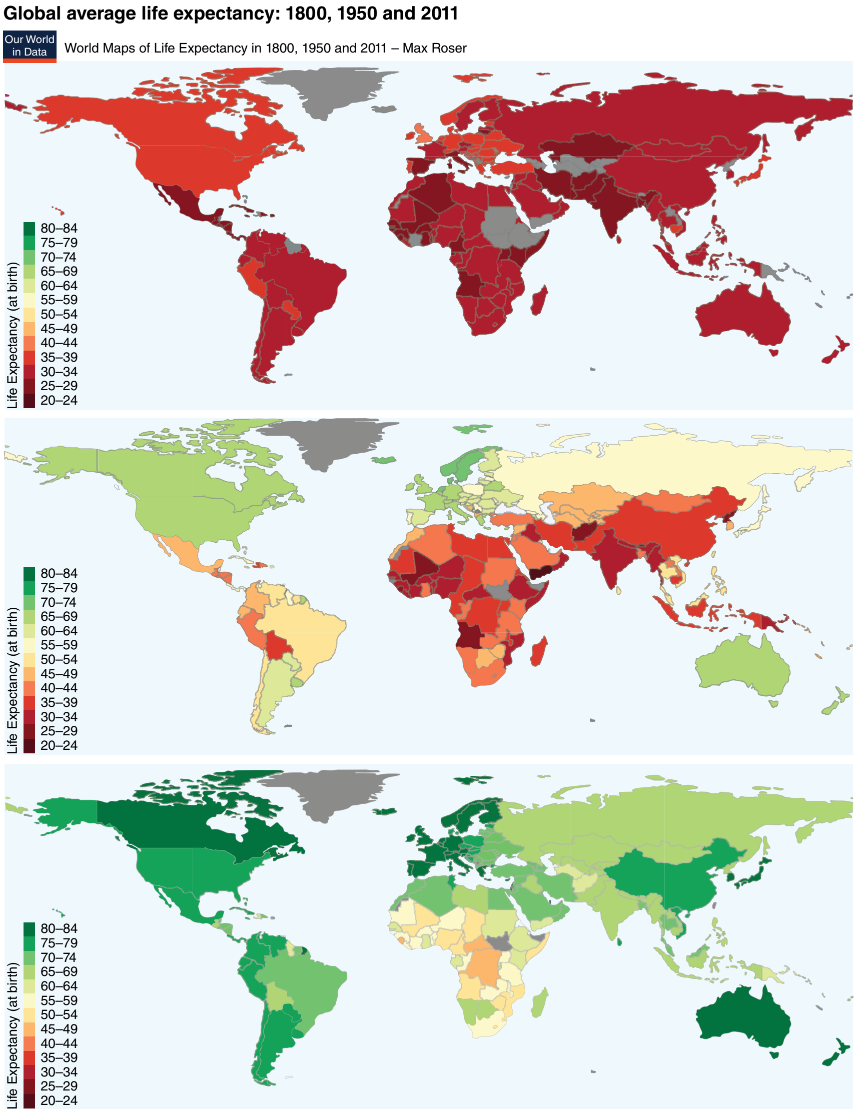

Fig. 7.1. Life expectancy changes worldwide since 1800. As life expectancy increases in industrial Europe and North America, Africa and Asia lag behind. Asia is now catching up, but life expectancy in sub-Saharan Africa remains low in many countries. (From Roser, 2019.)

and under-5 mortality (see Table 7.1), which begs the question: What makes some places inherently less healthy across an entire human lifespan than others?

Such startling differences raise challenging questions about why gains that have been made in some countries are not being felt equally around the world.

Table 7.1. Life expectancy in different countries and the global average. Countries with the longest life expectancy at birth (those above the global average) tend to have very low rates of neonatal mortality, while those with the lowest life expectancy at birth (below the global average) have high rates of neonatal mortality. Some countries are clearly healthier from birth to death. (From WHO/GHO, 2015.)

Country	Life expectancy	Neonatal mortality per 1000 live births
Japan	83.70	0.9
Switzerland	83.40	2.9
Singapore	83.10	1.1
Australia	82.80	2.2
Spain	82.80	2.0
Global average	71.4	18.6
Côte d'Ivoire	53.30	36.6
Chad	53.10	35.1
Central African Republic	52.50	42.3
Angola	52.40	29.3
Sierra Leone	50.10	33.2

Nor are they being felt equally across all socio-economic or ethnic groups, or regions, within a country. For example, in 2012, white Americans had an additional 3.6 years of life expectancy at birth compared with black Americans, while Hispanic Americans had a life expectancy advantage of 3.0 years over non-Hispanic white Americans and nearly 7 years over non-Hispanic black Americans (Arias *et al.*, 2017). In Scotland, UK, a life expectancy advantage at birth of more than 10 years has been observed between men in the most well-off segments of the population and those least well-off (ScotPHO, 2017) with marked differences even between wards of the same city (Walsh *et al.*, 2017).

7.3 Economic Development and Health

Neonatal mortality, under-5 mortality, and life expectancy are all closely tied to economic factors, in particular a country's GDP per capita and health spending per capita.

People born into lower income economies, or lower income households within an economy, are more likely to face health challenges throughout their lives. This link with the economy remains apparent in the changes that have resulted from this dramatic increase in life expectancy in recent decades, explained through the demographic transition and the epidemiological transition, covered in the following section. Box 7.1 outlines the main factors in health inequality.

Box 7.1. Factors in health inequality

Ethnicity: In 2012, white Americans had an additional 3.6 years life expectancy compared with black Americans.
Income: In Scotland, men from the top fifth income group have a life expectancy advantage of 10 years over men from the lowest fifth income group.
GDP: Neonatal mortality, under-5 mortality and life expectancy all show a linear improvement with a nation's GDP.
Government investment in healthcare: Health improves more rapidly with increased public spending per capita on healthcare than with GDP alone.

Life expectancy at birth in the 35 countries of the Organisation for Economic Co-operation and Development (OECD) shows a close positive correlation with GDP (OECD, 2017) (Fig. 7.2). The BRIC nations (Brazil, Russia, India and China), and particularly India and Russia, lag behind the more developed regions of Europe, North America and Japan. There is an even stronger positive correlation between life expectancy and health spending per capita, with a similar lag behind Europe for the BRIC nations (Fig. 7.3). The USA is an interesting outlier: health spending per capita is higher, but this delivers only the same level of life expectancy enjoyed in 'poorer' regions such as Eastern Europe and South America: around 77–78 years for men, and 81 for women (Kontis *et al.*, 2017).

7.4 Three Key Transitions in Human Development

The following chapters give an overview of three key trends, or 'transitions' in human health and their interaction with global environmental change (Abdel-Motaal and Cole, 2017):

- **The demographic transition** – from high numbers of births with many people dying in early childhood and few surviving to old age, to low numbers of births with most of the population surviving to old age.
- **The epidemiological transition** – from most deaths being caused by infection, malnutrition and complications during childbirth, which can be addressed by medical treatment, to most deaths being caused by non-communicable diseases such as cancer and heart disease, which can be linked to living long lives in unhealthy environments.
- **The ecological transition** – from living close to nature in sustainable natural systems to living in increasingly synthetic urban, industrialized, resource-depleting environments.

These three transitions do not act in isolation, but together give a strong underpinning to the study of human progress and the pressures that are being placed on the socio-ecological system during the Anthropocene.

Life expectancy, GDP per capita and health spending in OECD countries

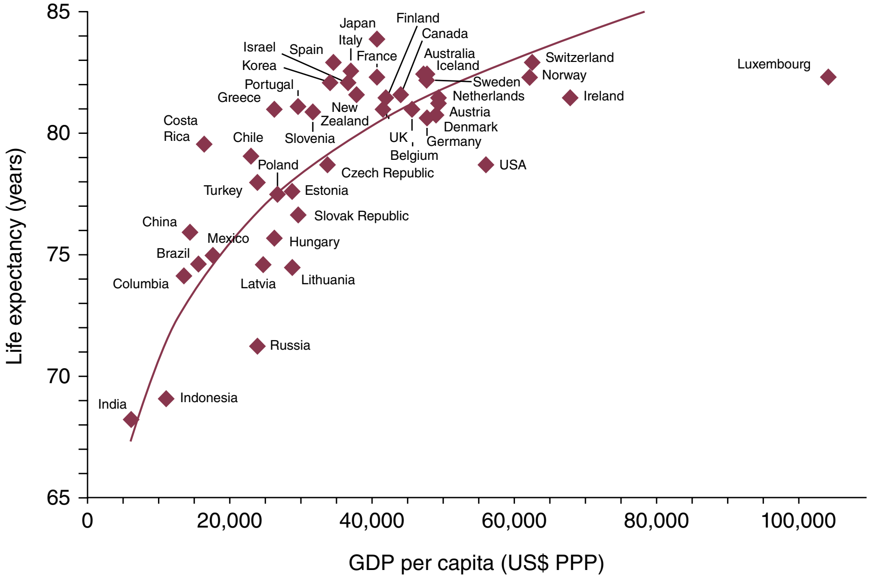

Fig. 7.2. Life expectancy in Organisation for Economic Co-operation and Development (OECD) countries improves rapidly with increased gross domestic product (GDP) per capita. PPP, purchasing power parity. (Data from OECD, 2017.)

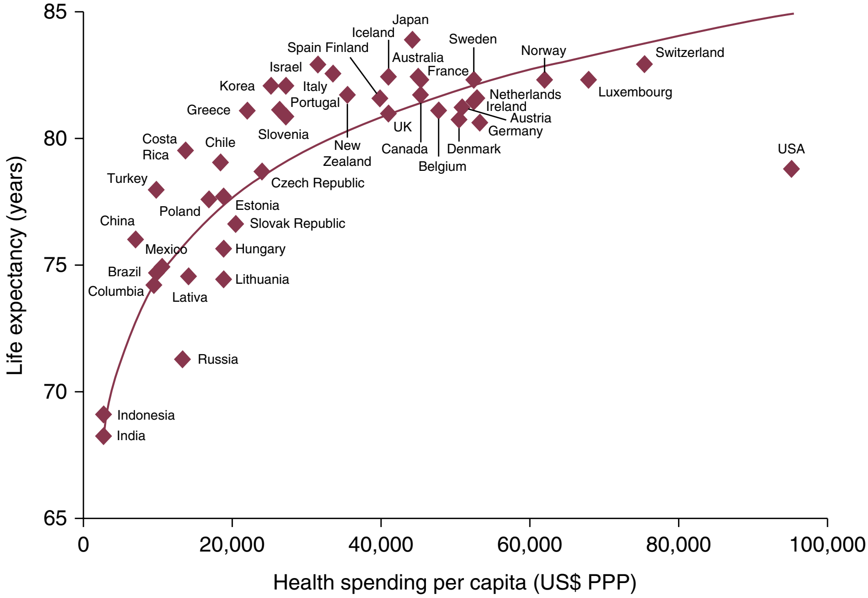

Fig. 7.3. Life expectancy improves more sharply with health spending per capita than with GDP. (Data from OECD, 2017.)

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8 The Demographic Transition

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8.1 Population Changes over Time

A key challenge for planetary health is the sheer numbers of people now living on Earth. The global population grew at a rate of less than 0.05% per year between 10,000 years ago and the late 18th century to stand at around 1 billion in 1800. Since then, it has increased dramatically over the past 250 years, reaching 3 billion in 1959 and thereafter following a typical Great Acceleration trajectory. The global population reached more than 6 billion by the end of the 20th century, increased to 7 billion by 2015 and at that time was projected to reach 10 billion shortly after 2050.

This increase has been linked to four key factors that go hand in hand with improved living standards: (i) reduced variability in the food supply (food security); (ii) better housing conditions; (iii) improved sanitation; and (iv) progress in preventative medicine, including vaccines, and cures including antibiotics and cancer treatments (Sanderson, 2013).

As societies progress, advances first in agriculture and then urbanization remove or reduce many of the common risk factors for disease and ill health. In developed countries, families no longer starve because their crops fail, freeze to death in winter because their homes are inadequately heated or die from infectious disease.

8.2 Population Increase and Planetary Health

In more developed societies, as children become more likely to survive to adulthood and people begin to live longer in general, the age distribution of the population changes from high numbers of young people and low numbers of elderly, with most deaths occurring in early childhood, to a more even distribution across all age groups and most deaths occurring at ages 70 and above. This is known as the **demographic transition** (Thompson and Whelpton, 1933; Caldwell, 2007). It has five stages (see Fig. 8.1).

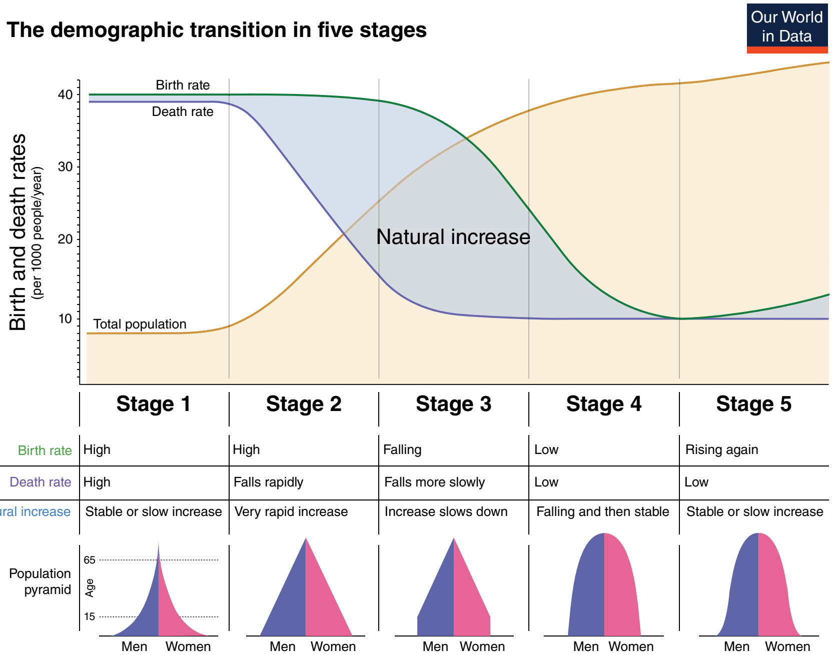

Fig. 8.1. As rates of neonatal, infant and childhood mortality drop, the structure of the population changes to a more even age distribution. (From Roser and Ortiz-Ospina, 2017.)

In Europe, the demographic transition began in the 18th century, concurrent with the start of the Industrial Revolution, and the five identified stages are closely linked to economic, social and technological development. Most European countries have now completed Stage 4, as have others such as Japan and the USA, but the transition has not happened simultaneously in all regions of the world. Many developing countries, particularly those in sub-Saharan Africa, are still in Stage 1.

Populations in each stage have a distinct health profile, explained in the next section. Countries still in Stage 1 are invariably low-income economies; those in Stages 2 and 3 are low-middle and upper-middle; and high-income economies are in Stages 4 and 5.

8.3 Stages of the Demographic Transition

Stage 1 is epitomized by a high birth rate and high childhood mortality, with a steady decline in numbers of people reaching older ages. Only a small percentage of the population is over 65. For all age groups, the main causes of death tend to be disease and malnutrition. The steep-sided demographic pyramid of Stage 1 was typical of Europe and other now-developed countries prior to the mid-20th century and persists in the 21st century in developing regions, particularly those with a high rural to urban population ratio and low-income economies. Examples of countries showing this distribution include Sierra Leone, the Democratic Republic of Congo and Afghanistan.

As **Stage 2** begins, the shape of the pyramid changes as more children survive childhood. The fertility rate drops (from five-plus children per mother to around two, due to family planning and the availability of birth control), and people become less likely to die before reaching old age. This is usually concurrent with several environmental and social changes happening in the associated countries, including advances in hygiene and sanitation which, along with medical developments such as vaccination and antibiotics, mean that fewer people die from infection. The introduction of safer working practices protects adults – particularly men – from death due to accidents in early and mid-adulthood. As economic development and increasing GDP lifts people out of absolute poverty, food security becomes less of a problem. The percentage of the population living in cities increases; however, this can increase exposure to health risks such as air pollution, heat stress and poor sanitation. Examples of countries showing this distribution include Turkey, Saudi Arabia and India.

Stage 3 is a continuation of Stage 2, as those who have survived childhood begin to reach old age. Increasing education and employment opportunities for women, along with the virtual guarantee of childhood survival, sees smaller families becoming the norm. Examples of countries in this stage include Mexico, Chile and Georgia. If the birth rate drops very quickly, the bottom section of the pyramid can become thinner than the middle, with higher numbers of the population in middle age than in childhood or old age. Estonia and China are among the countries currently showing this distribution.

In **Stage 4**, the evening out of the age distribution at the bottom of the pyramid seen in Stage 3 has worked its way up, as people born in a period of high childhood survival begin to reach old age. This stage is associated with fully developed, modern societies in which good sanitation and hygiene ensure that serious infections are rare; access to healthcare offers vaccination against or treatment for many causes of ill health, including cancer and diseases more likely to affect the elderly. Starvation due to extreme poverty has been eliminated. Most of the population survives at least into their mid–late 60s. Examples of countries showing this distribution include most European countries, the USA and Chile.

Stage 5 is largely hypothetical at present but considers what might happen to populations once the age distributions have stabilized in Stage 4. The hypotheses cover a ‘more fertile’ model, in which the birth rate may begin to increase again, and a ‘less fertile’ model, in which the birth rate drops below replacement level, creating a bulge in the middle of the pyramid. The less fertile model appears to be characteristic of countries that go through stages 3 and 4 very rapidly, such as Japan, Russia and China, over one or two generations. This has been described as a potential second demographic transition (Omran, 1971), in which populations may shrink, rather than continue to grow.

As the age structure of the population changes, however, so too do the types of health challenges it encounters. This is known as the epidemiological transition (Omran, 1971), which will be covered in the next chapter.

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9 The Epidemiological Transition

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9.1 The Three Stages of Epidemiological Transition

As people become more likely to live into old age, the main causes of illness and death within a population change. This is the epidemiological transition (Omran, 1971), and it can be divided into three stages:

- **First epidemiological transition**: The emergence from an 'age of pestilence and famine' experienced by pre-agricultural, historical, and traditional hunter-gatherer societies, where the main causes of death are starvation due to crop failure and intermittent epidemics. In early agricultural/urbanized societies, however, increased contact with animal and human waste, contaminated water supplies and overcrowded conditions (often exacerbated by poor nutrition) results in regular and persistent infections (Klepinger, 1980).
- **Second epidemiological transition**: The transition towards an 'age of receding pandemics', in which infectious (communicable) disease has receded as a major cause of death. This is brought on by a combination of cleaner conditions, including better sanitation and improved housing conditions, along with more secure food supplies and hygienic storage, increased medical care, early vaccination and higher standards of living in general.
- **Third epidemiological transition**: The transition to the 'age of chronic disease'. Chronic degenerative diseases such as cancer and heart conditions (non-communicable conditions) become the main causes of death. Some of this transition is the consequence of an ageing population, as conditions such as cancer, Alzheimer's and dementia are more likely to be experienced in later years. However, much is also attributable to the quality of the environment in which populations live (Prüss-Üstün *et al.*, 2016), combined with the ease with which they can access – and afford – healthcare.

9.2 The Main Classes of Disease Types

The World Health Organization (WHO) breaks down the causes of death into three main groupings:

- **Group I**: communicable, maternal, perinatal and nutritional conditions;
- **Group II**: non-communicable diseases (NCDs); and
- **Group III**: injuries and conflicts.

Communicable diseases are infectious diseases spread by direct contact from one infected person to another (e.g. chickenpox or influenza) or indirectly through vectors such as rats or mosquitoes (e.g. bubonic plague and malaria). They are caused by exposure to harmful viruses, bacteria and parasites and spread more quickly in densely populated areas such as cities.

NCDs cannot be transmitted from one person to another but are conditions in which the body experiences an unhealthy state such as cancer, asthma or diabetes. What causes NCDs is complex, but there is often a link with long-term exposure to risk factors such as poor air quality, harmful chemicals and toxins, and poor diet.

9.3 Disease Risk and Relationship to Income

The World Bank groups countries into four categories based on their gross national income (GNI) per capita: (i) low income; (ii) lower-middle income; (iii) upper-middle income; and (iv) high-income countries.[1] The ten leading causes of death for each income group are different (Fig. 9.1).

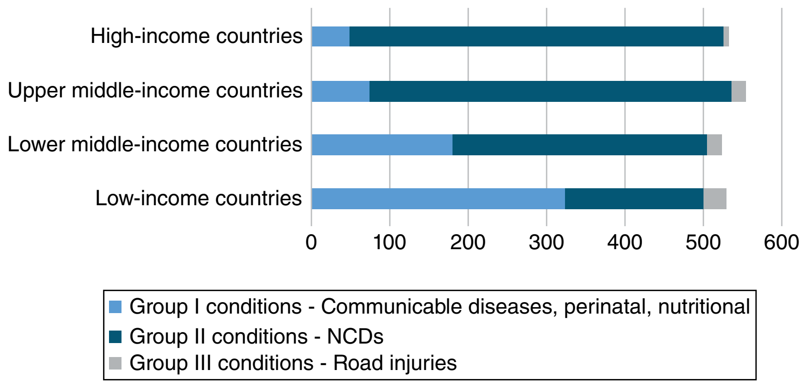

Fig. 9.1. Deaths per 100,000 population/year caused by the top ten causes of disease. In low-income countries, the main cause of death is Group I conditions, but the ratio of Group I to Group II causes of death is reversed for higher income economies. (From data in Global Health Data Exchange, 2016.)

The causes of disease and mortality rates are closely linked to a country's level of economic development and its stage in the demographic transition.

9.4 Group I Diseases: Infection, Malnutrition and Childbirth

The communicable diseases of Group I conditions disproportionately affect the young in low-income developing countries, as well as the infirm, the poor and the excluded in more developed ones. High levels of infectious diseases can trap low-income economies, and post-conflict or disaster regions, in the age of pestilence and famine by affecting productivity and putting a huge burden on already under-resourced healthcare sectors.

In 2012, diarrhoea, malaria, respiratory infections, HIV/AIDS (acquired immune deficiency syndrome), tuberculosis and meningitis accounted for more than 50% of all deaths in the Democratic Republic of Congo (Mancini *et al.*, 2014), for example. Five million of the 5.7 million deaths (88%) from infectious and parasitic diseases in 2015 occurred in low- or lower-middle income economies (WHO Press Office, 2016, personal communication). In these countries, at any one time as many as half of all available hospital beds can be filled with people suffering from diarrhoea (Hutton *et al.*, 2009).

In addition, of 303,449 maternal deaths in childbirth globally in 2015, 281,190 (93%) occurred in low- or lower-middle income economies.

These Group I diseases virtually disappear in high-income economies. They would disappear completely from the top ten causes of death if not for the fact that the WHO category 'lower respiratory conditions' includes pneumonia, which disproportionately affects the very elderly, at ages well beyond the average life expectancy of most low-income countries. Respiratory conditions are also linked to air pollution, which can increase the severity of existing symptoms (Chauhan and Johnston, 2003); the worst air pollution also tends to be experienced in the large urban centres of developing countries such as Beijing in China and New Delhi, India.

New infectious disease and disease spread

The early 21st century has seen diseases such as malaria and West Nile fever reaching new regions (Pongsiri *et al.*, 2009) and an increased incidence of new diseases, including severe acute respiratory syndrome (SARS) (Peiris *et al.*, 2004) and Middle East respiratory syndrome (MERS) (Zumla *et al.*, 2015) being transmitted from animals to humans for the first time. Outbreaks of others, such as Ebola which emerged in the mid-20th century (Dobson *et al.*, 1997), are happening more frequently and on a larger scale. One reason for this may be that natural habitats, disturbed by changes to land use and food production in previously remote and densely forested areas, are pushing animal vectors into closer contact with human populations (see Chapter 16, this volume). This threatens a new age of emerging diseases (Rogers and Hackenberg, 1987).

Antibiotic resistance

Such risks are further exacerbated by the increasing resistance of pathogenic bacteria to antibiotics, which is making infections harder to treat (Holmes *et al.*, 2016). This could undermine what would otherwise be the final stage of the epidemiological transition, to an 'age of medical technology' and/or an 'age of sustained health' (Rogers and Hackenberg, 1987), in which medical progress confers a significant health advantage on future generations, with all members of society surviving into extreme old age.

9.5 Group II Diseases: Non-communicable Diseases and Lifestyles

In 2015, 40 million of the 56.5 million deaths – 70% – recorded worldwide were due to the non-communicable diseases of Group II (WHO Press Office, 2016, personal communication). The largest killers were:

- cardiovascular disease (17.7 million deaths worldwide);
- cancer (8.8 million deaths worldwide);
- lower respiratory infection (3.2 million deaths worldwide); and
- diabetes (1.6 million deaths worldwide).

Most deaths from these Group II conditions occur in middle- and high-income economies. Low-income countries account for only 800,000 of the 17.7 million global deaths from cardiovascular diseases; 376,000 of the 8.8 million global cancer deaths; 544,000 of the 3.2 million global deaths from lower respiratory infection; and fewer than 78,000 of the 1.6 million global diabetes deaths recorded. These figures are confounded by the fact that the percentage of countries considered to be low-income countries is dropping: from 36% in 1990 to 10% in 2015, and that in such countries, people die from infectious disease and other Group I conditions before the age when NCDs become an issue. When such factors are taken into account, the risk of early death from many of these later-life conditions, such as lower respiratory disease, is actually higher in the lower income countries.

As the economy progresses through lower-middle, upper-middle and eventually high-income status, other new Group II conditions emerge, such as Alzheimer's and dementia, which are associated with later-life onset. This has been described as a further epidemiological transition associated with an unnatural extension of the human lifespan. Such conditions are still rare in lower-middle income countries but by the second decade of the 21st century had started to become part of the top ten causes of death in upper-middle income countries, accounting for 20 deaths in every 100,000 (60 per 100,000 in high-income countries). Ischaemic heart disease was present in low-income countries, but rates rose from 49 deaths per 1000 to 145 with increasing income levels.

Health into old age

Group II conditions are epitomized by later life; long-term conditions affect those who have had the luxury of surviving childhood. Three out of every four cancers in the USA are diagnosed in people over 55, and in the UK, half of all cancers are diagnosed in people over the age of 70, for example. Alzheimer's and dementia are conditions that begin far beyond the life expectancy within most sub-Saharan African countries.

The risk of death from infection and starvation is reduced in high-income environments, only to be replaced by new risk factors such as exposure to pollutants, more sedentary lifestyles and inappropriate diet. The resulting cancers, heart conditions and diabetes can be survived long term by those with access to affordable medical care and treatment; however, some scholars predict that children growing up in developed countries today have much less healthy lifestyles than previous generations and may die at an earlier age than their parents' cohorts (Olshansky *et al.*, 2005).

Populations in the later stages of the demographic transition do not inevitably experience higher levels of Group II conditions. Some countries that have completed Stage 4, such as Japan, have much lower rates of cancer and diabetes than others, such as the USA. This suggests that something more than just age is impacting on population health and the type of conditions experienced.

9.6 Group III: Conflict, Accidents and Disasters

Group III conditions, which include injuries directly incurred during wartime or conflict, or as a result of disasters such as flooding and earthquakes, are increasing due to the impacts of environmental change (Leaning and Guha-Sapir, 2013). Such events also disrupt existing healthcare systems, which can lead to the breakdown of vaccination programmes (Cole, 2014) and diminish the ability of those affected to access the care required for existing conditions (Cole, 2019). Such conditions both trap regions in lower levels of development and disproportionately affect lower income regions, creating a vicious circle that is difficult to break.

9.7 Increasing Exposure to Risk Factors

Exposure to the risk factors that increase vulnerability to Group II and III diseases, such as pollutants, poor diet, poor air quality and increased conflict, disaster and extreme weather events is driven by a third mega-trend: human development and progress. This will be discussed in the following chapter – the **ecological**

transition, which describes a shift away from rural living to more urbanized and industrial lifestyles. The changes in land use and energy use that result from this threaten increased exposure to risk factors for Group II diseases and a new age of emerging infections. The challenge to human health in the Anthropocene is increasing.

Note

1. Low-income economy countries have a GNI of US$1005 per annum or less; lower-middle income economy countries have a GNI of US$1006–3955; upper-middle economies have a GNI of US$3956–12,235; and high-income economies have a GNI of US$12,236 or more. Taken from World Bank definitions 2018.

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The Ecological Transition

10

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10.1 Redefining our Place within Nature

The third mega-trend affecting human health is the ecological transition (Bennett, 1976; Baldwin, 1995). This transition concerns both changes we have already made to the way we live, and the changes we need to make in future to preserve the environment and our health.

Since the first cities and agriculture emerged 10,000 years ago, the human race has increasingly modified the environment for its own benefit (Lawson, 2016), moving from a natural existence *within* nature to lives spent in increasingly synthetic urban environments that are *separated from* nature. Many of the human health challenges this raises were discussed in Chapter 3 (this volume). As human actions and activities have moved beyond the biological aspects of those transactions (i.e. what we need to take from nature to ensure only sufficient food, shelter and heat) to societal drivers based on consumer demand for things we simply *want*, the resulting degradation and pollution (Baldwin, 1995) threatens the loss of valuable ecosystem services that may not be fully substitutable with technology (Cohen *et al.*, 2018). For the sake of our own health and the health of the planet, we need to make an ecological transition back towards nature (Frumkin, 2001).

10.2 The Need for Better Environmental Stewardship

The promotion of a focus on better environmental stewardship (Palmer, 2006) has led to the rise of ecological movements such as Transition Towns (Taylor, 2012) and ecovillages. While such ground-up movements may not be scalable to a world of 10 billion or more inhabitants, they may provide pointers towards how we can live more sustainably with nature into the future (Litfin, 2016) and how we might incorporate nature more closely into urban living as we strive to transition away from the most damaging aspects of the modern world.

Plants and animals are part of the workspace for rural communities but are associated more with leisure activity (if at all) for urban dwellers (Keniger *et al.*, 2013).

Within urban environments, finding space for nature can be particularly beneficial to the physical and mental health of those people with lower socio-economic status (Dadvand *et al.*, 2016), possibly because higher income individuals are more likely have opportunities to leave the urban environment and interact with nature on countryside holidays, or to have garden space and be able to keep pets at home (WHO, 2015). Green (plants and trees) and blue (water) spaces within urban settings are increasingly seen as an important part of human well-being and environmental health.

10.3 The Ecological Transition and Human Health

An increasing amount of research is emerging on how our relationship with nature intersects with human health, including the impact on the human biome of exposure to microbes and microbial diversity within the urban ecosystem (Wells *et al.*, 2017), between human health and urban diets (Popkin, 2004), urbanization and risk of heat stress, and nature's impact on psychological well-being. More contact with the natural world during infancy may be essential to enable the immune system to develop properly (Rook, 2013), while better access to parks and green spaces within urban neighbourhoods has beneficial effects on physical and mental health of individuals and communities.

10.4 Long-term Benefits of Engaging with Nature

There is growing evidence that incorporating more natural environments into urban areas brings long-term health benefits, including greater longevity, reduced cardiovascular disease, and less incidence of depression and stress by providing spaces for sport, active recreation, relaxation, contemplation and neighbourhood social cohesion (WHO, 2002, 2015). A reduction in the prevalence of several NCDs and their risk factors can be linked to the quantity, proximity and usability of natural spaces in urban environments (Annerstedt *et al.*, 2012).

Mental disorders contribute to a significant portion of the global burden of disease. Depression alone accounts for 4.3% of the total burden, with children in developed countries suffering from what has been called a 'nature deficit disorder' (Louv, 2008) in which the lack of interaction with outdoor space contributes to anxiety and stress (Driessnack, 2009). There is also strong evidence for the positive effects of contact with wild animals and domesticated pets on human mental and physical health (Frumkin *et al.*, 2017).

Urban green spaces also encourage the spiritual values that may help us to better appreciate nature (Pretty *et al.*, 2008) and thus protect it. It is unlikely to be a coincidence that modern-day communities living more traditional lifestyles within high-income, developed countries, such as the Amish and Mennonite communities of North America (Mitchell *et al.*, 2012), the Seventh-day Adventist communities of New Zealand (Webster and Rawson, 1979), and rural mountain villages in

Italy and Japan experience some of the greatest longevity, best health and lowest recorded rates of non-communicable diseases of any human populations (Poulain *et al.*, 2013). Such communities also have little impact on the environment.

10.5 Conclusions

We need to consider how we might rekindle our relationship with nature as we consider the three major factors that have driven environmental change throughout the Anthropocene: (i) the growth of cities; (ii) the rise of large-scale, industrial agriculture; and (iii) an upward trend in the use of energy, which until recently has been derived mainly from fossil fuels. These three factors have interlinked over time to encourage the over-exploitation of natural resources (Nordhaus and Tobin, 1972; Sima and Marinescu, 2012), resulting in many problems with pollution and climate change that will be discussed in the following chapters. If human health and the health of the environment are to be preserved into the future, we need to find a way to live more sustainable lives as part of nature, not separate from it.

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11

Agriculture: Land Use, Food Systems and Biodiversity

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11.1 Farming and Human Progress

Agriculture is defined as the science and practice of farming. It includes cultivating the soil to grow crops, and rearing animals to provide food (including meat, eggs and dairy), products (such as wool, fur and leather) and to use as work animals. Its emergence has enabled humanity to prosper (Jacobs, 1961). Large-scale farming, helped by irrigation, frees people from hunter-gatherer and subsistence existences by providing a more secure and centralized food supply, which also allows them to settle, organize into larger towns and cities and to develop more complex, stratified societies. Surplus food can be stored for the winter, to protect against times of scarcity and can be traded for other goods and services. It is no longer necessary for everyone to be involved in food provision or production, facilitating the stratification of urban society that enables scholars, engineers, scientists and doctors to emerge (Toye, 2004).

Agriculture has been extremely positive for humankind but the environment has not necessarily fared so well. Dramatic changes in land use, water systems and, in more modern times, the large-scale use of artificial fertilizers and pesticides do not always have a positive impact on the natural world and its ecosystems: agriculture contributes to greenhouse gas emissions, water stress, soil degradation and biodiversity loss.

In addition, agriculture has separated humans from nature. Members of society who are not involved in food production may no longer interact with the natural world, which has implications on physical health, including diet, the immune system, activity levels and mental health (Rook *et al.*, 2017; Wells *et al.*, 2017).

11.2 Scale of Land Conversion and Land Use Change

Large-scale agriculture and cities appear virtually simultaneously in the historical record and, once they do, land use changes dramatically. Between 10,000 and 1000 BCE, cultivated cropland increased gradually to 500 million ha. Since 1000 BCE, land has been converted at a much faster rate, and by 1950 nearly 5 billion ha had been converted. Cultivated lands provide a more stable supply of grains, fruit and vegetables and can significantly improve crop yield but humans currently use more than half of the Earth's habitable surface (i.e. land that is not sea, ice or desert) for agricultural production: three-quarters of this is used to graze animals or produce food for those animals, and only one-quarter for direct human food consumption.

Of this conversion, 80% has happened over the last 300 years, and 50% has happened since 1900 (Goldewijk *et al.*, 2017) (Fig. 11.1). The rate has slowed recently as humans have become more efficient at using land: technological advances have enabled greater agricultural yields to be achieved. This is essential, as the world population has risen: each hectare now needs to provide more food per inhabitant of Earth than ever before. In 5000 BCE, there were 2.3 ha of domesticated land per person, decreasing slowly to 1.5 ha per person until the middle of the 20th century and declining sharply since then to around 0.67 ha per person in 2015. In 2014, agricultural land accounted for more than 37.5% of the Earth's terrestrial land surface (World Bank Data, 2017). Just 1–3% of the Earth's surface is covered by urban infrastructure (0.05 billion ha of the Earth's surface), but 1.3 billion ha are dedicated to cropland and 5.3 billion ha to grazing food animals that feed the growing populations of the urban regions.

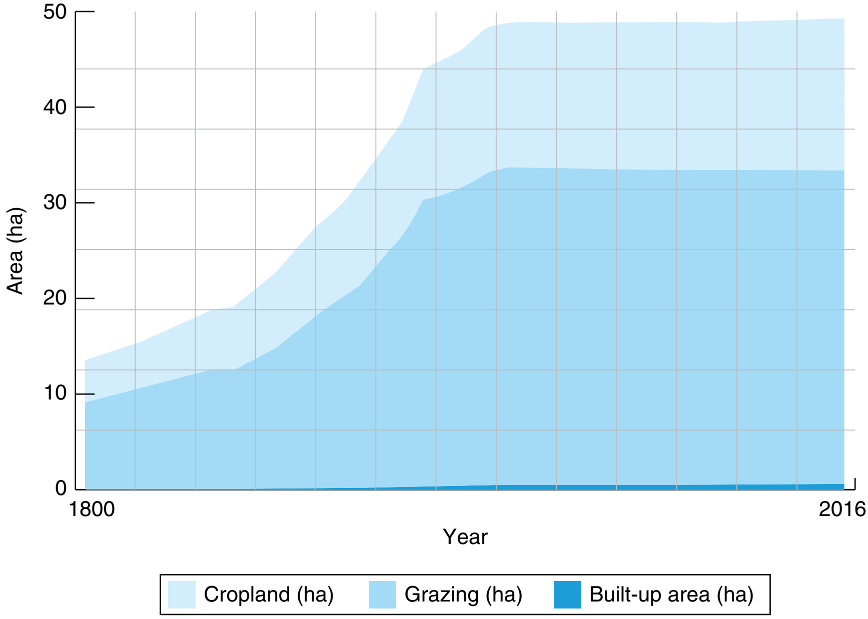

Fig. 11.1. Land use changes 1800–2016. The area of land modified by humans has increased since 1800, though the amount of agricultural land needed per person has fallen. Built-up areas account for a tiny amount of land cover, but urban lifestyles drive the more dramatic land use changes needed to sustain urban food systems (McCarthy, 2014).

This increased efficiency has required extensive use of artificial fertilizers, which can have damaging effects on the environment. Heavy cultivation has resulted in the contamination of water courses and coastal regions and the loss of micronutrients in plants and soil as crops are no longer rotated or land 'rested' between harvests.

Food for urban centres is mostly supplied by large-scale, industrial agricultural facilities and processes that can have a more damaging impact on water and soil systems than small-scale farming. Rural and urban land use does not have to be incompatible, however – at the end of the 20th century, an estimated 800 million urban dwellers grew food or raised livestock (Lawson, 2016). The more developed urban populations become, however, the less likely food production and urban living is to take place side by side.

Agriculture and water resources

An extremely important part of agricultural history is the development of irrigation, which helps crops to grow in regions where rainfall alone is not sufficient. This improves food availability and security but can also have a damaging impact on water systems. Irrigation diverts rivers, uses up water, contributes to the depletion of soil nutrients and can help to pollute water bodies with fertilizers and pesticides. This damages life in rivers and disrupts ecosystems. Irrigation uses much greater volumes of water than natural systems and accounts for around 70% of all freshwater used globally (Khokhar, 2017).

Worldwide, groundwater is being extracted faster than it can be replenished; in 2015, irrigation was responsible for 20% of this (Whitmee *et al.*, 2015). The most depleting regions of the world are those with the highest agricultural production, including north-west India, north-east China, Midwestern USA and California's Central Valley. Better water management, including the reuse and recycling of wastewater captured by improved sanitation practices and sewer systems can ease the pressures (Cole, 2018), but requires adequate water treatment processes to ensure human health is not put at risk.

Improving agricultural yields

While the amount of land available for cultivation is running out, the Earth's population is still increasing, requiring improved yields from current land use if future populations are to be fed adequately. Improved yields are possible: over the past 60 years, US maize production has quadrupled while the area used to produce it has only increased by half. In 2016, US agricultural practices yielded on average 11.0 t/ha of maize and 5.6 t/ha of rice, whereas Indian practices yield only 2.8 t/ha of maize and 2.4 t/ha of rice (OECD, 2018). However, countries where yields are higher tend to use more artificial fertilizers, pesticides and generally damaging practices.

11.3 Livestock and Greenhouse Gases

A second important interaction between agriculture and greenhouse gas emission is the impact of livestock. Food products are a major source of greenhouse gas emissions – 7.1 gigatonnes (Gt) of CO_2 equivalent/year according to the Food and Agriculture Organization of the United Nations (FAO) (Gerber *et al.*, 2013) – adding to the challenges from energy use. This represents 14% of all annual anthropogenic emissions. Of this total, approximately 44% is in the form of methane, 29% is nitrous oxide and 27% is CO_2. Cattle alone are responsible for 65% of these emissions. Producing 1 kg of beef results in almost 300 kg of CO_2 equivalent/kg of protein produced, which is higher than for all other livestock animals: producing chicken meat and eggs, pork and cows' milk (without beef) all result in emissions below 100 kg CO_2 equivalent/kg of protein produced. The amount that would be produced by an entirely plant-sourced diet would be even less.

Better farming practices and techniques can reduce this impact. The FAO points towards improving feeding techniques and using better quality feeds, which can reduce the amount of methane generated during digestion and manure decomposition. Manure can be collected and reused as natural fertilizer, as well as to produce biogas and clean energy. This recycles nutrients and energy and offsets the emissions from livestock against the environmental damage that would otherwise be caused by artificial fertilizers and carbon fuel production. In some regions, improved management of grazing land could also offset the emissions through carbon sequestration, by an estimated 0.6 Gt of CO_2 equivalent/year.

In 2013, the FAO estimated that by improving current practices, the farming industry could reduce global greenhouse gas emissions from livestock by 30% annually, particularly in the developing world: (i) by 38% in South Asian mixed dairy systems; (ii) by 19–30% for specialized beef production in South America; and (iii) by 27–41% for West Africa's small ruminant sector.

This will be increasingly important to planetary health as the countries of the world strive to reduce their carbon emissions and meet the nationally determined contributions of the Paris Agreement to the United Nations Framework Convention on Climate Change (Dinesh *et al.*, 2017). The contribution of agriculture to planetary health challenges and solutions needs to be considered holistically with the challenges related to energy use.

11.4 Biodiversity: Less Diverse Ecosystems and Health

The third major issue in land use change is the effect it has on biodiversity. Biodiversity refers to the number, variety and genetic diversity of plant and animal life that coexists within an ecosystem. Biodiversity loss – a reduction in the numbers of individuals, populations, genetic variation within populations and species (McGill *et al.*, 2015) – may affect human and environmental health, as a high level of biodiversity builds the foundation for strong, resilient and properly functioning ecosystems. This in turn influences air quality, water purity, soil fertility, fish stocks and Earth's surface temperature (WHO, 2015).

The biosphere, habitats and biomes

The Earth has a 'living surface' of plant and animal life on land, in the sea and in the air. This is referred to as the biosphere. Within the biosphere are ecosystems or habitats (e.g. a pond, a forest or a city), in which the living plants and animals coexist. The biosphere is subdivided into biomes – types of environments that share similar characteristics, for instance Lake Michigan in the USA and Lake Victoria in Africa each have their own distinct ecosystem but share aquatic freshwater biome characteristics that influence the plants and animals within them.

The human body is itself a microbiome, consisting of human cells and microorganisms, such as bacteria in the gut that influence nutrition and regulate our immune system. Humans first evolved to live within the wider ecosystems of temperate grasslands (Marlowe, 2005): to live comfortably in other biomes, we have to make technological modifications. Each human being is also a unique ecosystem (Turnbaugh *et al.*, 2007), with trillions of microbes living on and within them. The plants and animals that humans encounter within different ecosystems provide essential dietary nutrients through food, ingredients for medicinal compounds, natural fibres for clothes and materials to build shelter.

Different biomes have different levels of biodiversity: moist tropical forests have the highest rates and high-altitude land the lowest (Gonthier *et al.*, 2014). Lands that have been cultivated for agriculture (Tsiafouli *et al.*, 2015) and urban environments (Shochat *et al.*, 2010) tend to have less biodiversity than natural habitats.

Biodiversity loss has several, often interrelated, impacts on planetary health:

- It threatens human health by reducing the diversity of the human diet, making us more vulnerable to the absence of essential nutrients; included in this is decreased marine biodiversity caused by overfishing and marine pollution (Gamfeldt *et al.*, 2015).
- It heightens plants' vulnerability to infectious disease, risking the loss of entire harvests.
- Ecosystem services of benefit to health may be lost if we do not preserve biodiversity. Rich soils offer protection against diarrhoeal disease in areas where open defaecation is common, for example. There is also considerable evidence that biodiversity loss – particularly the loss of mangroves and wetland environments – makes populations more susceptible to natural disasters such as coastal flooding (Rodríguez *et al.*, 2016) and hurricanes (Escudero-Castillo *et al.*, 2018).

Rate of biodiversity loss

Globally, the Earth lost 52% of its biodiversity between 1970 and 2010, including more than three-quarters of freshwater wildlife, 39% of terrestrial wildlife and 39% of marine wildlife (McLellan *et al.*, 2014). An estimated 42% of mammal species in Europe had been lost by 2010; and a further 15% of bird species and 52% of freshwater fish were threatened with extinction (EU, 2010). Alien and invasive species of plants and animals, transferred from one habitat to another either deliberately or accidentally, can be problematic (Shochat *et al.*, 2010). Weeds degrade land and water. Agricultural pests reduce crop and livestock productivity and can outcompete native species to dominate the ecosystem.

Intensive agriculture and monoculture

While intensive agriculture is essential to enable the feeding of a growing population with changing dietary habits (Godfray *et al.*, 2010), it also leads to homogenization or monoculture – a situation where a single, often human-adapted crop, is grown over a large area. This reduction in native biodiversity challenges food security and food quality (MEA, 2005), though concentrated monoculture can 'spare' more uncultivated land for conservation protection.

Since the middle of the 20th century, there has been a marked decline in both the number of crop species commonly grown and the genetic diversity within species. There are more than 300,000 known edible plant species, of which around 7000 are known to have been used by humans at one time or another throughout history (FAO, 1997; IUCN, 2012), but only around 200 are eaten today (Galluzzi *et al.*, 2011; Warren, 2015). Just 30 crop species provide 90% of the energy consumed by humans and half of all plant-sourced protein comes from three crops: wheat, maize and rice. Five species of livestock (chickens, cattle, ducks, sheep and pigs) provide 95% of animal-derived food (MEA, 2005).

Monoculture, particularly where there is little in-species genetic diversity, could lead to severe food shortages as it heightens the risk of an entire crop being affected by one disease. Lack of genetic diversity in Irish potato crops was a factor in the potato famine of 1845, caused by *Phytophthora infestans*, which resulted in around 1 million people dying of starvation and a further million migrating (Ristaino, 2002). Lack of diversity was also a factor in the decline of the 'Gros Michel' variety of banana as a popular commercial crop after several plantations were wiped out by Panama disease in the 1950s (Ordonez *et al.*, 2015). Cultivated crops, which have little in-species genetic diversity, are often cross-bred with wild relatives or older, non-commercial varieties to improve resistance to disease. If these other varieties become extinct, the ability to protect crops from future outbreaks may be diminished or lost. Intensive agriculture and the demand for land also reduces the amount of land available for livestock to graze, pushing them closer together and allowing disease to spread more easily. This necessitates a high use of antibiotics for disease control, which has negative consequences for the emergence of antibiotic resistance (see Box 11.1).

Box 11.1. Agriculture, antibiotics and disease

Improving agricultural livestock practices will have a co-benefit to human health as it will also help to reduce the use of antibiotics in farming. Overcrowded conditions mean that infections can spread quickly through livestock, particularly if conditions are not particularly hygienic, but the use of antibiotics to prevent and treat animal infections drives antimicrobial resistance and impacts on the efficacy of antibiotics for human healthcare. Even bigger problems are the use of antibiotics as growth promoters, which also drives antimicrobial resistance, and antibotics' influence on animal and dung beetle microbiomes, which influences the amount of methane produced and can inhibit the breakdown of dung, leading to increased eutrophication. Improved hygiene practices, better animal welfare and more rational antibiotic stewardship are needed to address this (Giubilini *et al*., 2017). Replacing all or some of the meat in our diets with plant-derived protein, the production of which is less environmentally damaging, will also help (Godfray and Garnett, 2014).

Monoculture and dietary diversity

Dietary diversity across countries declined by 68% between 1961 and 2009 as diets became more homogenized. Wheat is a now staple in more than 97% of countries, while other historic staples have declined, including rye (by 45% worldwide), sorghum (by 52%) and millet (by 45%). Declines can also be observed within countries: (i) India had more than 100,000 varieties of rice a century ago, but now has only a few thousand; and (ii) the USA once had 5000 varieties of apple, but this has dropped to only a few hundred. The biodiversity of our dietary intake is declining considerably.

A diverse food supply is important for the delivery of a mix of macronutrients such as carbohydrates, proteins and fats, and micronutrients in the form of vitamins and minerals (Burlingame *et al.*, 2009). Nutrient content can differ significantly across different varieties of plants or breeds of animals and is affected by their environment. For instance, the consumption of 200 g of rice/day can represent less than 25% of the recommended daily intake (RDI) of protein or more than 60%, depending on the variety consumed (Kennedy and Burlingame, 2003). While one apricot variety can provide less than 1% of the RDI of vitamin A, which protects against eye conditions and respiratory infections, another can provide more than 200% (Munzuroglu *et al.*, 2003).

A healthy human diet is composed of hundreds of beneficial bioactive compounds, and a varied diet is the best way to ensure adequate intake (Hatløy *et al.*, 1998). The dietary diversity score (DDS) demonstrates that individuals with more diverse diets tend to have fewer digestive problems, vitamin and mineral deficiencies, lower incidence of stomach cancer, stronger immune systems and lower mortality in general (Johns, 2001). Diversity has, however, declined in favour of a narrow range of staple foods, threatening human health.

Pollinated food crops are the source of vitamins and minerals in the human diet and loss of pollinators could have serious implications for human health (see Box 11.2).

Box 11.2. Pollinator loss

Pollinator loss is both a result of, and driver of, biodiversity loss as pollination is required for 87 leading food crops and 35% of annual food production (Springmann *et al*., 2016). In South Asia, 50% of plant-origin vitamin A is derived from pollinated crops, and globally 12–15% of iron and folate is derived from pollinated crops. A 50% loss of pollinators would lead to an increase of 0.7 million annual human deaths (Smith *et al*., 2015). The use of neonicotinoid insecticides, to protect crops from other more damaging insects, is a serious concern to planetary health because these chemicals are toxic to bees.

11.5 Plant-derived Medicines

Plants are not only a food source; they are also a source of medicines. More than 70,000 different plants worldwide are used in traditional and modern medicine (FAO, 1997) and half of the 100 most prescribed drugs in the USA originate in wild plant species. Plant-derived drugs include: (i) the stimulant ephedrine, from *Ephedra sinica* (also known as Ma Huang), used to treat low blood pressure, asthma and narcolepsy; (ii) the anti-malaria drugs quinine from the cinchona tree (*Cinchona ledgeriana*) and artemisinin, also known as quinghaosu, from *Artemisia annua* (Krishna *et al*., 2008); and (iii) salicin from *Salix alba* which can be used for pain relief, to bring down body temperature and as an anti-inflammatory drug. Ginseng (*Panax quinquefolius*) has properties that can ease the side effects of cancer treatment (Barton *et al*., 2010) while Asian maypole (*Podophyllum hexandrum*) and the Western yew (*Taxus brevifolia*) are also important for the treatment of cancer (Giri and Narasu, 2000). Only a fraction of the world's plant species has currently been investigated for pharmacological potential – their loss may limit the development of new pharmaceuticals and the ability to breed disease-resistant crops in future (Ratnadass *et al*., 2012).

11.6 Loss of Habitat and Zoonotic Disease Spread

Biodiversity loss also impacts health through disturbed and degraded habitats that mediate exposure to disease. As humans encroach on natural habitats, they come into closer contact with animal and insect vectors of disease (Dobson *et al*., 1997; Keesing *et al*., 2010). Forest fragmentation and land use change have been linked to Ebola outbreaks in Africa (Rulli *et al*., 2017), for example, and can be exacerbated by road networks created by and for logging operations, that also enable people to travel further and spread the disease.

11.7 Land Use and Ecosystem Services

What land is used for, and how it has been modified by humans, has a strong impact on the ecosystem services that land can provide (Constanza *et al*., 1997).

Groundcover conserves water, prevents flooding and reduces runoff from fertilizers, poorly managed latrines and pesticides. This helps prevent toxic agricultural chemicals from entering the food chain and water systems, controls soil erosion and protects biodiversity, which in turn protects human health.

Arguably, the most damaging effect of land use change on the environment is the destruction of forests – often by burning – for cropland or logging. Forests play a vital role as reservoirs for biodiversity and carbon storage: approximately 80% of above-ground terrestrial carbon and 40% of below-ground terrestrial carbon is stored in forests. Forest cover is essential for the removal from the atmosphere of CO_2 released by burning fossil fuels. Globally, forest clearance by burning has accounted for 9% of all human-produced greenhouse gas emissions from 1959 to 2011 (Le Quéré *et al*., 2015).

During the early days of the Roman Empire, more than 90% of Europe was forested, but more than 99% of this primary forest has since been lost. In total, the Earth has lost an estimated 80% of the forest cover it had 8000 years ago and 50% of the world's tropical forest has been lost since the turn of the 20th century. Of an original 1.5 billion ha, only 700 million remain (Global Forest Watch, 2017). Agricultural soils contain 25–75% less organic carbon than those in comparable natural ecosystems such as undomesticated meadowland (Lal, 2010).

Though forest cover across the globe reduced dramatically in the 20th century, the past 25 years have seen some positive developments. The net rate of forest loss dropped from an annual net loss of 0.18% per annum in the 1990s to 0.08% in the period 2010–2015, according to the FAO, and sustainable forest management has increased. Planted forest area increased by 105 million ha between 1990 and 2015, though there was a net forest loss of 129 million ha overall, and carbon stocks in forest biomass decreased by nearly 11 Gt, mainly driven by land use changes. While the past quarter century has seen real progress, important challenges remain.

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12

Urbanization, Living Standards and Sustainability

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12.1 The Urbanization of Planet Earth

Whether urbanization drove agriculture or vice versa is debated endlessly but the two developments go side by side in history (Jacobs, 1961) and are twin drivers of environmental change. Civilization – complex societies characterized by greater urban development – emerged around 10,000 years ago alongside a marked decrease in rainfall in the north of Africa. This appears to have created conditions that pushed human hunter-gatherer and pastoral communities towards larger settlements supported by irrigated agricultural land and more complex social systems in which specialized roles emerged, releasing some members of society from a life of subsistence farming (Wright, 2017).

Since that time, the human race has increasingly modified the environment for its own benefit. Increasing numbers of cities, and increasingly large cities, have developed across the world. The percentage of the world's urban population increased from 3% in 1800, to 14% in 1900, 30% in 1950, and 50% in 2015. The urban population is projected to continue to grow (Fig. 12.1) and by 2050, an estimated 70% will live in urban areas (World Population Bureau, 2017) and one in three of those in a city with more than 500,000 inhabitants (Marchal *et al.*, 2011). In China, 80% of the population is expected to live in urban areas by 2050 (Khanna *et al.*, 2016).

12.2 The Urban Environment and the Urban Penalty

Urban populations are more concentrated than those in rural communities, and this can create challenges with waste disposal, air pollution and the provision of clean water. In poorly planned and managed cities, diseases can easily proliferate. Diarrhoea caused 1.4 million deaths in 2015 and was the world's eighth biggest

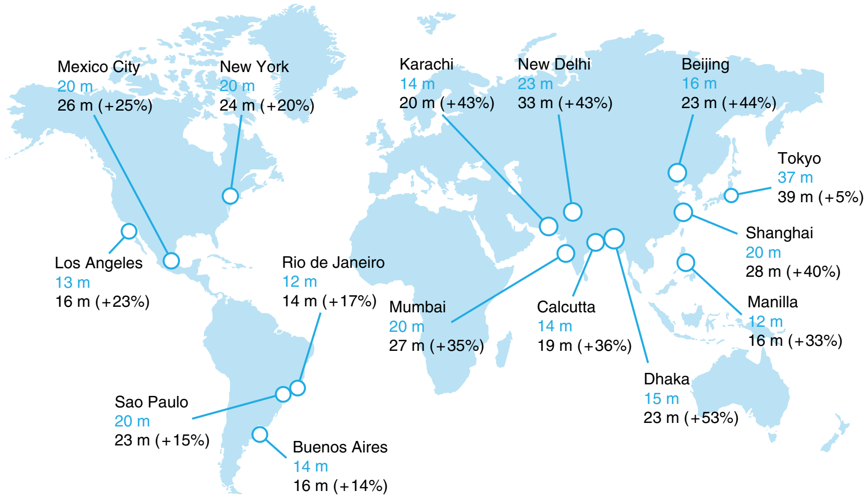

Fig. 12.1. Projected population growth (millions) in the world's 15 largest cities, 2011–2025. The number of cities and megacities worldwide is growing, as well as the size of their populations. (From McCarthy, 2014.)

killer (GBD collaborators, 2016). Crowded conditions facilitate the spread of infectious diseases such as measles, influenza and chickenpox (Klepinger, 1980). Pollution poses a second health hazard: in developing countries, 98% of urban areas fail to meet WHO air quality guidelines and even in developed countries the figure is 50%.

In pre-industrial Europe, before the advent of large-scale vaccination, piped and disinfected water supplies and good sanitation, an 'urban penalty' associated with overcrowded, dirty and polluted conditions resulted in lower life expectancy in cities than in rural areas (Kearns, 1988). In 19th-century Europe, urban children were 2.5 times more likely to die than rural children, and urban men between the ages of 35 and 60 had a much lower life expectancy than their rural counterparts. In 1900, there was a difference of just under 7 years in life expectancy at birth between the populations of provincial European capitals and rural areas. In 1930, diseases of the digestive tract and respiratory tract were 75% higher in urban areas of Spain than rural ones (Reher, 2001). The urban poor were often particularly affected.

As conditions in cities improve, however, the higher exposure to risk factors in the urban environment is eventually overtaken by the benefits conferred by higher incomes and better standards of living. Today, cities are the most cost-effective way to provide basic services, opportunities and a high quality of life (Stern and Zenghelis, 2018). This provides a clear urban advantage in most settings. This is particularly true in the case of health: healthcare services and providers, in the form of highly skilled nurses and doctors, tend to be clustered in well-equipped city hospitals. High economic growth supports medical research, development and efficient healthcare systems.

12.3 Urban Health, Development and Demographics

Historically, the urban penalty has been more likely to affect countries during the early stages of development and the demographic transition, turning towards an urban advantage as standards of living and incomes rise. Health inequalities today are not only due to poor sanitation and crowded conditions that facilitate disease spread, however. City dwellers risk exposure to the drivers of non-communicable diseases (NCDs) and respiratory disease due to many interconnected factors including: (i) low-quality, processed diets; (ii) a higher likelihood of proximity to sources of pollution such as busy roads; (iii) lack of exercise due to poor availability of quality green space and the leisure time to use it; and (iv) higher likelihood of exposure to risk factors for stress, such as high levels of noise. Urban areas also tend to exhibit more marked socio-economic inequality than rural areas. The urban poor are disproportionately affected (Rogers and Hackenberg, 1987) by the risk factors for NCDs, while also remaining at higher risk from infectious diseases such as tuberculosis, diarrhoeal disease and parasite infection.

In highly developed countries, the urban/rural relationship sometimes swings back again, however, with countryside areas outperforming their urban neighbours. In 2017, the Public Health Observatory of Scotland, UK (ScotPHO, 2017) recorded the highest life expectancy in remote rural areas of Scotland: 79.5 years for males and 82.8 for females. Such trends may be due to wealthier members of a very urban society moving back to the countryside after retirement, combined with good access to healthcare services becoming more even between rural and urban areas. At this micro-level, it is often the marginalized poor within high-income urban settings who have the worst health outcomes (Hotez *et al.*, 2016).

12.4 The Benefits of Urbanization

Cities are not, therefore, all bad news for humanity. Nor do they have to be bad for the environment. Urbanization enables economies of scale and resource efficiencies (Baldwin, 1995; Rees and Mathis, 1996) and enables administrative functions to emerge, including strong public health programmes and advanced medical systems.

It is important to recognize that it is not necessarily cities and their technology per se that cause potentially irreversible damage to the environment, but the use of high-impact technology by so many people (Bronowski, 1972). Condensing living space can reduce energy use and water use per capita (Chini *et al.*, 2017), and can allow more of the natural environment to be preserved; denser cities may be better overall for biodiversity, for example, than more sprawling ones (de Oliveira *et al.*, 2011). Therefore, considerations of the ecological transition need to intersect with those of the demographic: what is damaging per se and what is damaging when practised by a global population of 10 billion or more people?

The root cause of environmental damage also needs to be considered: it is not the car that pollutes the atmosphere, but the hydrocarbons burned in the fuel it uses. A car fuelled by alternate means – such as by cleanly generated electricity – will offer the same benefits without negative consequences. With proper urban planning, cleaner, more sustainable cities can be developed in future. Some existing ones, such as Oslo in Norway (Næss, 2014) and Curitiba in Brazil (Gouldson *et al.*, 2015), provide blueprints for how this might be achieved.

12.5 Health and Urban Infrastructure

Another undeniable benefit of urbanization is that human health benefits from strong healthcare infrastructure and systems, and good access to these. Such infrastructure tends to be centralized in major cities. This is of little benefit if those same cities are driving ill health, however – and some countries have barely begun to build the infrastructure on which healthy urban living depends (e.g. sanitation infrastructure and good quality housing), let alone the healthcare infrastructure needed to address those failings. In 2017, 844 million people (more than 10% of the global population) did not have clean drinking water and 2.3 billion (about one-third) did not have adequate sanitation (Cole, 2018). This points to an unfinished public health agenda in much of the developing world. Africa and much of Asia has yet to go through the same transformation in public health that took place in European and North American cities in the late 19th and early 20th centuries (Geels, 2006) and time is running out to lock-in good urban planning to the world's emerging urban regions. Many NCDs are aggravated by sedentary lifestyles, which are more common in urban settings than in rural ones. Low levels of physical activity and stress lead to poor mental health, and as weight gain is linked to the use of antidepressants (Sarris and O'Neil, 2016) this can create a vicious circle more likely to be prevalent in cities.

12.6 Urbanization and Sustainability

Urbanization provides humanity with a more stable and secure food supply, improving health and our resilience against uncertain harvests, for example – but the environmental footprint of cities is high. Cities use high levels of electricity, for example, and while this has been key to human progress and development, cities' heavy reliance on fossil fuels and the large amounts of CO_2 released into the atmosphere has led to unprecedented climatic change and pollution.

Human society would have less environmental impact (and thus fewer negative consequences for human health) if we: (i) sourced only the materials we needed from sustainable yields; (ii) recycled finite resources such as minerals and metals; (iii) disposed of plastics and other non-biodegradables responsibly; and (iv) used no fossil fuels. If all populations lived this way (as most did, before the Industrial Revolution) the human race would be in equilibrium with the natural environment. A key dilemma in planetary health is how – or if – we can maintain modern standards of living without continuing to degrade and pollute the environment (Bina, 2013).

This is at the heart of many ecological movements and theories, including green economics (Pearce *et al.*, 2013) and transition towns (Hopkins, 2008). The key to overcoming the urban challenge is to ensure that future urban development and expansion is carefully managed to preserve the health of the environment inside and outside the city, as well as the health of the urban inhabitants within it.

12.7 Conclusions

As cities develop, poor planning can increase the risk of communicable disease due to inadequate sanitation and overcrowding, as well as increasing the risk of exposure to urban and industrial pollution. Lack of access to beneficial green and blue spaces can lead to insufficient activity and affect psychological well-being. Excess salt, sugar and fat in processed diets, smoking, high levels of alcohol consumption, poor housing and unsafe working conditions also add to the urban penalty. Poverty can exacerbate all of these issues and impede access to the healthcare that can mitigate urban risks.

If unaddressed, the health burden in such environments is likely to considerably impact government budgets in developing countries over the coming years, threatening to destabilize economic and social development.

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13

Energy Use, Greenhouse Gas Emissions and Global Warming

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13.1 Energy: the Driver of Human Progress

The previous chapters set out how human health has changed with human progress, how the rural environment has been altered by that progress and how urban development challenges both human health and environmental health. This chapter will focus on another main pathway through which global environmental change has impacted human and environmental health: our use of energy, particularly when produced from non-renewable, carbon-based fuel sources.

Energy use is the key driver of climate change. The energy sector alone is responsible for two-thirds of all global CO_2 emissions (Ritchie and Roser, 2018) and thus its use leads to increased land, water and air temperatures, heat stress, more severe weather events and ocean acidification. Depending on the energy source, its use can also release toxic materials into the environment.

The impacts on human health are not always straightforward, however. Energy has many benefits: it generates electricity to power heating, stoves and refrigerators, homes and hospitals, factories and schools. It provides heat and light, fuel for transport and power for manufacturing. Access to electricity is, rightly, one of the Sustainable Development Goals: Goal 7, *Ensure access to affordable, reliable, sustainable and modern energy for all.*

Climate change does indeed 'threaten to undermine the past 50 years of gains in public health [and] a comprehensive response could be the greatest global health opportunity of the 21st century' (Watts *et al.*, 2015), but the negative impacts of energy use on the environment need to be weighed against more positive ones on improved standards of living.

13.2 Increasing Rates of Energy Use

The amount of energy used by humans – collectively and individually – has increased dramatically over the course of the Anthropocene (Malhi, 2014).

Since mastery of fire enabled humans to cook, survive in less hospitable habitats and develop early tools (Gowlett, 2016), the main source of energy used has changed from renewable biomass (mainly wood), through water-powered early mills and steam power, to non-renewable fossil fuels including coal, oil and gas – used directly or via electricity networks. Prior to the beginning of the Industrial Revolution, most of the world's fuel came from wood, but from the early 19th century onwards an increasing amount came from coal, which provides more energy per kilogram burned, but which cannot be replaced. Burning fossil fuels releases the carbon stored underground into the atmosphere as carbon dioxide (CO_2), whereas renewable biomass is already part of the active climate system, in which oxygen and CO_2 must be exchanged in equal measure to maintain ecological balance. The source of the energy, as well as the amount of energy used, has a significant impact on global environmental change.

In the early 20th century, oil and natural gas, which are more efficient sources of fuel than coal, began to replace coal as the world's principal source of energy (Fig. 13.1). The mid-20th century saw the introduction of nuclear power, which produces far fewer emissions than fossil fuels but raises safety concerns due to the risk of nuclear accidents (Rashad and Hammad, 2000). In more recent decades, cleaner, safer, renewable sources such as solar and wind power are increasingly being incorporated into the global energy mix. This is a positive development, and future energy systems need to continue this trend.

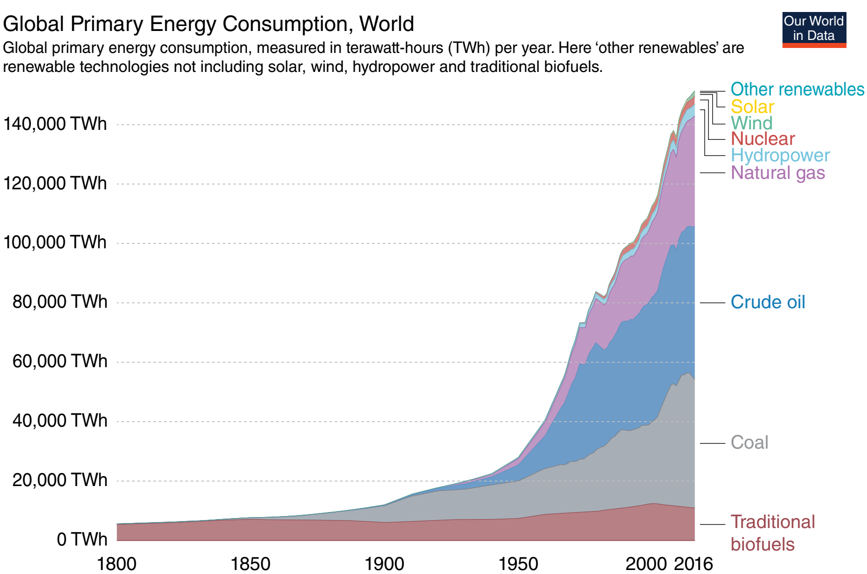

Fig. 13.1. Global primary energy consumption, 1800–2016. TWh, terawatt hours. (From Smil, 2017 in Ritchie and Roser, 2019.)

13.3 Energy Use and Population Numbers

As with most of the Great Acceleration trends, total global energy use rises with increasing population numbers. Per capita energy consumption also rises with GDP (Fig. 13.2). In low-income countries such as Afghanistan, each person on average may use as little as 5 GJ (gigajoules)/person/year, but this rises to more than 1000 GJ each in high-income economies such as Qatar. Over the past 200 years, the amount of energy the world has used has steadily increased, with a six-fold increase in energy use between 1950 and the present day. This is predicted to rise by 50% again by 2030 (Schwab, 2017).

Energy use is closely tied to urbanization: cities require more energy than rural areas to fuel the industries they support. Urban populations tend to have higher incomes and more money to spend on domestic and social uses of energy including heating and cooling, cooking and refrigeration, lighting, transport and entertainment. In 2015, Chinese urban residents used 1.6 times as much energy each compared with rural residents (Khanna *et al.*, 2016). As rural incomes increase, energy use is likely to rise across the entire population. The indirect energy impact of cities (i.e. the energy needed to supply goods and services to city dwellers, for example the transport costs of delivering food from rural areas) can increase the energy use of individuals by a factor of three (Khanna *et al.*, 2013). Energy is needed to power sewage systems and water treatment works to dispose of human waste, and to enable transport systems to deliver food from farms to supermarkets, and commuters to their places of work.

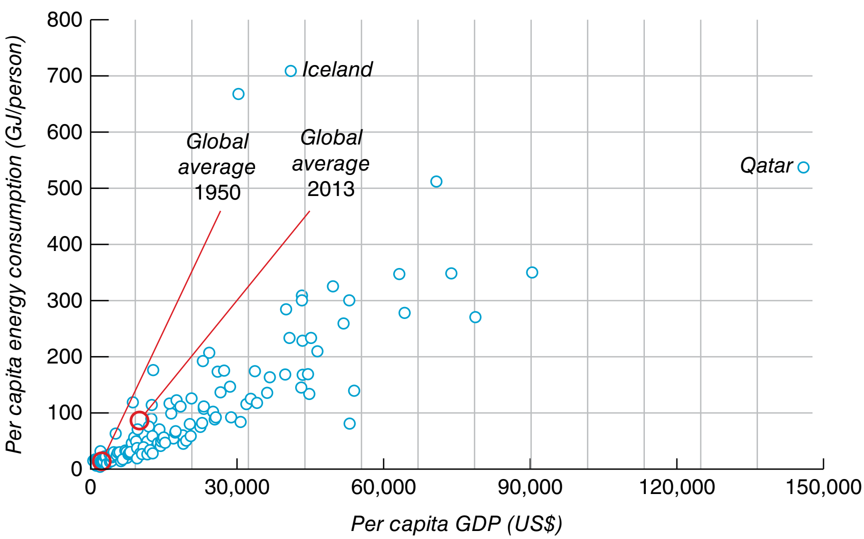

Fig. 13.2. Energy use per person per year as a function of per capita GDP. Residents of countries with higher GDP use more energy per person than residents of lower income economies. (Data from World Bank Open Data provided by David Bice, The Pennsylvania State University, with permission.)

13.4 Greenhouse Gases and Climate Change

The problem with burning fossil fuels is that greenhouse gases (GHGs) are released into the atmosphere at a faster rate than natural ecosystems can remove them. The GHG of main concern is CO_2, followed by methane (CH_4) – much of which is produced by livestock – nitrous oxides and halocarbons (which include CFCs and their replacements).

The CO_2 released by fossil fuels traps heat in the atmosphere that would otherwise radiate out into space. It can take thousands of years for this carbon to be removed from the active climate system again and while it is trapped, the excess CO_2 in the atmosphere heats up the planet, drives sea level rise and ocean acidification (as it dissolves in the oceans to form carbonic acid). By 2016, global average atmospheric CO_2 concentrations had increased from pre-Industrial Revolution levels of 280 ppm to above 400 ppm (Bala, 2013; Jones, 2017), far in excess of the natural range (180–300 ppm) observed over the past 650,000 years. Levels increased more rapidly between 1995 and 2005 than over the previous 40 years. Global atmospheric levels of methane and nitrous oxide have also increased over the same period.

A secondary pollutant, tropospheric ozone, can be produced downwind following reactions between nitrogen oxides (e.g. from burning sources, or soils) and volatile organic compounds. Tropospheric ozone is not only a GHG, but at high concentrations is also a lung irritant and detrimental to crops.

This represents a dilemma to planetary health: energy is needed to maintain the quality of life on which good health depends, but more renewable and cleaner ways of producing it are needed.

Increasing world temperatures

The mean surface temperature of the Earth has been increasing since around 1800. Since the 1970s, the rate of increase has been about 0.2°C per decade, and projections are that global temperatures could rise by between 2.6°C and 4.8°C (above pre-industrial levels) by the end of the 21st century. The 2017 United Nations Environment Programme (UNEP) *Emissions Gap Report* predicted a temperature increase of 3.2°C by 2100 (UNEP, 2017), even if the National Determined Contributions of the Paris Agreement are fully implemented. While the effects of increased surface temperatures vary, based on local climatic conditions and the extent of urbanization, even the lower end estimates will have a significant impact on some parts of the world.

Global warming is more pronounced over land than sea, and more pronounced in urban areas than rural ones (Emilsson and Sang, 2017) due to synthetic surfaces such as asphalt and concrete that retain more heat than natural ground cover – especially at night, when humans need to cool down in order to remain healthy. Lack of shade and density of polluting traffic particularly impact urban temperatures. It has long been recognized that people living in such urban 'heat islands' (Clarke, 1972; Taha, 1997), which can be 10°C hotter than surrounding areas, are at greater risk of ill health during extreme heat events (Uejio *et al.*, 2011).

13.5 Climate Change and Health

High-end estimates predict as many as 38,000 people could die from direct effects of heat exposure each year between 2030 and 2050, with up to 251,000 dying from indirect effects of just three diseases (increased incidence of malaria, diarrhoeal disease and undernutrition) (Kleiman *et al.*, 2017), mostly in sub-Saharan Africa and Asia where temperatures will be highest. Hospital admissions for respiratory conditions, which already contribute to more than 3 million deaths a year worldwide, show marked increases on hotter days in many regions of the world (D'Amato *et al.*, 2013; Tao *et al.*, 2014) and this has been linked to increased air pollution. Levels of sulphur dioxide, ozone, nitrogen dioxide and particulate matter are all made worse by excessive heat (Qian *et al.*, 2010).

Increased temperature and heat stress

Another growing concern is heat exhaustion, which occurs when body temperature rises. Normal average body temperature is 37°C – if it rises above 38°C, the person experiences a state of heat stress; they may feel dizzy, tired, weak or nauseous, and develop a headache or thirst. If their temperature rises above 40°C, there is a risk of organ failure and loss of consciousness. At such temperatures, death can occur after just 30 minutes (Bouchama and Knochel, 2002).

When the ambient temperature of the environment is lower than that of the human body, heat can be naturally dissipated to the surrounding air should it rise during, for instance, physical exercise or manual labour. The hotter and more humid the environment, the more difficult this process becomes. Temperatures above 26°C pose a moderate to high risk of heat stress symptoms and temperatures of 34°C or above pose a severe risk (Kjellstrom *et al.*, 2009). Chronic diseases such as diabetes and heart disease magnify individual risk (Basu and Ostro, 2008; Sokolnicki *et al.*, 2009), as do factors such as age – infants and the elderly are both disproportionately affected, with risk increasing sharply above 50 years of age (Kovats and Hajat, 2008).

13.6 Temperature Rise and Extreme Weather Events

As global average surface temperatures increase, more regions of the world are experiencing regular summer temperatures in the moderate to high risk bracket (26–33°C) for heat stress. Climate change has at least quadrupled the risk of extreme summer heat events in Europe (Fouillet *et al.*, 2006). In June 2017, local records were broken in the Netherlands, Portugal and Spain, where the average temperature was 4°C hotter than usual in July. Afternoon temperatures above

40°C, often alongside night-time temperatures above 30°C, were experienced in Corsica, Italy and Croatia. In the 1900s, a similar heatwave would have been extremely rare (WWA, 2017) but by the middle of the 21st century this could rank as a normal summer average (Russo *et al.*, 2017). The chance of a severe summer heatwave, like those experienced in 2003 and 2017, happening again in Europe in any given year is predicted to be 12% at current world temperatures, rising to 25% should the global temperature rise reach 1.5°C, and to 42% with a 2.0°C temperature rise.

There is a strong positive correlation between increased heat and increased mortality and morbidity (Kovats and Hajat, 2008). Daily mortality rates in many areas of Japan have been shown to rise as temperatures surpass 28°C (Honda *et al.*, 1998). The 2003 heatwave in Europe caused 14,802 excess deaths in France alone (Fouillet *et al.*, 2006; Kovats and Hajat, 2008). Italian hospitals saw a 15% spike in hospital admissions during the 2017 heatwave (WWA, 2017). In Wuhan, China, air-pollution-related deaths have been shown to be higher on hotter days. In New York, daily mortality spiked after a city-wide power failure in August 2003 that caused air conditioning to fail (Anderson and Bell, 2012).

Around 125 million additional people aged over 65 are estimated to have been exposed to heatwaves annually between 2000 and 2016 due to a combination of climate variation and demographic change (Watts *et al.*, 2017). More than 15% heat-related excess mortality is predicted towards the end of the 21st century in Southern Europe, South America and South-east Asia (with no data available for Africa) under the highest emission scenarios (Gasparrini *et al.*, 2017).

Poor urban planning, poor building design and lack of air conditioning can magnify the impact of higher temperatures. Rapid and poorly planned urbanization may lead to negative health outcomes (Kovats and Hajat, 2008), particularly in the low-income economies of sub-Saharan Africa and South-east Asia (Takahashi *et al.*, 2004). A similar problem may be faced in Southern Europe, where most buildings have not been designed with heat dissipation in mind. Before access to electricity was widespread, buildings in hot climates were designed to keep inhabitants cool through architectural features alone, but modern buildings rely more on air conditioning, which in turn requires energy to power the systems.

13.7 Increasing Temperatures and Disease

In addition to the direct health effects of higher temperatures, there are various indirect health effects. The disease burden caused by salmonella food poisoning in Australia could double by 2030 if temperature increases by 1.5°C (Zhang *et al.*, 2012). Increasing temperatures threaten to increase the spread of several vector-borne diseases including malaria, dengue, Lyme disease and encephalitis (Kleiman *et al.*, 2017). Deaths and injuries caused by forest fires were reported in Albania, Serbia, Macedonia, Greece and Italy during the 2017 summer heatwave; 60 people are reported to have died in forest fires in Portugal alone (Russo *et al.*, 2017). Box 13.1 outlines some of the impacts of heatwaves.

Box 13.1. Heatwave impacts

2003: There were 14,802 excess deaths in France alone (Kovats and Hajat, 2008).
2017: Italy records 15% spike in hospital admissions (WWA, 2017).
2017: 60 people killed in forest fires in Portugal (Russo *et al*., 2017).
By 2030 cases of food poisoning in Australia could double (Zhang *et al*., 2012).
By 2050 afternoon temperatures above 40°C may become common in Europe (Russo *et al*., 2017).

13.8 Climate Change, Food Systems and Nutrient Balance

Temperature rise also affects food security. Droughts and famines have long affected Africa but may become more common in other regions of the world, too. A projected increase in weather-related disasters driven by climate change could affect two-thirds of the European population – around 350 million people – annually by the year 2100, compared with just 5% – 25 million people – between 1981 and 2010, with 50 times more fatalities.

As many as 530,000 global annual deaths have been projected due to the impacts of climate change on crop yield by the middle of the 21st century, leading to reductions in fruit and vegetable consumption (Springmann *et al.*, 2016). Droughts and flooding due to climate change diminish the quality of the crops that do grow, as well as causing crop failure (Fanzo *et al.*, 2017). Per capita freshwater availability has declined by 75% in the Arab world over recent decades, which significantly threatens food security.

Food shortages may increase in previously temperate climes as well as the areas of sub-Saharan Africa that have long been prone to drought and famine. Half of Bosnia's agricultural output was affected during the 2017 European heatwave, resulting in a 10% reduction in economic output. The Italian agriculture sector anticipated a loss of billions of dollars. At a global mean warming level of 2°C, a third of the total land surface could be arid although this could be avoided in two-thirds of these regions if warming is limited to 1.5°C (Park *et al.*, 2018).

Higher CO_2 levels significantly reduce essential nutrients such as protein, zinc and iron in crops including rice, maize and soybean. Wheat grown under high levels of CO_2 can contain 9% less zinc, 5% less iron and 6% less protein; rice can contain 8% less protein and 3–5% less iron and zinc. Zinc content in wheat could drop by as much as 10% by 2050.

A reduction of these nutrients may lead to nutrient deficiency, particularly in babies and pregnant women. Around 2.4 billion people globally get 60% of their zinc and iron from these plants, and in countries including Bangladesh and Armenia, it can be over 75% (Dietterich *et al.*, 2014). If levels of CO_2 in the atmosphere rise as predicted by 2050, this could put an additional 25 million more children at risk of malnutrition from failing crops, higher food prices and poorer quality food (Nelson *et al.*, 2009). As the loss of protein content sometimes leads to increased carbohydrate concentration in certain foods, the change could lead to higher rates of diabetes, heart disease and stroke. Eating a greater volume of food to receive the same quantity of nutrients is not a feasible option, though breeding strains that are less susceptible to rising CO_2 levels might be.

13.9 Health Impacts of Ocean Acidification, Sea Level Rise and Ocean Warming

Increased levels of atmospheric CO_2 have led to changes in the chemical composition of the oceans, dropping their natural alkalinity by 0.1 pH since the beginning of the Industrial Revolution. This amounts to a 26% change in ocean acidity, which is predicted to increase by 170% by 2100 (IGBP-SCOR, 2013). This causes damage to marine life, including many species that are an important food source for many communities. Coral reefs that provide habitat for marine species and dissipate wave energy to protect coastal communities from flooding, are particularly affected. The full impacts of ocean acidification are not yet entirely known, but they represent another large-scale environmental change at the global level.

Sea levels rose at a rate of 2.8–3.6 mm/year between 1993 and 2010 (Engels *et al.*, 2015), from melting of land ice and from the expansion of water as it heats up. As many as 1.4 billion people could be living in low-lying coastal zones by 2060, which will be at risk of flooding due to sea level rises. A large proportion of these people will be in Asia – which has the highest area of land mass at risk of flooding – and in Africa, where significant urban growth is taking place in coastal regions (Neumann *et al.*, 2015).

Salinization of freshwater, caused by inefficient agricultural irrigation, withdrawal of seawater due to temperature rise and low annual rainfall in coastal regions, is a further problem. In Bangladesh, salinization of freshwater systems in coastal areas has been linked to increased risk of high blood pressure in pregnant and non-pregnant adults (Scheelbeek *et al.*, 2017).

13.10 Conclusions

Such environmental changes can be avoided if cleaner sources of energy and tighter regulation on emissions can be more widely adopted. When damaging change is recognized, environmental legislation can be put in place to protect the environment and the health of the people who live in it. A useful example of such legislation is the creation of the US Environmental Protection Agency and the subsequent Clean Air Act 1970 and Clean Water Act 1972. The Clean Air Act saw a 70% drop in the aggregate emissions of six common air pollutants between 1970 and 2015 (EPA, 2011); while not all of these are directly responsible for climate change, they share a root cause: the burning of fossil fuels and the growth of heavy industry. Limiting their emissions also brings down carbon emissions but the only way to seriously reduce the rate of global warming is more investment in and adoption of cleaner, more renewable fuel sources.

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14

Environmental Protection: a Key Tool for Planetary Health

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14.1 Environmental Contamination

Agriculture, urbanization and energy use all cause pollution – the release of unwanted, often dangerous materials into the Earth's atmosphere, threatening human health and harming ecosystems (MEA, 2005). The release of CO_2 and short-lived climate pollutants into the air is the most pressing problem for planetary health, but water and soil pollution from fertilizers, pesticides, metals, chemicals and plastics are also serious issues.

In 2015, approximately 9 million premature deaths each year could be attributed to pollution – 16% of all deaths worldwide and three times more than from AIDS, tuberculosis and malaria combined (Landrigan *et al.*, 2018). The risk of exposure, and the impact of those risks, is not equally distributed across the world, however. Harm often falls on those far away from the pollution's point of release. This chapter aims to give a brief overview of the key concerns.

14.2 Air, Water, Land and Occupational Hazards

Pollution can be grouped into four main categories (Landrigan *et al.*, 2018): (i) air pollution; (ii) water pollution; (iii) soil pollution; and (iv) pollution in the workplace (the exposure to certain pollutants due to a particular profession, such as agricultural workers' exposure to fertilizers or garment manufacturers' exposure to chemical dyes).

Pollution can travel across national boundaries, continents and oceans, impacting health far from where the pollutant was released. An estimated 12% of deaths caused by air pollution occur in a region of the world different to the one in which the pollutant originated: air pollution in China causes deaths in Europe and the USA, for example, while the market for consumable goods in Europe and the USA drives and maintains the growth of polluting manufacturing industries in China (Zhang *et al.*, 2017).

Short-lived climate pollutants such as black carbon, methane, tropospheric ozone and hydrofluorocarbons (HFCs) pose direct threats to human and environmental health, and many are linked to greenhouse gas emissions and climate change.

This transfer of pollution from regions of the world where raw materials are produced or extracted to where they are manufactured into tradeable goods and eventually sold is an increasingly important concern as the world undergoes further development. In the field of planetary health, however, the cost of pollution has to be weighed against the economic development that may be stifled without the industries that create it. How lifestyles can improve without increasing the ecological footprint of people in developing regions is a key consideration.

14.3 The Health Impact of Pollution

In low-income settings where there is little industrialization, the main pollution concerns are contaminated water – a major cause of Group I disease, particularly diarrhoeal disease – and lower respiratory infections, exacerbated by indoor air pollution from cooking and heating, is also a serious health risk.

Drinking water is often contaminated with bacteria such as *Escherichia coli* and *Salmonella* species, and microscopic parasites including *Cryptosporidium*; rivers and lakes can be contaminated with agricultural fertilizers and industrial chemicals. Lack of tap water, toilets and sanitation/sewer infrastructure are mainly to blame. Worldwide in 2012, diarrhoeal disease was responsible for 57 million DALYs (disability-adjusted life years – a method of calculating how many years of life have been affected by ill health, disability and early death). Of these, 57% were due to modifiable environmental factors, with 70% of all deaths from water pollution attributable to diarrhoea.

Air pollution is a risk factor for lower respiratory infections, which were responsible for 51 million DALYs in 2012. Of these, 35% could have been prevented (Prüss-Üstün and Neira, 2016). Poor regions face a double risk from household air pollution caused by burning wood for cooking and heating homes, and by ambient air pollution caused by land-clearance fires. The fine particles emitted by wood when burning damage the lungs, increasing susceptibility to respiratory infections and pneumonia, and can lead to cancers and heart disease (Bølling *et al.*, 2009). Poor air quality also increases the likelihood of low birthweight in babies (Boy *et al.*, 2002; Siddiqui *et al.*, 2008).

Lifestyles in which these conditions are prevalent are falling with declining incidence of extreme poverty worldwide, though in 2015, 2.3 billion people across the globe still lacked access to a basic toilet, 844 million people lacked clean drinking water, and 1.2 billion people did not have access to electricity.

The eradication of poverty will prevent many of the deaths from pollution we currently see, but it will not solve all the problems. Economic development creates its own set of environmental challenges and new forms of pollution. These can lead to non-communicable diseases (NCDs), such as cancer, heart disease and diabetes. Box 14.1 outlines pollution's impact on health.

Box 14.1. Pollution's impact on health

Nine million deaths annually are attributable to pollution; this is 16% of all deaths worldwide.

Seventy per cent of deaths worldwide caused by pollution are NCDs.

Ninety-two per cent of pollution-related deaths occur in low- and middle-income countries.

Air pollution is a causal factor in lower respiratory infections – the only form of infection that appears in the top 20 cause of deaths in high-income countries.

(Source: Prüss-Üstün and Neira, 2016)

14.4 Air Quality Impacts

The rapid increase in the burning of fuel that comes with industrialization has a significant impact on pollution and health not only due to increased emissions of CO_2 and other short-lived climate pollutants, but also because of the particulate matter released into the air. In total, 85% of particulate matter air pollution is caused by fuel combustion, as is almost all sulfur dioxide (SO_2) pollution, which contributes to acid rain, and nitrogen pollution, which causes respiratory problems and affects plant growth. Coal, used in electricity generation and large-scale manufacturing, is the most polluting fuel (and coal mining is an extremely hazardous occupation). Vehicle fuels are also highly toxic.

In 2012, air pollution was linked to 21% of all global deaths from cardiovascular disease, 23% of all stroke-related deaths, 51% of all death from pulmonary disease and 43% of all lung cancer deaths (Prüss-Üstün and Neira, 2016). Box 14.2 provides more recent data for 2015 and 2016. Air pollution is also an aggravating factor in other conditions, including hypertension, premature births and low birthweights (Fleischer *et al.*, 2014), and diabetes (Eze *et al.*, 2015). More than 80% of people living in urban areas that monitor air pollution are exposed to air quality levels that do not meet WHO guidelines,[1] and in low-income cities this rises to 98%. Deaths from air pollution are predicted to increase by more than 50% by 2050 (Lelieveld *et al.*, 2015).

Deaths related to particulate matter air pollution increased from 3.5 million in 1990 to 4.2 million in 2015, with India and Bangladesh showing particularly sharp increases (Prüss-Üstün and Neira, 2016). However, this is partly due to demographic factors: a larger number of more elderly people who are more susceptible to disease. When such factors are adjusted for, the incidence of deaths from air pollution in fact declined by 12% worldwide over the same period, due in part to increasing regulation on air quality at national level.

14.5 Industrialization and Manufacturing

Manufacturing and mining industries, both of which are important drivers of the economy and of modernization, can be highly polluting. Product manufacturing

Box 14.2. Air pollution

In 2016:

- 91% of the world's population lived in places where World Health Organization (WHO) air quality guideline levels were not met; and
- outdoor air pollution caused an estimated 4.2 million premature deaths, and indoor air pollution 3.8 million.

In 2015, air pollution contributed to:

- 21% of global cases of cardiovascular disease;
- 23% of stroke deaths; and
- 43% of deaths from lung cancer.

Air pollution is caused by vehicle emissions, industrial emissions and landscape-clearing fires.

(Source: Health Effects Institute, 2018)

(e.g. clothing and toys) and chemical manufacturing (e.g. fertilizers, pesticides and paints) release toxic pollutants into the environment if not regulated sufficiently. Production is often concentrated in low- and lower-middle income countries where health and environmental protection can be weak. Products banned in some countries are often still used in lower income ones, where they may be produced illegally (Wilson and Tisdell, 2001). As well as manufacturing plants that are still operational, legacy (i.e. abandoned) and unregulated sites for manufacture, storage and recycling can pose a specific danger (Chatham-Stephens *et al.*, 2013).

The health effects of some of the chemicals released by these activities are well known, such as the link between asbestos and lung disease (Lin *et al.*, 2007), or chlorofluorocarbons (CFCs) with skin cancers and cataracts due to ozone depletion (Diffey, 1992), but others are not. Since 1950, more than 140,000 new chemicals and pesticides have been synthesized. Of these, the 5000 that are produced in the greatest volume have become widely dispersed in the environment. Fewer than half of these have undergone any testing for safety or toxicity. As more are assessed, our understanding of the health burden they impose is likely to rise (Whitmee *et al.*, 2015).

Despite their known health impacts, the use of certain heavy metals, including mercury and chromium, is increasing. Artisanal gold mining is particularly damaging, due to the use of mercury to remove gold from ore (Telmer and Veiga, 2009), as is artisanal tanning, which releases chromium if the process is not carefully controlled.

Lead pollution, which can cause heart disease, kidney failure and stroke in adults and attention deficit disorders, hyperactivity, cognitive impairment, antisocial and criminal behaviour in children and adolescents (Nevin, 2007), is also on the rise. Lead production has more than doubled since the 1970s, largely due to the use of lead in mobile phone batteries and cars. In many low-income countries, lead is still used in pottery glaze, paints and plumbing. An estimated 82% of all deaths from lead

Box 14.3. Toxic contaminants

The size of the population at risk from toxic contaminants is:

- lead – 13 million;
- mercury – 8 million;
- chromium – 5 million;
- petrochemical sites – 4 million;
- radionuclides – 3 million; and
- pesticide manufacturing – 1.2 million.

(Source: Pure Earth/Green Cross, 2016)

pollution occur in low- and middle-income countries, largely due to unsafe practices employed during lead recycling. Better occupational health and safety would remove much of this disease burden. It is also important to note that some recycling activities are themselves highly polluting – the world's most polluting industry is the recycling of lead-acid batteries used in cars (Pure Earth/Green Cross, 2016). These batteries can be recycled safely and cleanly in proper recycling facilities, but such facilities are not always provided and many used batteries are broken up into their recyclable components by hand. Poorly controlled waste disposal causes unnecessary pollution. Box 14.3 highlights the size of populations at risk from toxic contaminants.

Neurotoxins and endocrine disruptors

Lead is a neurotoxin, which damages the nervous system and can affect brain development and cognitive function. Reducing the mean blood concentration of lead in the USA since 1980 has resulted in an increase of 2–5 intelligence quotient (IQ) points across the population (Grosse *et al.*, 2002).

Many chemicals used in manufacturing have neurotoxic effects, particularly those used in the manufacture of herbicides and pesticides (Grandjean and Landrigan, 2006, 2014). These products can also contain endocrine-disrupting chemicals (EDCs), which mimic, block or alter the actions of normal hormones and may be linked to obesity, diabetes, cardiovascular diseases, male and female reproductive problems, hormone-sensitive cancers such as breast and prostate cancers, thyroid disruption, decreased IQ and behavioural disorders (Gore *et al.*, 2015). Effects can be particularly strong if encountered during pregnancy. EDCs are present in an estimated 0.5 billion kg of pesticides used annually in the USA and nearly 2.5 billion kg used globally. They are also present in flame retardants, soaps, shampoos, plastics and food containers.

Active pharmaceutical ingredients (APIs)

A further form of pollution in industrialized nations comes from APIs in pharmaceutical waste. The chemicals used to produce anti-inflammatory drugs, antibiotics, the contraceptive pill and radionuclides from cancer therapy agents are all commonly detected in the environment due to leakages during the manufacturing process, impacting at the point of manufacture, and small amounts in excretion (Larsson, 2014), impacting on the end-user's local environment.

14.6 Chemical Pollution to Water Supplies

Pollution of water sources by toxic chemicals and EDCs affects water ecosystems. Fish and shellfish can be damaged, eliminating them from the food chain (Nelson *et al.*, 2009). EDCs and neurotoxins concentrate in marine food stocks living in polluted waters, adding to human exposure if they are eaten. Phosphorus from detergents and fertilizer runoff also causes the eutrophication of water bodies – excessive plant growth that suffocates some plant species while promoting excessive growth in others.

Water systems are also becoming increasingly contaminated with microplastics – small plastic particles in the environment: 83% of all water samples worldwide are contaminated, including 94% of all US water supplies. One study found an average of 4.8 fibres/500 ml of water in the USA and 1.9 fibres/500 ml in Europe (Tyree and Morrison, 2017), including HDPE (high density polyethylene) which has been linked to breast cancer, can alter sex ratios, is a risk factor for testicular cancer and poor semen quality, can induce early puberty, and can cause reproductive tract malformation. PVC (polyvinyl chloride) is an EDC which has been linked to the improper development of reproductive organs in fetuses. BPA (bisphenol A) has also been linked to hormonal changes, reproductive problems, asthma and obesity. PS (polystyrene) is considered a human carcinogen.

14.7 Preventing Pollution

Most forms of pollution can be eliminated through strong environmental protection, better manufacturing practices and stronger occupational safety procedures, and how these can best be incentivised is an important area on which planetary health should focus.

In the UK, the Public Health Act 1891 began to regulate industrial emissions, and the Clean Air Act 1956 stipulated that only smokeless fuels should be burned within towns and cities. This led to a drop in the level of suspended particulate matter (spm) from around 200 $\mu g/m^3$ in the 1950s to 16 $\mu g/m^3$ in 2016. In developing nations – particularly the BRICs – where regulation and compliance may be weak, pollution levels mirror those seen in the 1920s and 1930s in London and New York. In India, this has been blamed on several factors including poor implementation and compliance of regulation and inadequate monitoring (Bhave and Kulkarni, 2015). Regulation and environmental protection at a national level has seen marked improvements in air quality in developed nations.

International treaties also play a key role, including those such as the Montreal Protocol on Substances that Deplete the Ozone Layer (UNEP, 2018a; see Box 14.4),

Box 14.4. The ozone layer and the Montreal Protocol: a success story for planetary health action

An excellent example of an early recognition of global environmental change and its impact on human health is the story of the Montreal Protocol. The ozone layer is a part of the Earth's stratosphere; ozone is a gas that shields the Earth's surface from the sun's potentially harmful ultraviolet (UV) rays. Since the 1950s, emissions of first CFCs and later HCFCs (hydrochlorofluorocarbons) released into the atmosphere from refrigerators, aerosol cans, solvents and air conditioners depleted the ozone layer, enabling more UV radiation to reach the Earth. This resulted in an increase in skin cancers and cataracts.

In recognition that something had to be done, the 1987 Montreal Protocol placed controls on the use of ozone-depleting substances (ODS), along with incentives for investment in less-damaging alternatives and aims to see CFCs and HCFCs phased out completely by 2040. This has resulted in 2 million fewer skin cancers/year globally (14% reduction) (Chipperfield *et al*., 2015) and an estimated 22 million fewer cataract cases in the USA for Americans born between 1985 and 2100 (Andrady *et al*., 2012) compared with scenarios in which ODS use would have continued at pre-treaty levels.

Adherence to the Montreal Protocol has reduced the amount of ODS in the atmosphere and is predicted to result in a return to pre-1980 ozone levels by mid-century. However, even with swift action, the ozone hole is only now showing the first tentative signs of recovering (WMO, 2014). Other anthropogenic emissions, of nitrous oxide and other halogenated gases in the tropics in particular, can also destroy stratospheric ozone, so there is concern that these emissions may slow the recovery of the ozone hole (Oram *et al*., 2017).

There is a climate co-benefit of reducing ODS, as they act as greenhouse gases. However, if the current mix of HFCs (hydrofluorocarbons) that are used as replacement gases remains the same, projections for demand show that the climate gains would be reversed. For this reason, the Kigali Agreement (UN Treaty Collection, 2016) agreed to limit HFCs in a bid to avoid 0.5°C of warming by the end of this century.

This shows that global environmental change can be reversed if identified early enough, and with sufficient political incentive for concerted action at the international level. However, progress and policies must continuously be evaluated (as the Montreal Protocol is) to ensure the positive consequences of actions outweigh the negative.

the Basel Convention on Controlling Cross Boundary Movements of Hazardous Wastes and Their Disposal (UNEP, 2018b), the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade (UNEP, 2018c), the Stockholm Convention on Persistent Organic Pollutants (UNEP, 2018d) and the United Nations Framework Convention on Climate Change (UNFCCC, 2018) but protecting the environment needs to be a ground-up as well as top-down effort. We should all make efforts to reduce our ecological footprint and ensure we guarantee the health of the planet and of future generations.

Note

1. WHO guidelines (2006) for clean air are: (i) annual average concentrations below 20 μg/m^3 of particulate matter with diameter less than 10 μm (PM_{10}) and annual average concentrations below 10 μg/m^3 of particulate matter with diameter less than 2.5 μm ($PM_{2.5}$); (ii) concentrations of ozone (O_3) below 100 μg/m^3 over an 8 h mean; (iii) annual average concentrations of nitrogen dioxide (NO_2) below 40 μg/m^3; and (iv) concentrations of SO_2 below 20 μg/m^3 over a 24 h mean.

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15

Conclusions: Equity, Distribution and Planetary Health

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15.1 Changing Times, Changing Challenges

The previous chapters have shown how, as countries develop, the health challenges faced by their populations change: from infectious disease, insufficient nutrition and childbirth challenges to NCDs linked to increased risk factors including old age, polluted environments, sedentary lifestyles and poor diets. Challenges also arise from the types of industry on which regions' economies rely and the impact this has on the environments in which their populations live.

Planetary health must achieve health for all populations and for all regions of the world, but at present there is striking inequality and injustice. Large-scale mining and heavy manufacturing began in Europe with the Industrial Revolution (Clapp, 2014) but since the middle of the 20th century such industries have largely now moved out of high-income countries into developing ones, creating an uneven geography of pollution that has a disproportionate effect in sub-Saharan Africa and Asia. More than 90% of all pollution-related deaths are estimated to occur in low- and middle-income countries (Landrigan *et al.*, 2018). Pollution is often worst in rapidly urbanizing countries where infrastructure development lags behind industrial development (Schwarzenbach *et al.*, 2010). Industrial and pharmaceutical pollutants have a more severe effect in regions where sanitation and water infrastructure is poorly developed and water treatment plants are inefficient at removing pollutants. The most polluted areas of the world are those that lag furthest behind in the demographic and epidemiological transitions, and which are lower income economies (Landrigan *et al.*, 2018). Traditionally, as countries have moved through the process of development, pollution has been high initially but has then decreased; if lessons identified during this process can now be applied to developing nations, it may help them to avoid the most polluting phase of development, or keep it as short as possible, by ensuring that clean energy provision, active transport networks, circular economies and green growth is built-in during the development process (see Box 15.1).

Box 15.1. The Kuznets curve and the environment: a disputed correlation

The Kuznets curve, developed by economist Simon Kuznets (Kuznets, 1955), describes the association between income inequality and per capita income during economic development. In the early stages of urbanization and industrialization, inequality grows, but the widening gap later closes. This has been extended to postulate that pollution and environmental degradation must also get worse before they get better.

However, later research has disputed this (Dinda, 2004), and theorizes that it should be possible to achieve modernization and reach a high-income economy cleanly through clean energy generation, environmental protection legislation and the avoidance of chemicals that are known to be toxic, capitalizing on lessons learned in Europe, North America and Japan.

15.2 The Uneven Distribution of Environmental Degradation

Helping lower income countries to invest in cleaner technologies would also alleviate the cost burden associated with polluted environments. This is also unequally distributed: pollution-related diseases account for less than 2% of annual health spending in high-income countries, but 7% in middle-income countries. As cities grow in poorer regions (Wilkinson *et al.*, 2007) energy demands, petrol- and diesel-powered vehicle use, consumerism, and the intensification of agriculture increases rapidly, but protective environmental policy and regulation is not always put in place quickly enough. Nor is investment in infrastructure always sufficient.

In 2015, approximately 3 million people died from exposure to outdoor air pollution and 4.3 million people died from indoor air pollution, most of which was caused by wood-burning stoves. More than 50% of all global air pollution deaths occur in just two countries, China and India, even though these account for only 36% of the global population. In developing countries, 98% of urban areas with populations of more than 100,000 failed to meet WHO air quality guidelines (Prüss-Üstün and Neira, 2016). The figure was closer to 50% even in high-income urban areas.

There is a common accusation that high-income countries deliberately move more polluting industries from their own backyard to lower income countries with less stringent environmental and occupational protection regimes. An example of this is the US-owned Union Carbide pesticide factory in Bhopal, India, where an explosion caused by a gas leak in 1984 killed 3787 people and injured more than half a million.

Almost 80% of obsolete electronics delivered to a recycling service in the USA will end up in low or lower-middle income countries such as Nigeria, Pakistan and Vietnam, and low-income areas of China and India for recycling. High-income economies also use lower income countries as dumping grounds for their unwanted toxic products, including some that are banned or highly regulated under the 1989 Basel Convention on the Transboundary Movements of Hazardous Wastes and

Their Disposals, or site their hazardous and polluting manufacturing industries there. Toxic waste from Europe shipped to Côte d'Ivoire in 2006 resulted in the release of toxic gas that killed 17 people and caused 100,000 cases of respiratory and gastrointestinal disease, for example (Margai and Barry, 2011). There is also evidence, however, that multinational manufacturing companies employ less polluting processes than local industries and can drive local adherence to international standards (Eskeland and Harrison, 2003).

15.3 In-country Inequality

In high-income economies, pollution is often greatest in poorer areas. In New York, bus depots that emit pollutants which can cause an increase in asthma and other respiratory diseases tend to be in or close to less advantaged neighbourhoods (Watkins *et al.*, 2009). Poorer people tend to live in poorer quality environments, exacerbating health problems and creating a vicious circle of poverty and poor health.

15.4 Managing the Pace of Change

The regions of the world that are urbanizing most rapidly are also the ones that are most likely to be at risk from climate change, biodiversity loss and pollution. The countries that will be the most exposed to temperatures above 34°C, the threshold for high-risk heat stress, for example, are in sub-Saharan Africa and South-east Asia. They face an increasingly elderly population, living in the type of urban environments where heat stress, pollution and low biodiversity are more likely.

The reliance of such economies on manufacturing industries and agricultural production leads to high numbers of workers employed outdoors, undertaking physical labour in extreme heat (Basu and Ostro, 2008). Poorly designed urban environments that provide little shade or protection from heat could impact the ability of the workforce to operate during the hottest parts of the day, with repercussions on economic growth and development. A workforce undertaking light work can operate continuously in 31°C heat, but needs to rest half an hour, each hour, when temperatures rise to 32°C. If people are engaged in more strenuous work, required rest time rises to 75%, and heavy-duty assignments are not recommended. Heavy labour can only be safely undertaken for sustained periods at temperatures below 26°C (Basu and Ostro, 2008). Global labour productivity is already estimated to have declined by around 5% since 2000 (Watts *et al.*, 2015). Air pollution is also worse in high temperatures.

15.5 Demographic Impacts

All these health impacts disproportionately affect children under 5 years old and the elderly, minorities, the marginalized and lower socio-economic groups.

Poverty, poor health and social injustice are deeply entwined, and have a circular effect – exposure to pollutants in childhood is associated with lower cognitive function, lower educational attainment and lower social mobility, trapping those born into polluted environments into a cycle of poverty. Poor families may not be able to afford to live in the cleaner, fresher areas of their city or country.

Cities can be made more liveable and attractive, however: environmental protection and regulation, properly implemented and monitored, can play a strong role in enabling this. Urban environments can be cleaner, with more sustainable and more circular economies, but this must be applied across the globe; it is not enough to clean up one region by moving pollution-generating industries and practices elsewhere.

15.6 Conclusions

Across the preceding chapters, this book has attempted to present the background evidence on the relationship between global environmental change and human health – the health of current and future generations.

Exactly how the environment impacts human health is complicated, particularly at the global level, due to the long timescales involved and the challenge of isolating environmental impact from the many other variables at play. Human life expectancy has risen from 30–40 years prior to the 19th century to a global average of 71 years in 2015, mainly due to higher incomes, a safer and more stable food supply, and improved public health in cities. Medical technology has also played an important part, particularly in the form of antibiotics and vaccines. Human health has nevertheless suffered from pollution and global environmental degradation. Many of the interconnections have been documented in this book, but there are many others that still need to be better understood and it is the task of the next generation of academic scholars, policy makers and practitioners to document the challenges, analyse them, and develop solutions that can and will be implemented.

In sum, while rising incomes and a variety of other factors have led to substantial progress in human health, this progress has been uneven across the globe. If pollution and global environmental change are not seriously tackled, the health of future generations could be seriously undermined. Part 4 of this volume presents some case studies of how these challenges can be – and have been – addressed.

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16

Climate Change, Land Use and Waterborne Infectious Disease

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This chapter is based on the following report: Messina, J. (2018) *Environmental Change & Infectious Diseases*. Rockefeller Foundation Economic Council on Planetary Health, Oxford Martin School, Oxford.

16.1 Introduction

Since the 1940s, more than 335 infectious diseases have emerged globally (Jones *et al*., 2008), 60–80% of which have originated in animals (Morens and Fauci, 2013). While emergent diseases have caused deadly pandemics for millennia, these figures raise questions as to why zoonotic disease transmission to humans, and the oft deadly pandemics that follow, have become more common. Many factors are to blame, and while rapid and ongoing vaccine development and the strengthening of health systems are necessary channels for tackling the global spread of infectious diseases, we must also urgently address the conditions that allow diseases to emerge or re-emerge in the first place.

Crucially, environmental change has resulted in the disruption of the natural habitats of many animals, weakening the barriers between humans, animals, and the pathogens they carry. Failure to prevent ongoing climate change and degradation of natural ecosystems will lead to a continued regularity of infectious disease outbreaks in humans. This chapter outlines four modes of infectious disease transmission and emphasizes the role of environmental change in fuelling global disease emergence, particularly with regard to water.

16.2 Infectious Disease Transmission

There are four main types of disease transmission. While it is essential to identify the type of pathogen responsible for an infection (e.g. virus, bacteria, protozoa),

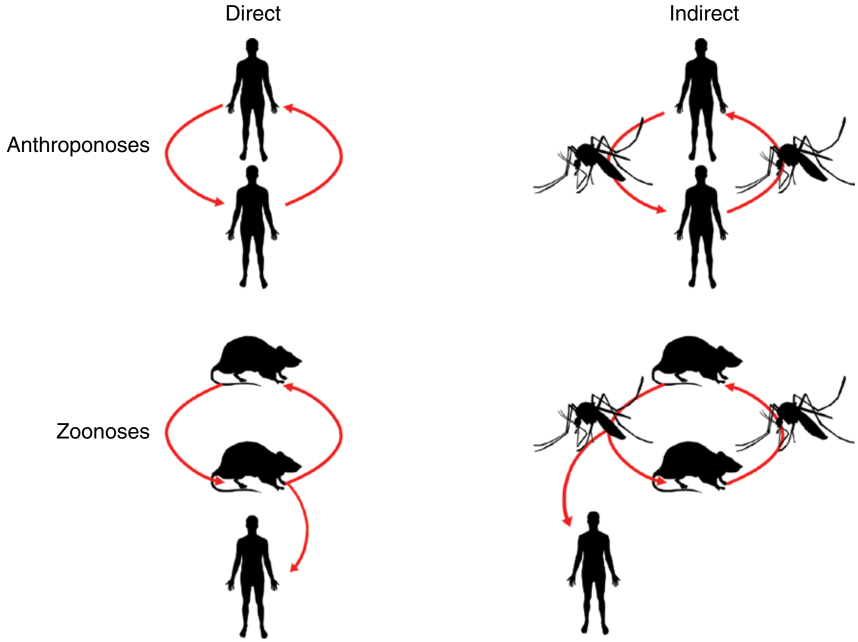

Fig. 16.1. Four types of infectious disease transmission. Rodents represent animal hosts and mosquitoes represent vectors/vehicles of transmission.

identifying the source of infection is fundamental to understanding how these pathogens spread to humans. Typically, infections are either anthroponotic (human source) or zoonotic (animal source), and within each of these categories, diseases are transmitted either directly or indirectly to humans (Hubálek, 2003) (Fig. 16.1).

16.3 Anthroponoses

Direct transmission

Diseases may be transmitted from human to human through direct physical contact, or else via some type of material surface or matter (such as a door handle or table top). Examples of diseases transmitted directly between humans are HIV/AIDS, herpes and other sexually-transmitted diseases, as well as tuberculosis, leprosy and measles. While direct human-to-human transmission is least tied to the physical environment, changes in ecosystems, land use and weather patterns may affect human behaviours in such a way that risk for contact with pathogens is increased. Lack of basic hygiene facilities, such as clean water for handwashing or for washing kitchen surfaces and pots, can greatly affect the likelihood of disease transmission.

Indirect transmission

Some anthroponoses are transmitted between humans indirectly, either via an intermediate, 'vector' host, or via contact with contaminated water. Vector-borne anthroponoses include diseases like malaria, dengue, Zika and Lyme disease. Transmission is closely tied to the natural environment, with temperature, rainfall and the abundance of vegetation all having an impact on the reproduction, survival and biting rates of mosquitoes. Consumption of or contact with contaminated water may also result in the transmission of diseases between humans, as is the case for diseases such as cholera, schistosomiasis and *E. coli*.

16.4 Zoonoses

Direct transmission

Some animal diseases can be transmitted directly from animals to humans, often with subsequent human-to-human transmission. Some pathogens infect humans via animal bites or saliva, as is the case with rabies, while others such as avian influenza are airborne, infecting those working in close proximity to infected animals. Ebola is a complex zoonosis, transmitted to humans via close contact with the blood and other bodily fluids of infected wild animals such as primates and fruit bats. Changes to the environment which bring people in closer contact with wild animals are therefore of particular concern. In some resource-poor settings, the disposal of animal waste can contaminate water and make it a channel for the transmission of parasites such as *Cryptosporidiidae* to humans via exposure or direct consumption.

Indirect transmission

Much like indirectly transmitted anthroponotic diseases, some zoonoses require water or vectors as intermediate pathogen hosts for transmission. These are strongly linked to the environment and therefore sensitive to environmental changes which affect vector abundance. Examples include West Nile virus, which is spread to humans by *Culex* species mosquitoes that have fed on infected bird reservoirs. These mosquitoes require standing water for laying eggs.

16.5 Types of Environmental Change

Irrigation

Dramatic increases in the number of water resource development projects over the past seven decades have led to many global environmental transformations which have subsequent negative effects on human health (Keiser *et al.*, 2005). Irrigation canals and drainage networks can increase the availability of habitats for vector species across wide areas of farming land. Furthermore, the use of dams leads to year-long water supply in some areas, allowing certain organisms to survive which would have normally perished during dry seasons (Jobin, 2014).

In many countries, irrigation has been developed without consideration for the effects on public health. Malaria, schistosomiasis, filariasis (see Box 16.1), Japanese encephalitis, and onchocerciasis are all examples of high-burden diseases in such countries.

Urbanization

There are many ways in which the rapid urbanization seen across the globe since the 18th century has led to the emergence and re-emergence of infectious diseases. While some aspects of living in a city are beneficial to human health (e.g. via higher incomes and better access to healthcare), there are often large discrepancies in health conditions between neighbourhoods within large cities. The overcrowded slum settlements characteristic of many rapidly expanding cities are often accompanied by poor sanitation, contaminated water supplies, lack of ventilation, and proximity to vectors and their breeding sites. Examples of diseases whose transmission has been facilitated by urbanization include cholera, dengue and Zika (see Box 16.1).

Climate change

For at least a decade, scientists have been deliberating the potential effects of climate change on infectious disease emergence and re-emergence (Altizer *et al.*, 2013). Although the exact response of infectious diseases to climate change will differ in a multitude of ways according to the pathogen, the message that disease risk will be modified in some way by changes in temperature and precipitation is clear. Examples of infectious diseases whose geographic range and rate of spread have been and/or continue to be affected by climate change include hantavirus, red tide poisoning and most vector-borne diseases (e.g. see Box 16.1).

16.6 Conclusions

Human activities are known to have caused many detrimental effects to the environment, from local to global scales – and water ecosystems are not the only ones that have been affected. Humans are increasingly coming into contact with the reservoirs and vectors of infectious pathogens. As such, addressing environmental

Box 16.1. Case studies of climate change and infection

Resurgence of lymphatic filariasis in Egypt

Lymphatic filariasis (also known as elephantiasis) is a parasitic disease which weakens the lymphatic system and can cause extreme swelling and enlargement of the limbs, breasts and scrotum. It is caused by microscopic worms that are spread from human to human by *Culex pipiens* mosquito bites. The Aswan High Dam, built in the 1960s in the southern Nile Delta, resulted in increased surface and sub-surface moisture and the subsequent rapid rise in the abundance of these *C. pipiens* mosquitoes. Consequently, prevalence of lymphatic filariasis in the region rose from less than 1% in 1965 to over 20% after the construction of the dam (Ingram *et al*., 2012).

Zika virus in Brazil

Zika virus is transmitted to humans by *Aedes* mosquitoes, which also act as vectors for dengue and chikungunya viruses throughout the tropics. These mosquitoes thrive in poor urban settings where water-storage practices often lead to stagnant pools ideal for laying eggs and larval growth. Although discovered in 1947 in Uganda, it was only in 2007 that a large outbreak was seen (in the Federated States of Micronesia) (Weaver *et al*., 2018). In 2013, the virus began to spread across other parts of Oceania and in 2015 a large outbreak in Latin America began in Brazil. The WHO declared Zika virus a Public Health Emergency of International Concern when it was discovered that infection during pregnancy could result in the virus passing from the woman to her fetus, potentially causing birth defects such as microcephaly. Although the peak of the outbreak has since passed, long-term disappearance of the disease is unlikely to occur without improvement of living conditions in the many slums across Brazilian and other South American cities.

Rift Valley fever in Kenya

Rift Valley fever is a mosquito-borne viral disease transmitted competently to humans by more than 30 species of mosquito (Martin *et al*., 2008). As with other vector-borne diseases, climate changes may impact all aspects of Rift Valley fever transmission, but rises in temperature and the consequent potential for increased mosquito abundance is of particular concern. While a low level of endemic transmission occurs in all rainy seasons, El Niño climate fluctuations have been associated with larger epidemics. An epidemic of haemorrhagic fever caused by Rift Valley fever was experienced in 1997–1998 in East Africa, namely North-eastern Kenya, where the disease was originally discovered in 1931 (Linthicum *et al*., 1999). Another epidemic was seen in 2006; both were correlated with heavy rainfall due to El Niño. The increasing rainfall anticipated to occur in East Africa due to climate change means that many scientists assume the larger Rift Valley fever epidemics will continue to grow in frequency and severity.

degradation can have multiple benefits to human health, including the prevention of new and re-emerging epidemics caused by contaminated water and poor sanitation and hygiene infrastructure. Combatting carbon emissions which lead to climate change, protecting biodiversity, supporting the development of clean water sources, and favouring sustainable agricultural and irrigation systems will be important tools in curbing the trend of pandemic disease becoming the global 'norm'.

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17 Sanitation, Clean Energy and Fertilizer

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17.1 Sanitation and Health

Sanitation plays an indispensable role in human health (Mara *et al*., 2010). It helps to drive the second stage of the epidemiological transition (Omran, 2005) as it reduces the number of deaths caused by infectious disease, especially in early childhood. This in turn helps to drive the demographic transition and its close ties with economic development (Wilkinson, 1994).

The health risks from poor sanitation come from exposure to the bacteria and viruses contained in human faeces or carried by the vectors that feed and breed on it. The average person excretes 130 g of faeces each day and 800–2000 ml of urine. One gramme of faeces can contain 100 million pathogens and as many as 10,000 parasites (Feachem *et al*., 1983) responsible for diseases such as cholera, dysentery, hepatitis A, polio, typhoid, schistosomiasis and trachoma.

In 2017, the World Bank recorded that 99% of populations across all high-income countries – and 100% of their urban populations – had access to improved sanitation but this is not true for all regions of the world. Gaps in access are clear markers of inequality and disadvantage (Andersson *et al*., 2016) with the poorest people in developing countries facing a triple burden of communicable disease due to: (i) inadequate sanitation; (ii) lack of access to healthcare services including vaccination programmes that would help to protect against some water-borne diseases; and (iii) increased risk of exposure to pollution from human waste. Challenges to improving sanitation across the world must be addressed holistically if the health, environmental and economic opportunities are to be recognized (Moe and Rheingans, 2006).

17.2 Sanitation for the Environment

A planetary health approach sees sanitation not only as the disposal of human waste but as a system that enables resource management, ensures environmental protection, prevents actions that might otherwise lead to pollution and can stimulate economic opportunities (Cole, 2018). The properly managed collection, removal, treatment and reuse of large quantities of human waste captures nutrients (phosphorus and nitrogen) for reuse as natural fertilizer, and methane (the gas produced during decomposition) for clean energy (Swachh Bharat India, 2018) or vehicle fuel (Jewitt, 2011), while also conserving water.

Improvements in sanitation, monitored by the WHO and United Nations International Children's Emergency Fund's (UNICEF) Joint Monitoring Programme (UNICEF/WHO, 2017), not only help countries reduce the burden of infectious diseases and child mortality, but also improve educational achievement, empower girls and women (Khanna and Das, 2016), make cities more liveable and improve access to clean energy and food security (Keraita *et al.*, 2015).

17.3 A Source of Natural Fertilizer

Human waste contains valuable nutrients such as nitrogen and phosphorus (Esrey, 1998), which can be used as agricultural fertilizer. There are enough micronutrients in one person's excreta to grow the wheat and maize needed to feed that person for a year, reducing artificial fertilizer use and making a significant impact on the annual finances of smallholder farmers and their families (Rosemarin *et al.*, 2008). Such approaches also reduce the risks of the high-nutrient content in human waste causing eutrophication (excessive plant growth in water courses) or river and coastal dead zones (Defra, 2012) if it is released to the environment untreated. Recycling waste water, or installing more water-efficient sanitation systems, can also ease pressures in regions of the world under water stress. Waterless sanitation systems are also a viable option in such contexts (Yermán *et al.*, 2017).

17.4 Biogas and Clean Energy from Waste

During decomposition human waste emits methane, which can be captured to provide clean household cooking fuel, create biogas for vehicles, and to generate clean electricity. This can reduce emissions of greenhouse gases and black carbon (Jewitt, 2011), preventing hundreds of thousands of premature deaths, particularly from indoor air pollution (Bruce *et al.*, 2015). As pit latrines can create over 1 t of CO_2 equivalent/year due to increased methane emissions of anaerobic decomposition in the pits (Kulak *et al.*, 2017), the environmental impact of this needs to be factored in to ensure the methane is captured as sanitation improves in developing regions.

At a municipal scale, biogas captured from waste treatment plants can be used to power vehicles, added to energy grids, and used to power the treatment plants themselves (Jewitt, 2011). The global biogas market could be worth US$50 billion annually by 2026 (Future Market Insights, 2017).

17.5 Cultural Challenges to Sanitation

Based on disability-adjusted life years (DALYs) and the Global Burden of Disease (GBD), the two most commonly used health metrics, investment in sanitation is estimated to be the second-best health investment in the world, behind only hygiene promotion (Cairncross *et al.*, 2010). Economic benefits are in the range of US$5–16 for every US$1 spent (WHO/UNICEF, 2012). Less than half the global population uses a safely managed sanitation service (UNICEF/WHO, 2017), however, and barriers to improving this vary depending on rural or urban environments, local resources, national wealth and cultural attitudes to human waste (Cole, 2018). In some countries, behavioural change campaigns are needed to break through ingrained cultural attitudes to human waste (Mendez *et al.*, 2017). Some cultures consider a toilet to be ritually unclean (Coffey *et al.*, 2015) and others consider it inappropriate for all family members to share facilities (Thys *et al.*, 2015).

17.6 Sanitation Infrastructure and Public Policy

Perceptions and behavioural change around sanitation can be as important as technological innovations in driving forward changes: the transition from cesspools to sewer systems in Europe during the Industrial Revolution benefited from a framing in which the relationship between environmental factors and human health drove interest in improved sanitation onto political agendas (Geels, 2006). Framing sanitation as a key public service enables it to be used as a cause on which to build pressure for further social reform, particularly if the issue is adopted by regime insiders. In 1947, Mahatma Gandhi declared good sanitation for all to be more important than independence (Rathi, 2014).

Highlighting the wider benefits through a more holistic approach to valuing sanitation provides greater incentives for public investment. Sanitation has to be a community-wide – if not nationwide – endeavour. There is little benefit to one household in a community installing a toilet if others do not: people will still be exposed to pathogens and their environment will still be polluted.

The Western European/North American model of flush toilets and extensive sewer infrastructure may not be appropriate everywhere, however, particularly in regions of high water stress and/or low population density (Narracott and Norman, 2014), where construction materials are unavailable and where urban centres are still developing. In some settings, safety managed faecal sludge management (FSM) systems, that collect faecal waste from tanks in regions where municipal sewers have not been installed, are more practical and easier to facilitate than fully plumbed municipal sewers (Chowdhry and Kone, 2012).

17.7 Conclusions

At present, sanitation is widely considered to be part of public health and increasingly as an important part of environmental protection. It is not yet widely considered to be a resource management tool, however. A planetary health approach can help to highlight additional environmental and economic opportunities (Moe and Rheingans, 2006) ensuring that good sanitation infrastructure and services are locked-in early to developing urban regions.

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18

Trees, Well-being and Urban Greening

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18.1 Introduction

There are approximately 3 trillion trees worldwide. Forests range the globe in tropical and subtropical, temperate and boreal regions and in cities the percentage of land covered by trees exceeds 20% in some of the greenest cities in the world: Singapore, Sydney, Vancouver, Johannesburg and Frankfurt (MIT Senseable City Lab., 2018). Trees have a positive impact on human health and well-being through multiple services including carbon sequestration, timber production, places for recreation, shade to protect from heat and air purification. However, an estimated 15 billion trees are cut down each year (based on 2000–2015 trends), and the global number of trees has fallen by about 46% since the start of human civilization (Crowther *et al.*, 2015). This chapter outlines some examples of how trees benefit human health and well-being and shows why the role of trees in urban planning and their value as natural capital should be considered important to planetary health.

18.2 Trees and Urban Heat

Urban areas can be significantly warmer than surrounding rural areas because of the way hard surfaces absorb and reradiate heat, which can also be trapped by tall buildings (Graham *et al.*, 2016). High temperatures, particularly during heatwaves, can have serious effects on human health. For example, nearly 800 incidents of excess human mortality associated with heat in 164 cities in 36 countries have been reported between the period 1980 and 2014 (Mora *et al.*, 2017). Trees in urban areas can lower maximum daily temperatures by several degrees due to the cooling effect of water evaporation from leaves and by providing shade. Their presence can also provide protection from UV radiation. In Seoul, South Korea, trees in urban public spaces provide eight times the protection from UV radiation than other land uses in the city (Na *et al.*, 2014). In Toronto, neighbourhoods with less than 5% tree cover had five times more ambulance calls for

 Planetary Health: Human Health in an Era of Global Environmental Change (J. Cole) heat-related illnesses during heatwaves than neighbourhoods with more than 5% tree cover (Graham *et al.*, 2016). In the UK, heat-related premature deaths are forecast to increase by approximately 70% in the 2020s, 260% in the 2050s and 540% in the 2080s compared with the 2000s baseline of around 2000 premature deaths/year, with risks greatest in large urban areas unless mitigating action is taken (HPA, 2012). Globally, in warmer regions such as central and southern parts of America or Europe, and South-east Asia, excess mortality related to heat may rise more than 10% by the end of the 21st century as a result of climate change (Gasparrini *et al.*, 2017).

As extreme summer heat events are likely to become more common in response to climate change, trees and urban greening (e.g. green roofs, cool pavements) need to be included in urban planning and development to a larger extent than is the case at present, to support long-term heat health and resilience of towns and cities and their inhabitants.

18.3 Trees, Physical Inactivity and Obesity

Globally, physical inactivity causes 9% of premature deaths and is the cause of 6–10% of the major NCDs (coronary heart disease, type 2 diabetes, breast and colon cancers). If physical inactivity decreased by 25%, more than 1.3 million deaths globally could be averted each year, and elimination of physical inactivity would increase life expectancy of the world's population by 0.68 years (Lee *et al.*, 2012).

The presence of trees can increase levels of physical activity. Across eight European cities, people living in the greenest areas were 40% less likely to be obese (Ellaway *et al.*, 2005). A study of the 5-year survival rate of senior citizens in Tokyo, Japan, found that walkable green spaces near the residence was a significant predictor for survival over the 5 years (Takano *et al.*, 2002). Both studies controlled for socio-economic factors. The longevity of senior citizens can be linked to increased physical activity, improved air quality and more favourable conditions encouraging outdoor activity. One 2009 estimate suggested that £2.1 billion annual savings could be made through averted health costs if everyone in England had equal 'good perceived and/or actual access to greenspace' (Natural England, 2009).

However, there are inequalities in green space provision in urban areas, depending on socio-economic background: (i) poorer communities often have less access to and poorer quality of green space; and (ii) in deprived areas residents may be less likely to use the spaces because of negative perceptions of it (Jones *et al.*, 2009). Careful design and planning of green space type, quality, distance from households and safety are therefore important for reducing inequalities in the benefits the green spaces provide, particularly in densely populated cities.

18.4 Trees and Well-being

Trees are a source of relief from chronic stress and psychiatric disorders (e.g. depression) linked to urban lifestyles. Urban trees can screen stress factors such as urban sounds and can facilitate mental restoration and recovery from stress (Watts, 2017). An additional tree per kilometre of street in London was found to be associated with 1.18 fewer prescriptions of antidepressants per thousand population (based on 2009–2010 values and accounting for socio-economic variables) suggesting that street trees play a role in supporting neighbourhood mental health (Taylor *et al.*, 2015). In Tokyo, street trees in front of buildings helped reduce the feeling of oppressiveness, particularly as building heights increased (Asgarzadeh *et al.*, 2012). Direct experiences of trees and views of trees may also have an effect on social and emotional well-being in schools and education centres. Studies in the USA found that views, access and proximity to trees has been linked to lower rates of criminal behaviour and behavioural problems, higher test scores, reading performances and graduation rates, once socio-economic factors are accounted for (Hodson and Sander, 2017).

Forest environments aid stress recovery and restoration due to features including low density of people, low levels of noise and movement, a slow rate of change, privacy and solitude (Shin *et al.*, 2010) though they can evoke fear (Gatersleben and Andrews, 2013).

18.5 Trees and Air Pollution

Trees play an important role in protecting people from air pollution, which can be in the form of solid or liquid particulate matter (PM), or as a gas such as ozone. The World Health Organization estimates that air pollution is responsible for 4.2 million deaths worldwide (equivalent to 7.6% of deaths, 2016 values) with 91% of the world's population living in places where air quality exceeds guideline limits (WHO, 2018).

Trees play a small role in producing ground-level ozone, a lung irritant (Hirabayashi and Nowak, 2016) but they also remove it from the air; ozone removal provided by forests in central Western Italy was valued at over US$85 million during 2005 (Manes *et al.*, 2012). In the UK, vegetation is estimated to remove about 13% of ground-level ozone, which saves around 1900 lives annually (Jones, 2017).

18.6 Trees and PM Air Pollution

PM – composed of particles such as dust, soot or smoke – affects lungs and blood vessels. An estimated 130,000 people die annually in the USA due to PM pollution with more than 1 million life years lost among populations aged 65–99 years (Fann *et al.*, 2012). PM can settle on trees, reducing the concentration in the air; the amounts are small, but the benefit value of health effects can be significant, ranging from US$1.1 million to US$60.1 million/year in US cities including Syracuse and New York (Nowak *et al.*, 2013) and more than €160 million/year in Rome, Italy (Marando *et al.*, 2016). Trees do, however, also have a minor role in producing PM, and also produce large quantities of airborne pollen, which is a human allergen.

18.7 Health Impacts of Tree Loss

Tree loss has demonstrated measurable health and well-being impacts (Donovan *et al*., 2013). The loss of more than 100 million ash trees to emerald ash borer across the USA has been associated with an additional 6113 deaths related to lower respiratory system illness and 15,080 cardiovascular deaths between 2002 and 2007 (Donovan *et al*., 2013). It has also been linked to a reduction in life satisfaction (happiness) comparable to one caused by a 2.3% nationwide contraction of the US economy, or a reduction in annual per capita income of US$3175, with effects greatest in adults 18–24 years old (Jones *et al*., 2017).

Considering the role of trees in urban planning is crucial in sustaining the health and resilience of towns and cities and their inhabitants. The protection and maintenance of trees worldwide is essential for planetary health.

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19

Livestock, Antibiotics and Greenhouse Gas Emissions

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19.1 Introduction

Food from animal products has a disproportionately large impact on the environment compared with food from plants (Poore and Nemecek, 2018). Good practice will help us to stay within planetary boundaries and achieve the Sustainable Development Goals (SDGs) on zero hunger, acting on climate change, producing and consuming responsibly and preserving life on Earth; however, acting to improve one SDG may impact on others. Livestock sustainability, the health of the environment and the health of people must be considered holistically.

19.2 Livestock Impacts: the Full Cost of Food

Livestock supply only 17% of human calories and 33% of protein (Herrero *et al.*, 2013) but use disproportionately large quantities of resources including land, greenhouse gas (GHG) budgets and antimicrobials. The livelihoods of 1 billion people, including 600 million of the poorest, depend on livestock farming, however, and not just for food: animals also provide fertilizer (via manure), are used as work animals, and are a form of insurance. They play important roles in poverty alleviation, can improve gender equality and may become even more important in a world with an increasingly extreme climate (Thornton *et al.*, 2007). For some communities, livestock products are the only currently available source of sufficient nutrients.

In higher income settings, however, consumption of certain animal products is associated with negative health implications: red and processed meat, and high levels of fat from dairy, are risk factors for many non-communicable conditions including heart disease, cancer and obesity (Bouvard *et al.*, 2015).

19.3 The Future of Livestock

Across the world, animal product consumption is increasing, due to shifting diets and population increase (see Fig. 19.1).

Between 1980 and 2002, meat production in developing countries tripled and demand for animal products is predicted to double again by 2050 – largely due to changing dietary preferences. To meet this demand, food animal industries are expanding and intensifying. Most expansion is in monogastrics (pigs and poultry) and is in Asia, followed by South America and Africa. There is great variation between regions, however: meat consumption is increasing in lower-middle income countries but has plateaued or is decreasing in high-income countries (Godfray *et al.*, 2018).

19.4 Land Use Changes: Cropland, Grazing and Biodiversity

Increasing demand for livestock products leads to the expansion of land conversion and the intensification of livestock farming. Land use is becoming increasingly

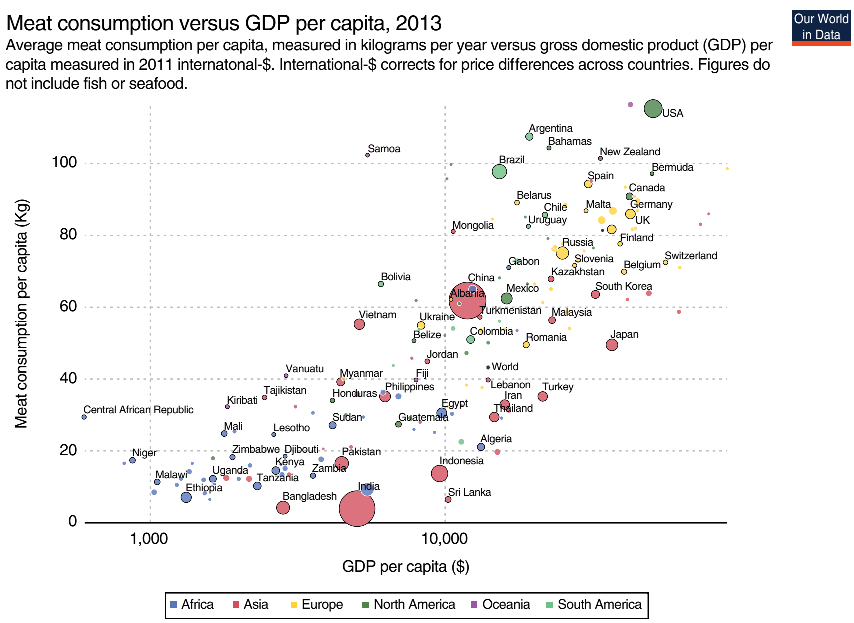

Fig. 19.1. Share of percentage of daily caloric intake from meat, seafood, eggs and dairy versus gross domestic product (GDP) per capita. (From Ritchie and Roser, 2017.)

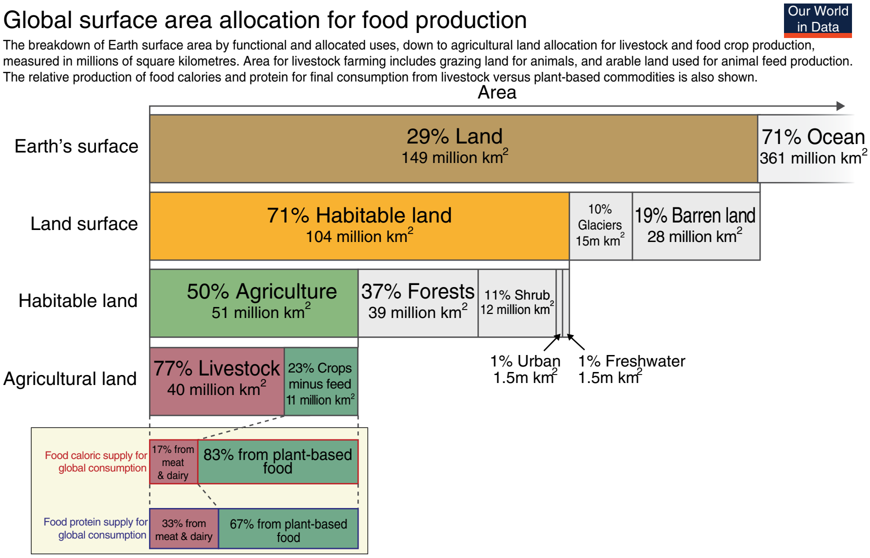

Fig. 19.2. Global surface area allocation for food production. (From Roser and Ritchie, 2019.)

efficient, however: the global average agricultural area per capita halved from 1.5 ha per person in 1961 to 0.75 ha in 2013 (FAO, 2017). Expanding and intensifying livestock systems also brings other challenges, including higher emissions of GHGs and increased use of antibiotics.

Livestock occupy 77% of Earth's finite supply of agricultural land (Fig. 19.2) and are the leading cause of land conversion and biodiversity loss (Foley *et al.*, 2005). Livestock use land less efficiently than crops: to produce 1 g of beef protein requires more than 1 m^2 land, whereas the equivalent in pulses is 100 times smaller (Fig. 19.3a). However, not all land is equal. Some agricultural areas that are unsuitable for crop production are suitable for ruminant grazing – but these areas are small and may also be suitable for biodiversity conservation or climate sequestration. Livestock consume over half of the world's grains (70% of which is consumed by monogastrics – pigs and poultry) – which could be instead consumed by people.

19.5 Livestock Impact on GHG Emissions

Livestock are responsible for 18% of all anthropogenic GHG emissions (67% of all emissions from food), and there is great opportunity for mitigation (Gerber *et al.*, 2013). Ruminants (including cows, sheep and goats) produce high levels of enteric methane (a potent GHG with 25 times the global warming effect of carbon dioxide) – and have a high emissions intensity (GHGs emitted per unit product) (Fig. 19.3b).

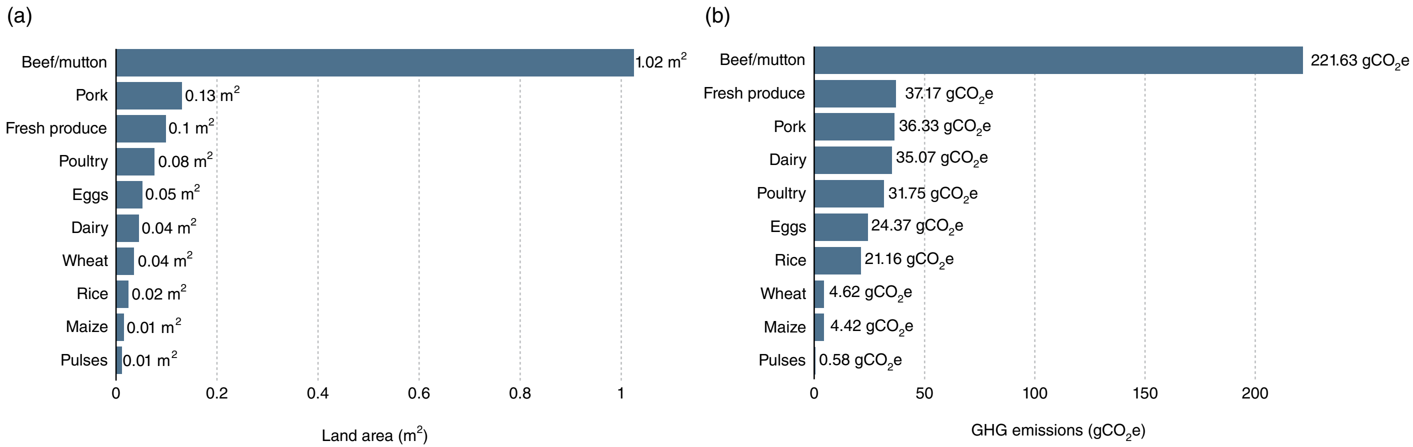

Fig. 19.3. (a) Land use per gramme of protein, by food type. (b) Greenhouse gas (GHG) emissions per gramme of protein, by food type. (From Ritchie, 2017a; Clark and Tilman, 2017.)

Pig and poultry systems have lower emissions intensities, but up to 60% of their GHG footprint is from feed production.

While emissions intensities of livestock production are reducing – by 45% between 1970 and 2007 and may reduce by a further 32% between 2007 and 2050 (Bennetzen *et al.*, 2016) – numbers of livestock, and therefore overall global livestock emissions, are increasing.

19.6 Use of Antibiotics in Livestock

Livestock also consume 70–80% of the world's antibiotics (Van Boeckel *et al.*, 2015). Antimicrobial use drives the emergence of antimicrobial resistance, which results in antibiotics used to treat disease becoming less effective, posing a serious (but currently unquantified) threat to human and animal health. Use is particularly high in monogastrics (pigs and poultry), where antimicrobials alter the gut microbiome and improve the feed conversion ratio, which can increase yields and profit. This use as a growth promoter is illegal in the European Union but widely practised in other parts of the world.

In a growing livestock industry with greater access to antimicrobials (especially in developing countries), in a business-as-usual scenario, livestock antimicrobial consumption is predicted to increase from 131,000 t in 2013 to more than 200,000 t in 2030 (Fig. 19.4).

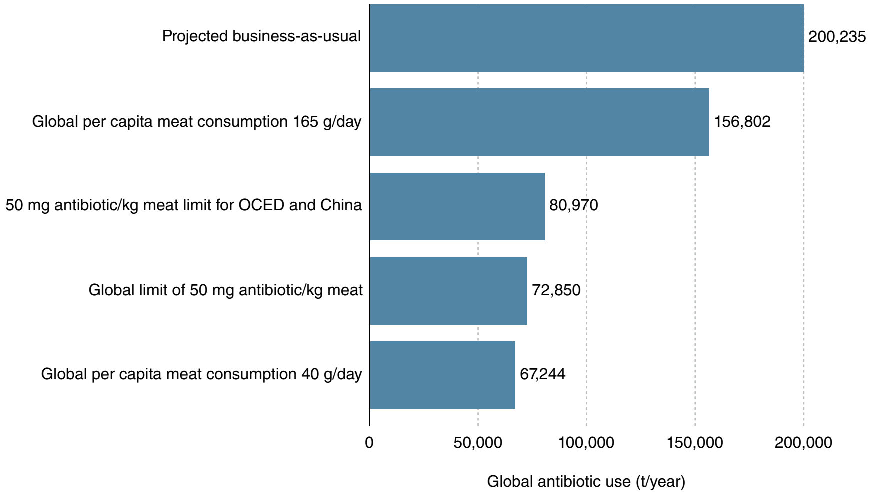

Fig. 19.4. Global antibiotic use in livestock under reduction scenarios, 2030, with a range of modelled reduction scenarios. Global antibiotic use is measured in tonnes per year. (From Ritchie, 2017b, using data from: Van Boeckel *et al*., 2015.)

19.7 Transmission and Rates of Zoonotic Disease

Livestock are also the source of many zoonotic diseases, such as avian and swine influenza, *E. coli*, salmonella and Anthrax. Sixty per cent of human infectious diseases have arisen from animals (Cunningham, 2005) and in intensive conditions disease may spread faster between animals, and the people they come into contact with.

19.8 Impact Competition: Interactions and Trade-offs

The above challenges, and their potential solutions, are interlinked. Deforestation from land use change is a major contributor to GHG emissions. Some practices, like feedlot finishing (where cattle are kept in yards and often fed concentrates) in Latin America may reduce emissions and land use (Balmford *et al.*, 2018) but may increase zoonotic disease risk or reduce animal welfare. When antimicrobials act as growth promoters they improve the feed conversion ratio, reducing gas emissions, but damage soil microbiomes, driving the emergence of antimicrobial resistance and inhibiting the breakdown of manure, which can have additional environmental consequences.

19.9 Addressing the Challenges

The single greatest way of reducing the impact of our diets on the environment, while also reducing antimicrobial use and reducing animal welfare problems, is to consume fewer animal products. Many of the people who are currently dependent on livestock products for essential nutrients and other resources are in poor regions, and as incomes increase it may become easier for populations to afford enough protein and other nutrients from non-animal sources. Increasing awareness of the environmental impact, as well as other concerns around animal welfare, healthy diets and antimicrobial resistance is leading to rising interest in vegetarianism and veganism in many countries, with many people actively reducing the amount of animal products they eat (Radnitz *et al.*, 2015).

This is not compensating for the increasing meat and dairy consumption in many parts of the world, however. High population countries with traditionally low meat consumption (such as India and China) are rapidly increasing demand for animal products. There is a pressing need for research to investigate how to best produce food (and especially livestock) with minimal impact. An example of this is how to reconcile biodiversity and food production.

Field data from nine regions across five continents shows that land sparing (increasing yields on existing farmland, while conserving or restoring land) is the best option for ensuring biodiversity persistence (Balmford *et al.*, 2015). There is a common perception, however, that high yield agriculture (and therefore land sparing) has its setbacks: externalities per unit product (such as GHG emissions and antimicrobial use) are perceived to be higher (Robinson *et al.*, 2011), and animal welfare poorer.

19.10 Potential Paths of Action: Impacts, Trade-offs and Potential Co-benefits

An ongoing challenge is the extent to which trade-offs exist between paths of action. A system with a small GHG footprint may use more land and so have a greater impact on biodiversity, and vice versa. There is little robust large-scale evidence for any of the impacts mentioned (GHGs, biodiversity, animal welfare, economics, disease and antimicrobial resistance), and there is also evidence that these trade-offs are less common than typically perceived (Balmford *et al.*, 2018). Research is particularly limited by the lack of data associated with multiple impacts of a single system.

Interdisciplinary research could identify synergies between improvements within farming systems: for example, anaerobic treatment and capture is effective in reducing antimicrobial resistance load in manure and can also be an effective way of reducing GHG emissions from manure. Many more such synergies may exist, as will trade-offs, which are equally important to identify.

Systems transitions – substituting one farming system for another that is lower impact – also warrants more attention. Some appear particularly promising, such as silvopasture (woodland) beef systems: trees maintain and store soil and tree carbon, potentially benefiting biodiversity (Broom, 2017). Shade may improve animal welfare while also providing nutrition to the cattle and boosting yield compared to substitutable pasture systems but further evidence is needed. Organic systems for milk, eggs and meat are on average worse for GHG emissions, land use, eutrophication and acidification potential, but better for energy use (Clark and Tilman, 2017). It is equally important to identify the highest impact systems so that they can be prioritized for change.

19.11 Conclusions

Livestock farming has major impacts on planetary health, and the burden is increasing. To reduce these impacts, systems need to be considered holistically. A combination of reducing the impacts of production and reduced consumption is necessary to ensure SDGs are achieved and planetary boundaries are not crossed.

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Index

Note: bold page numbers indicate figures; italic page numbers indicate tables; page numbers followed by *n* indicate chapter endnotes.

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