THE ROYAL SOCIETY

Biodiversity – evidence for action

The case for ambitious steps to reverse the trend in biodiversity decline

The Royal Society is the independent scientific academy of the UK, dedicated to promoting excellence in science. The Royal Society Biodiversity Programme was established to ensure that current, relevant and authoritative scientific evidence is available to policymakers to inform, motivate and shape their actions in relation to biodiversity.

The Programme is contemporaneous with:

- The United Nations Convention on Biological Diversity 15th Conference of the Parties, Kunming, China;
- The United Nations Framework Convention on Climate Change 26th Conference of the Parties, Glasgow, UK; and
- The publication of the independent "Review on the Economics of Biodiversity" commissioned by the UK Treasury and led by Partha Dasgupta FRS.

The Biodiversity Programme was assisted by a Steering Group and informed by a series of essays submitted by experts in their fields. Details of members of the Steering Group, project team members and the authors of the essays are set out at Annexes A and B respectively of this Report. The Royal Society is grateful to all who have freely contributed their expertise to this work.

> "All the evidence to date is that when societies put their mind to solving a problem, they can generally do it. People are ingenious and determined and form a creative, problem-solving community, and so I believe that the means exist to solve even some very hard problems. I think the challenge is to break the problems down into manageable chunks and solve them – being careful not to set aside the difficult and important ones, and remembering that ultimately the benefits need to flow to all people and societies."[1]
>
> Dame Georgina Mace FRS

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Overview

Biodiversity matters. At its simplest, biodiversity is about living nature or life on Earth – different genes, species and ecosystems that comprise the biosphere and the varying habitats, landscapes and regions in which they exist. Biodiversity is the inherited biological wealth of the Earth, and has intrinsic value in its own terms. It is also essential for meeting the most basic of human needs – food, water, shelter, clothing, fuel and medicines. Biodiversity regulates nutrient and water cycles, influences climate and helps clean pollution from the environment. It is integral to spiritual, cultural, psychological and artistic wellbeing. Humans are embedded in the natural world, and so are part of biodiversity.

Today, the Earth is losing biodiversity at rates not before seen in the modern era, with some suggesting that we are on the brink of a mass extinction event. The issues have long been reported by reputable organisations and eminent scientists working in the field. In 1988, the United Nations Environment Programme brought together experts to begin a process which would lead to the agreement of the United Nations Convention on Biological Diversity in 1992 at the Rio Earth Summit to underpin and drive biodiversity conservation[2]. In 2005, the Millennium Ecosystem Assessment issued what it described as "a stark warning… Human activity is putting such strain on the natural functions of Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted"[3]. Most recently, the IPBES Global Assessment Report in 2019 concluded that, "An average of around 25 per cent of species in assessed animal and plant groups are threatened suggesting that around 1 million species already face extinction, many within decades, unless action is taken to reduce the intensity of drivers of biodiversity loss"[4].

The human population cannot survive without the biological systems which support it and the rest of the species on the planet. Almost every pressing issue for humanity is inextricably linked to biodiversity. Growth in world population, consumption and trade place ever greater stresses on biodiversity. Increasing temperatures brought about by climate change dislocate species and their habitats. The rise and spread of new human pathogens (such as the new coronavirus) can be linked to threats to the natural world such as deforestation, wildlife trade, increased livestock production and poor practices in animal rearing.

Central to the process of biodiversity decline are the demands placed on land by food production. Half of Earth's ice free and otherwise habitable land is now occupied by cropland and pastures and it has been estimated that, between 1962 and 2017, approximately 810 million hectares of new croplands and pastures were created globally (an area larger than the continental USA). Of the approximate 25,000 species which the International Union for Conservation of Nature has identified as threatened with extinction, 13,382 (more than half) are in jeopardy as a consequence of agricultural land clearing and degradation alone. Additionally, some 3,019 species are affected by hunting and fishing, and 3,020 by pollution from the food system[5].

Equally, however, biodiversity offers tangible and attainable solutions to these very same problems. Nature can be harnessed to mitigate and adapt to climate change, and provide buffers against extreme events such as floods and wildfires. Biodiversity management and conservation contributes resilience in the face of health and economic threats that emerging pandemics present. Diversity in livestock, crops and aquaculture is integral to the challenges of sustainably feeding the world. The resources of the natural world will be needed to rebuild economies in the wake of COVID-19 and sustain human wellbeing into the future.

Human responses to biodiversity decline at the global and national levels to date have been woefully insufficient. The Global Biodiversity Outlook (September 2020) reported that none of the 20 Aichi Biodiversity Targets, set out in the Strategic Plan for Biodiversity 2011 – 2020, had been fully achieved[6]. The UK's Sixth National Report, published in March 2019, shows the UK will miss most of its commitments for nature made in 2010 (14 out of 20)[7]. Since the ratification of the Convention on Biological Diversity in 1992, more than a quarter of the tropical forests that were standing then have been cut down[8].

To halt and reverse biodiversity loss, transformational change at the local, regional and international level is required. Biodiversity must be given far higher prominence and urgency in policy choices. The nations of the world have shown they can respond to scientific evidence with endeavour and ingenuity to address serious threats to the environment. Notably, the Paris Agreement in 2015 led signatory countries to pledge the contributions they will make to mitigate climate change.

CASE STUDY 1

International response to scientific evidence

In 1987 every nation on Earth signed the Montreal Protocol. This is a landmark multilateral environmental agreement that regulates the production and consumption of nearly 100 human-made chemicals which, when released to the atmosphere, damage the stratospheric ozone layer, As a consequence, it is expected that the ozone layer, acting as a shield to protect humans and the environment from harmful levels of ultraviolet radiation from the sun, will be fully restored by 2050. This is estimated to save an estimated two million people each year by 2030 from skin cancer[9].

There is now a significant opportunity to achieve similar advances for biodiversity presented by the forthcoming United Nations Convention on Biological Diversity Fifteenth Conference of the Parties (COP15) to be held in Kunming, China and at which a Post-2020 Global Biodiversity Framework can be agreed. Additionally, the United Nations Framework Convention on Climate Change Twenty Sixth Conference of the Parties (COP26) in Glasgow, UK provides the prospect of aligning the climate change and biodiversity agendas to ensure that they are mutually reinforcing.

The Royal Society wishes to stimulate and contribute to the debate by emphasising the urgent need for a systemic response to biodiversity loss that spans areas such as global food production, the built environment, energy and transport. Such a response will need to be underpinned by new ways of valuing and accounting for biodiversity so that economies no longer decouple economic growth from the long-term sustainability of the biosphere. It will require policymakers to seize the opportunity to apply systems thinking (looking at the various interactions that couple human, economic and social activities to the biosphere, atmosphere, hydrosphere and lithosphere), to generate cross-sectoral solutions that address the biodiversity, climate and other linked crises in a coordinated manner. A global monitoring network for biodiversity must also be established – not to assess the extent of species decline, which is already clear, but to provide accountability for countries’ efforts to meet biodiversity goals and give focus to conservation planning.

The need for action at scale on biodiversity is pressing. While individual initiatives have been successful at local levels and are to be welcomed, they are insufficient in themselves. Business as usual, continuing on the trajectory of recent decades of over-exploiting the environment, will only serve to deepen the global crisis of the natural world. There is, however, hope. Science offers a range of solutions which can transform the future pathway of biodiversity. What is needed is the political will, resources and momentum to seize hold of those opportunities.

Chapter 1: What biodiversity is

1.1 The variety of life

Biological diversity, or what might be called living nature, is defined by the United Nations Convention on Biological Diversity as: "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems"[10].

Critical to biodiversity are the complex interrelationships and networks within which organisms survive, called ecosystems. Like the species which inhabit them, these ecosystems are diverse in nature. They take their characteristics from the geology, prevailing climate, soils, water and other features of the environment in which they are established[11] together with the evolutionary history of the life within them.

Not all ecosystems have the same abundance of species as others. Just over one-third of Earth's land surface contains the entire global ranges of around 85% of all plant species[12], while freshwater habitats cover only 0.8% of the globe but are home to one-third of described vertebrates, including approximately 40% of fish species[13].

Looking at the UK and the European Union, there is significantly less forest cover in the UK (around 13% of the land) compared to the EU average of 35%[14], but areas of peatland are common and important for their role in carbon absorption and retention. Additionally, Europe, including the UK, has considerable impacts (known as "footprints") on biodiversity elsewhere in the world from trade and other activities. For instance, Europe (alongside the USA) exerts considerable pressure on the global hotspot for marine biodiversity in southeast Asia, largely through fishing, pollution and aquaculture[15]. In terms of wider global responsibility for biodiversity, it also has to be borne in mind that the UK is ranked 12th out of 80 nations in terms of the area of tropical coral reefs of which it is custodian. This results from the UK's Overseas Territories[16].

Highly biodiverse ecosystems, very different to those found in the UK and European Union, are found in the largest remaining tropical forests of the world, such as the Amazon forest. In contrast to temperate forests, which are often dominated by a half dozen species making up 90% of trees, a tropical rainforest may be home to 480 species of trees in a single hectare. The Amazon has an estimated 15,000 species of trees and 1,300 described species of birds[17]. Similarly, it has been estimated that the canopy of a single tree in the Amazon rainforest may house more species of ants than the whole of the British Isles[18]. The tropical rainforests contain an estimated 50% of Earth's species in just over 10% of Earth's terrestrial vegetation cover. Human activities – especially creating farmland, felling trees for timber or overhunting of key species – have affected over half of tropical rainforest areas[19].

1.2 Names and numbers

Current estimates are that there are now between 8 and 20 million of the more complex species (called eukaryotes and including animals, plants and fungi) on Earth. But there is much that is unknown about these. Only around 2 million have been identified and given a name. Furthermore, there are most likely a much greater number of prokaryotes (other types of single-celled organisms, such as bacteria) about which even less is known[20].

New species are still being frequently found – with more than 400 species of mammals (including over 50 types of primate) being discovered between 1993 and 2009 alone[21]. This applies to both inaccessible areas of the globe, such as in deep sea systems and isolated portions of the Amazon, as well as in geographic regions where biological research has been undertaken for centuries, including North America, Europe and the Caribbean[22]. Additionally, modern genetic technologies mean that many species recognised in the past have been found to consist of genetically very distinct groupings leading to a reassessment of their status and the development of different concepts of what constitutes a 'species'.

Important though species richness is as the principal metric for measuring biodiversity, there are other metrics which need to be applied to understand more fully patterns of population growth and decline. These include the abundance of individual species and diversity measures describing the composition of communities. Traits such as body size, age to sexual maturity, reproductive output, and habitat affinity are also important in predicting likely future change within and across species. These characteristics provide a much deeper understanding of trends and trajectories for biodiversity and the potential for extinction of species[23].

New technologies are playing a central role in understanding biodiversity. Genetic techniques now complement morphological traits in systematics work to define species and understand their evolutionary relationship to others. Technological advances help allow for quick species identification even in remote areas[24]. For the purposes of detecting invasive or threatened species, eDNA approaches are becoming increasingly important. While assessing the state of nature is difficult, a wide variety of advanced technologies can be deployed to assist in this task, such as aerial surveys to provide information about forest cover and soil quality, sonar technologies to estimate fish stocks in the oceans and remote sensing to assign values to the biosphere and what it produces[25].

1.3 The past and present

Life on Earth is not new, nor is it unchanging. Abiotic drivers of biodiversity change, such as climate change, sea level fluctuations and tectonic activity, have long shaped ecosystems[26]. Species themselves change and adapt, including the creation of new species. The fossil record shows that species' ranges are not stagnant over geological time either and that there have been notable instances of species mixing and competing with each other, such as when the Isthmus of Panama closed and led to the Great American Biotic Interchange 2.7 million years ago[27].

The effect of humans on the extinction of species began at least 60,000 years ago, when human ancestors first spread from Africa to other continents, and possibly before when meat-eating and fire-using hominids emerged in Africa. The relocation of people to new lands was followed by a wave of extinctions of giant land animals (or megafauna), such as mammoths, ground sloths and giant kangaroos, with overhunting being a likely factor[28]. The conversion of habitats by humans on a traceable scale can be detected in archaeological data from as early as 10,000 years ago and had become widespread globally by 3,000 years ago[29,30]. Species loss has continued throughout human history, with islands from Hawai'i to Madagascar being hotspots of extinction, where locally evolved species were particularly vulnerable to the impacts of humans and associated species such as rats. More than 100 endemic mammal species disappeared from the Caribbean islands alone, and human occupation of Pacific Islands led to extinction of at least 1,000 bird species, around 10% of all the world's birds[31].

Despite their relatively recent evolution, humans together with their domestic animals have come to dominate among mammals – constituting an estimated 95% of the Earth's mammalian biomass, with domestic poultry accounting for three-quarters of global bird biomass[32]. Human expansion has long been associated with people moving species outside their native ranges, though it is also clear that the rate of species introductions has accelerated markedly with increased industrialization and economic globalization[33].

CASE STUDY 2

Invasive species eradication

Although islands occupy only around 5% of terrestrial surface area, they are inhabited by 37% of all critically endangered bird species on the International Union for Conservation of Nature red list. 88% of the 140 bird species that have gone extinct since 1500 were endemic to islands. Study of programmes across the world to eradicate invasive non-native mammals (such as cats and rats) have clearly demonstrated that these can lead to increased seabird nesting success and enhanced adult survival[34].

From around 1950 onwards, there has been a very dramatic transition in human demand and influence on the planet[35]. Since then, the human population has increased threefold and per capita wealth and consumption have increased even more. For instance, between 1950 and 2016, in Western Europe, GDP per capita increased nearly seven times[36]. This is sometimes called, "The Great Acceleration". Human influence on the planet is now so great that some have adopted the term "The Anthropocene" to describe a new geological epoch characterised by humanity's increasingly dominant influence on many Earth system processes[37].

Inevitably, as a consequence, other life forms are under severe stress from humans and their activities. Extinction is a natural process, and the ultimate fate of all species. However, one of the most significant effects of humans on the natural world has been to considerably speed up the extinction process for many species. Approximately 700 vertebrate species are known or presumed extinct since 1500 CE, including 181 birds and 113 mammals (together with further extinctions of invertebrates and plants that are not possible to quantify)[38]. Over a quarter of the tropical forests that were standing in 1992, when the United Nations Convention on Biological Diversity was ratified, have since been cut down[39]. Today, about one million animal and plant species, perhaps one quarter of the total, are estimated to be threatened by extinction, many within decades[40].

Freshwater species provide a clear illustration of these trajectories of loss: almost one in three freshwater species is now threatened with extinction, while the size of monitored populations has declined by 84% since 1970. The fall in numbers is especially acute among freshwater amphibians, reptiles and fishes, across all regions, particularly Latin America and the Caribbean. Habitat degradation resulting from pollution, alteration of flow regimes, invasive species and sand mining in rivers have been cited as among the causes of this[41].

1.4 The future

The scale and pace of biodiversity loss can only be expected to grow. The IPBES Global Assessment Report in 2019 found that, without action, "there will be a further acceleration in the global rate of species extinction, which is already at least tens to hundreds of times higher than it has averaged over the past 10 million years"[42]. The acceleration to date has already caused some scientists to warn that we are on the brink of the Earth's sixth "mass extinction event"[43].

The main direct cause of biodiversity loss is land use change (primarily for large-scale food production) which drives an estimated 30% of biodiversity decline globally; this is followed by overexploitation (overfishing and overhunting) which drives around 20%. Climate change, though currently ranked the third most significant direct driver of biodiversity loss (14%, together with pollution, followed by invasive alien species with 11%), greatly amplifies the effects of other factors and is predicted by some models to become the primary cause of biodiversity declines in the coming decades[44]. The impact of all the main drivers of biodiversity loss is accelerating and, as a consequence, so is the pace of biodiversity decline.

The likely pace and acceleration of biodiversity loss varies according to the characteristics, scale and context of different types of ecosystem. It can take grasslands years to change to shrublands, and decades for a forest environment to become savanna[45]. Additionally, the process of transition can be complicated. In semi-arid regions, grasslands and deserts both may co-exist, before changing abruptly from one to the other when a climate threshold is passed[46]. Ecosystems that have become degraded by relatively short periods of human interference can take a long time to recover. For example, the eutrophication of soils leads to changes to vegetation which can take centuries to revert. The long-term severe effect of ecosystem degradation is equally apparent in the oceans as on land – 33% of fish stocks are classified as overexploited and greater than 55% of ocean area is subject to industrial fishing[47]. Aquatic communities continue to be characterised by the exploitation of seals and whales in the southern oceans over a century ago.

CASE STUDY 3

The oceans

Marine protected areas (MPAs) are increasingly being used globally to conserve marine resources. A global database of management and fish population data was established to assess relationships between management processes and ecological effects. 71% of MPAs positively influenced fish populations, with staff and budget capacity being the strongest predictors of conservation impact. Those MPAs with adequate staff capacity had ecological benefits 2.9 greater than MPAs with inadequate capacity[48].

The richness of some biological ecosystems, such as rangelands and traditionally managed landscapes, can be maintained and enhanced by positive human interventions in nature. Similarly, human developed agrobiodiversity is important for the continuity of food systems and for cultural reasons. What is clear is that the transformation in ecosystems has long been underway and is neither proportionate nor predictable in the way that it will proceed. For example, there are species (called 'keystone species') whose disappearance will have a disproportionate impact on other lifeforms. This effect has been witnessed in the loss of species as diverse as starfish in intertidal communities and sea otters on the West Coast of the United States. The decline in such species, frequently at the top of biological food chains, can lead to systemic reorganisation of ecosystems and resultant increases or decreases of other species which inhabit those ecosystems[49].

Equally, there are environments across the globe which have particular stresses placed upon them as a result of human activities. Such environments include coastal zones, which account for only around 20% of the Earth's surface but house 45% of the global human population and most of the world's mega-cities[50]. Coastal zone habitats, such as mangrove forests which have seen losses of between 20-35% in global extent over the last 50 years due to human activities such as shrimp and rice farming, provide essential benefits to the planet and surrounding populations[51]. These include storing carbon, sediment and nutrients; regulating water flow and quality; and mitigating soil erosion and storms[52].

Nowhere more than the Amazon rainforest are the delicate balances of biodiversity change, together with the potential ramifications for the rest of the planet, more evident. The Amazon has witnessed historic droughts in 2005, 2010 and 2016/17. It has been estimated that as little as 20-25% deforestation within the Amazon region could potentially result in rainfall reductions that turn large parts of the remaining forests into savanna-like vegetation[53], showing the fragility of the ecosystem. In turn, such deforestation may result in rainfall reduction in downwind regions in other parts of South America, and potentially change weather patterns even in other continents[54]. The transition is probably not, however, instantaneous and there is the possibility to move back from this crisis. Much of the marginal pasture lands in the Amazon could be encouraged to regrow as forest to secure the health of the hydrological cycle[55].

Chapter 2: Why biodiversity matters

2.1 Multiple values

Biodiversity is essential for meeting the most basic of human needs. Biodiversity provides us with food, water, shelter, clothing, fuel and medicines. It also helps clean pollution from the environment, influences climate and cycles nutrients crucial to life[56]. While biodiversity performs functions critical to human existence and wellbeing, it is important in and of itself. It is possible to categorise the worth of biodiversity through different values that can be attributed to it[57]:

- Instrumental values are human-centred. They represent the importance of nature as a means to provide for human needs, interests or preferences. They include the value of nature as a provider of food, shelter, recreation, inspiration and income.
- Relational values are also human-centred, but concern the meaningfulness of relationships, such as those between nature and people and among people within nature or fostered by nature. Examples of such values are the individual identity of a farmer derived from the relationship with her land, the sense of care for those natural sites that are essential for a community's livelihood and spiritual development, and the sense of responsibility and social cohesion fostered by social movements aiming to preserve life on Earth.
- Intrinsic values refer to the inherent worth of nature as an end in itself, regardless of any human experience, recognising that nature is the complex product of billions of years of evolution prior to human evolution and independent of human needs.

Humans are not distinct from biodiversity; they have evolved and are embedded within the biosphere. The fate of biodiversity and that of humanity are inseparable[58]. Nature is also deeply implanted in all human cultures. The concept of 'biocultural diversity' has developed to recognise this by examining the interactions between social and community heritage and nature conservation[59]. The 2020 Local Biodiversity Outlook shows that the value systems of indigenous peoples (the earliest existing inhabitants of a region, rather than those who have subsequently settled there) and traditional local communities are often based on the connections between people and nature, rooted in reciprocal and respectful relationships[60]. These relationships do not, however, only apply to indigenous and traditional peoples. The identity of peoples, and the accompanying societal cohesion that arises from that, is inextricably linked to the places – the biological environments – in which they live[61,62]. Across the globe, people have to consider their own relationship with the biosphere, especially those in rich countries in their relentless pursuit of growth in material living standards[63].

It is important to emphasise that instrumental, intrinsic and relational values, are closely interrelated[64]. Taking the example of a forest in which edible fungi grow, this can satisfy human needs for food (instrumental value) and become a meaningful place where those who forage learn to bond to each other and with nature (relational value), so leading to moral rights being ascribed to the forest in recognition of its intrinsic worth (intrinsic value)[65].

Taking a pluralistic approach to how biodiversity is valued leads to considerations of justice and equity reaching beyond conservation and ecological science[66]. This is because it opens space for the perspectives, interests and worldviews of different social actors, including those traditionally unheard on the grounds of nationality, ethnicity, gender, age, physical abilities or income, inviting their voices in the design of more inclusive policy.

CASE STUDY 4

Pluralistic approaches

Examples are emerging of more pluralistic approaches in nature valuation and conservation, deeply ingrained in cultural and legal approaches to nature, They often fuse Western rights concepts with non-Western spirituality. New Zealand's recognition of the Whanganui River and surrounding area as the legal person Te Awa Tupua (an "indivisible and living whole") resulted from a treaty settlement with a Maori tribe and that tribe's spiritual connection to the river. Similarly, the 2008 Constitution of the Republic of Ecuador recognizes the rights of nature enshrined in the existence, life cycles, functions and evolutionary processes of Pacha Mama, an indigenous nature deity[67].

2.2 Measurement and models

The values of biodiversity can be assessed using very different metrics and models. It is possible, for example, to estimate the instrumental values of biodiversity from an economic perspective and liken the assets of biodiversity to other forms of capital assets, such as produced capital (roads and buildings) and human capital (knowledge and skills). Within this framework, biodiversity may be considered part of natural capital – "the stock of renewable and non-renewable natural resources (e.g. plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people, both directly (e.g. by delivering clean air) and indirectly (e.g. by underpinning the economy)"[68]. Techniques, such as remote sensing, have been used to provide physical data that underpin assessment of the instrumental values of the natural world. The purpose of economic approaches is not to commoditise nature, but rather to ensure biodiversity and other components of natural capital are not overlooked in economic decisions.

Biodiversity, by its nature, however, is not readily susceptible to conventional pricing models. The many ways in which nature benefits human populations are poorly understood, hard to monitor, and changing (critical influences on biodiversity, such as climate change, for instance, have only more recently begun to become studied and understood). Nature is frequently mobile, silent, unobserved by humans and locally specific, which makes it challenging to accurately record by accounting or statistical systems how we make use of its benefits[69].

Even when physical measurement is straightforward, it is hard to value the goods and services provided by nature, a large number of which are open to all and are free. This is because there are not always market prices, and even if prices are available, there are also many externalities – arising where the private costs or benefits of a product or service do not fully reflect the costs or benefits to society of producing that good or service. In principle, the externalities need to be reflected in the 'shadow price' used to calculate the monetary value of nature's instrumental services. The high seas, for instance, are beyond national jurisdiction and there is no financial incentive to protect them from contamination or overfishing[70].

Economists have modelled the socio-ecological processes that govern the supply of ecosystem services and then estimated the value of such services in monetary terms, to make them comparable to other economic statistics. For example, it has been estimated that pollination might contribute an annual £510-690 million to the UK's agricultural production, despite not being counted as part of national output[71]. Any such estimate is, however, contingent on a wide range of considerable uncertainties and there are risks in attributing defined monetary figures to complex interactions involving nature and economic outcomes.

CASE STUDY 5

Valuing nature

The Ganges river runs for over 1,500 miles, providing water for irrigation, industry, and domestic use to more than 500 million people. In 1985, the Ganga Action Plan (GAP) was launched, one of the largest single attempts to clean up a polluted river anywhere in the world. The programme entailed investment costs of Rs.7,657 million (or £205 million) and operating costs of Rs.480 million (£6.4 million) (at 1995 prices and exchange rates). To estimate the economic benefits of the programme, a survey was undertaken of 2,000 households across 10 cities in India which asked respondents to evaluate their willingness to pay for a range of water quality scenarios. From this, it was calculated that the benefits of the Ganges cleaning programme would have delivered a Net Present Value of around Rs.4,150 million and an Internal Rate of Return of 15.4%. The study showed that even by the narrow notion of benefits the authors took in their study, reviving the river would bring enormous benefits[72].

In summary, the principle of accounting for natural capital is accepted in economics, but estimating the monetary value of biodiversity is difficult, both because physical measurement is hard and because assigning the equivalent of prices to put it in the same units (money) as other economic measures is also problematic. Nevertheless, as economic statistics evolve, it will be both possible and useful to incorporate the value of services gained from biodiversity (and nature generally) into mainstream definitions and measurements of economies. Substantial statistical efforts are under way, under the auspices of the United Nations, to develop the System of Environmental Economic Accounts as a basis for accounting more fully for nature. The purpose is to ensure that nature is not left outside the boundary of the economy, a position that has led to it being too often ignored.

2.3 Biodiversity values and policy

Over the past 60 years, policymakers and societies have adapted their actions according to the prevailing value framework attached to biodiversity[73]. For instance, from the 1960s through to the 1980s, conservation policy was heavily influenced by views on the intrinsic value, or inherent worth, of nature, regardless of human judgements or interests. This led to an emphasis, first, on protecting species and 'natural' ecosystems without people and, subsequently, addressing threats to species and ecosystems caused by humans. By the late 1990s, evidence showed that biodiversity loss could not be halted based solely on actions motivated by a belief in the intrinsic value of nature alone. Consequently, conservation activities became rooted in more pragmatic and utilitarian considerations. Most recently, the attention has turned instead to a more inclusive conservation, in which different cultures and worldviews are considered and the importance of relational values is increasingly recognised[74]. All of these frameworks are, nevertheless, highly relevant today in policymaking – it is not the case that one approach has supplanted all previous framings.

Whatever values are applied to biodiversity, unless urgent and concerted policy action is taken, biodiversity and the benefits it provides are projected to decline until 2050 and beyond driven ultimately by population growth and changing distribution, unsustainable patterns of production and consumption, and technological developments. The effects of this will be felt globally, but will impact most severely indigenous peoples and local communities and the world's most poor and vulnerable who are especially reliant on biodiversity for their wellbeing. Biodiversity decline will thus prevent the achievement of the Sustainable Development Goals[75].

In responding to these challenges, policymakers must take account of all the different lenses through which nature is viewed and valued. That requires facilitating ways in which biodiversity can be adequately accounted for in national and corporate accounts – ultimately the full value of biodiversity has to matter in policy, business and consumer decisions. Equally, this should not undermine the multiple other values of nature, including intrinsic and relational values. Critical to this would be developing a vision so that economies cannot decouple economic growth from the long-term sustainability of the biosphere.

Chapter 3: Biodiversity loss and other key challenges of our times

There are a number of causes of ongoing biodiversity loss. Biodiversity resilience is also central to potential solutions to some of the most pressing global challenges. Some of these areas are examined below.

3.1 Consumption

A predominant driver of biodiversity loss is human consumption of goods and services (such as energy, timber, water, minerals and, especially, food). More so than population growth, the challenge facing biodiversity is that of increased human wealth. Consumption is determined primarily by global per capita spending which rose from $600 in 1970 to $7,810 in 2018 (current US$). This increase is seen across a whole range of sectors. Calorie intake per person per day increased 31% between 1961 and 2013. Similarly, reflecting both population growth and higher average per capita use, there was a 5.9 fold increase in global freshwater use between 1901 and 2014; and global energy consumption increased 28 fold between 1800 and 2019[76]. The nature of consumption has changed, too. Products, including clothing and fashion garments, computers and communication devices, such as smartphones, now have higher rates of turnover than they used to[77]. Similarly, the product lifetimes of electronic appliances, buildings and motor vehicles has shortened over time, meaning the ongoing pressure on nature has increased[78].

Biodiversity is also directly affected by the illegal wildlife trade, fuelled by criminality and corruption. The proceeds of such trade now amount to nearly $23 billion a year and threaten some of the world's most iconic species[79]. Similarly, while difficult to estimate, the extent of illegal, unregulated and unreported fishing has been assessed at between 11% and 19% of reported catches, or 10 to 26 million tonnes of fish annually, with a value of between US$10 billion and US$23 billion[80].

Finally, consumption is increasingly conducted at a distance. Often referred to as "telecoupling", this includes all kinds of distant human-nature interactions such as trade, tourism, migration, foreign investment, water transfer, technology transfer and information dissemination. Food exports across country borders rose 45-fold between 1961 and 2018[81]. The rise in distance consumption can affect biodiversity adversely where this involves the movement of products from areas of high biodiversity to areas of low biodiversity. Additionally, consumers are likely to have less concern for standards where production is carried out far away.

Reversing biodiversity loss requires rethinking consumption. Aspects of this include increasing the relative consumption of plant-based food, which usually has a much lower land footprint than meat[82]; prolonging the life span of products; cutting waste; reducing the impact of 'fast fashion' and addressing other lifestyle choices. Other approaches to changing consumption behaviours could involve creating traceability of flows along supply chains and raising awareness and changing attitudes internationally about the impacts on biodiversity of consuming distantly made products. Achieving this may require explicitly pricing into goods the negative and positive impacts of production on biodiversity. It could also involve changing emphasis from local production, in places of high biodiversity, to production in areas of lower biodiversity. This would, however, need to be balanced against the adverse consequences of telecoupling and would require a focus on minimising energy use and CO_2 emissions during production and processing[83].

CASE STUDY 6

Tracing supply chains

Material flow, economic trade and biodiversity loss models were used to examine the production of soy (a main cause of deforestation and biodiversity loss) in the Brazilian Cerrado, home to more than 5% of the world´s species. This highlighted the impact of European Union consumers on recent habitat losses for the iconic giant anteater (*Myrmecophaga tridactyla*). These sorts of models enable companies and governments with sustainability commitments to understand and adapt their own supply chains, and unmask unscrupulous traders[84].

Ultimately, consumer footprints are shaped by factors such as the fixation on growth in wealthier countries and inequality of access to environmental goods. The average income in Africa today is barely over 11% of that in Western Europe[85]. The material imbalance between higher, middle and low income countries together with economic growth and the rising consumer habits of expanding middle classes in developing economies are core parts of the present threat to biodiversity.

3.2 Population

Between 1950 and 2018, the world population tripled in size, rising from 2.5 billion to 7.6 billion people. This has had wide-ranging adverse consequences for human welfare and the environment. The growth in human population, occurring mainly in Africa, Asia and Latin America, can be attributed primarily to falling death rates, in particular of infants and children, resulting from public health measures, including sanitation and improved nutrition, alongside medical and scientific advances such as the development and deployment of vaccinations and antibiotics. According to United Nations estimates, population is expected to continue to expand for the remainder of this century, reaching around 10.9 billion by 2100[86]. Most of this growth is expected to occur in sub-Saharan Africa, where population is expected to nearly quadruple by 2100 (from 1.0 to 3.8 billion)[87]. In most of the rest of the world, including Asia and Latin America, projected growth is much less.

However, it is not just population size which leads to human impacts on biodiversity, it is also how and where we live, in particular the growth of small and large urban settlements, the land we farm for food, and mine for resources, and the manner in which we exploit the natural environment, which has a direct impact on biodiversity. The percentage of the world's population living in urban environments rose from 30% to 56% between 1950 and 2020 and is projected to reach 87% in more developed countries and 66% in less developed countries by 2050[88]. Uncoordinated urban growth places pressure on large tracts of land, leads to an increasing disconnection with nature and results in sub-optimal resource use (such as in transportation and energy systems). It also inhibits falling rates of childbearing.

Education and health play an important role, both in determining childbearing rates and migration patterns (inter and intra country, and rural to urban), and also in framing the relationship between people and their environment. The scientific literature on the determinants of fertility identifies two general factors as the main drivers of fertility decline in the developing world over the past half century. The first is socio-economic development – in particular, the education of girls – and the second is family planning programmes, enabling couples to implement their preferences[89].

3.3 Food

The most significant causes of biodiversity decline are habitat change (loss, fragmentation and degradation) and over-exploitation resulting primarily from demand for food. This issue is closely related to changes in consumption and human population. There are projected increases in global food demand of between 70 and 100% by 2070, with many African countries potentially needing to triple or quadruple their 2010 cropland areas by 2060. Additionally, climate change, to which the food system contributes 30% of annual greenhouse gas emissions, is likely to become a major extinction risk to species over the next century[90].

Land clearing for agriculture continues to take place at pace. Between 1962 and 2017, it has been estimated that approximately 340 million hectares of new croplands were created globally, and an additional 470 million hectares of natural ecosystems were converted into pastures (a combined area larger than the continental USA). This has substantially affected almost 90% of critically endangered mammal species, and more than 80% and 70% of critically endangered amphibian and bird species, respectively, which cannot live in agricultural lands[91]. The adverse impact of certain types of agriculture on soils also needs to be factored into species decline (it has been estimated that more than 25% of the Earth's species live only in the soil or soil litter[92]). 95% of our food is directly or indirectly produced on our soils[93].

Significant on-farm benefits for biodiversity could be achieved by focussing efforts to use existing diversity within crop species to identify and develop varieties better suited to specific environmental conditions. Plant diversity can help improve pastures, potentially leading to increases in forage production. Improved food security has been seen in countries growing a greater diversity of crops through lower year-to-year fluctuation in harvests. Mixtures of varieties of a single crop can increase yields by decreasing disease incidence, or eliminating the need for fungicides to control pathogens[94]. Interventions that are beneficial for soil structure and biodiversity include encouraging wildlife such as earthworms, which act as 'ecosystem engineers' and aerate the soil as they burrow[95].

CASE STUDY 7

Smallholder farmers

Between 2005 and 2015, concerted efforts were made to engage over 20 million smallholder farmers in 452 counties in China to adopt methods for greater yield and environmental performance in fields with a total of 37.7 million hectares over the period. This involved more than 1,100 researchers collaborating with rural farming advisors and agribusinesses. The integrated soil–crop system management practices adopted increased maize, wheat and rice yields, nitrogen-use efficiency and farmer profitability[96].

However, major change in outcomes for biodiversity will only be achieved through more radical approaches to the production of human food. This could be pursued through a two-fold strategy of using sustainable routes to enhance agricultural yields combined with social and economic incentives to protect and restore natural habitats elsewhere in the landscape. In terms of agricultural and food chain practices, this would involve increasing land- and input-efficiency in growing crops; preserving portions of native ecosystems embedded within agricultural landscapes; implementing or developing policy and market mechanisms which explicitly tie yield improvements within farm landscapes to enhanced ecosystem protection elsewhere; and reducing global food demand through reducing waste and encouraging healthier diets[97].

3.4 Health

The global decline in biodiversity is mirrored by a rise in both diseases which affect animals only (including farm livestock) and so-called "zoonoses", which spread from animals to people and can lead to pandemics. Approximately 70% of emerging diseases (such as Ebola, Zika, Nipah and encephalitis) and almost all known pandemics (like influenza, HIV/AIDS, COVID-19), are zoonoses. Those diseases spread where there is contact among wildlife, livestock, and people[98].

As with biodiversity loss, land use change (deforestation, human settlement in wildlife habitats, urbanisation and crop and livestock agriculture) is an especially important driver of pandemics, having been responsible for the emergence of more than 30% of new diseases reported since 1960[99].

Complicated transference chains lead to disease spread among species. Investigations into the origins of COVID-19 indicate it is likely that bats served as reservoir hosts for its progenitor, with transference to humans occurring, possibly through an intermediate species[100]. As an indication of the potential threat from emerging and infectious diseases, it is estimated that there are 1.7 million currently undiscovered viruses existing in mammal and avian hosts of which between 540,000 and 850,000 could have the ability to infect humans. Mammals (including bats, rodents and primates), birds (especially water birds) and livestock (for instance, pigs, camels and poultry) are among the most important reservoirs of pathogens with pandemic potential[101]. This results from a range of factors, such as the species richness of such groupings, rather than necessarily as a direct consequence of particular susceptibility to disease of any given species.

Addressing the threat of pandemic diseases in the future will require a wholesale rethinking of current approaches, aligned closely with steps to address biodiversity loss. This would include significant measures to reduce land use change and the wildlife trade, together with One Health surveillance (linking human health, animal health and environmental health). The costs of such strategies are not insignificant, estimated at between $22 and $31.2 billion annually. This must, however, be set against the costs of pandemics themselves. One estimate places the cost of COVID-19 at $8-16 trillion globally by July 2020 alone. Until the disease is brought under control, by vaccines or other measures, those costs will continue to rise, as will human suffering and loss of life[102]. Any approach to dealing with pandemic disease threats must also be firmly embedded in wider strategies for human and animal disease management, embracing areas such as antimicrobial resistance and livestock husbandry practices.

Chapter 4: Securing a better future for biodiversity: societal goals and resilience

4.1 Climate

Global progress or deterioration in biodiversity will both be affected by and impact on progress or deterioration in a range of other fundamental challenges to the wellbeing of people and the planet. The relationship between climate change and biodiversity is one such area and demonstrates the complexity of the challenges at hand.

The Intergovernmental Panel on Climate Change's Fifth Assessment Report in 2014 found that climate change significantly disrupts biodiversity in a variety of ways: "Many terrestrial, freshwater and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances and species interactions in response to ongoing climate change"[103]. Closely interwoven with the causes of climate change is ocean acidification, caused by the uptake of CO_2 into the world's oceans. This has the potential to impact marine biodiversity on a scale similar to that of climate change, although it will not be solved by some of the interventions proposed to mitigate climate change.

Biodiversity has significant potential to help mitigate or adapt to climate change. One area of particular interest is land use change, which is the largest cause of biodiversity declines (accounting for approximately 30% of losses of global terrestrial habitat integrity[104]). Equally, agriculture, forestry and other land use accounts for just under a quarter of all anthropogenic greenhouse gas emissions, mainly from deforestation and agricultural emissions from livestock, soil and nutrient management[105]. A range of 'Nature-based Solutions' (NbS) – actions that involve working with nature to address societal goals – are being considered for their potential both to slow warming and to arrest ecosystem declines. In this way, ecosystems can become allies in reversing global change, rather than simply being threatened by the demands of the human population[106].

CASE STUDY 8

Wetland restoration

Bitterns (a type of heron) completely disappeared from Britain in the 1870s, recovered during the 20th century and then declined until, by 1997, there were just 11 males. This was substantially due to the loss of wet reedbed habitat, with good populations of rudd, eels and sticklebacks, relied on by bitterns. Two EU-funded projects together with legal safeguards within Special Protection Areas helped reverse this decline. Since 2006, there has been a year-on-year increase in bitterns in Britain until, by 2019, 198 males were recorded at 89 sites[107,108]. Wetlands provide valuable flood storage, buffer storm surge, and assist in erosion control[109]. The UK bittern population remains at risk from climate change. As sea levels rise, saltwater could flow into coastal reedbeds, making the habitat unsuitable for bitterns. As a result, several new reedbeds are being created inland, away from vulnerable coasts[110].

Such NbS need to be rigorously evaluated to understand what is feasible in practice and whether there are unintended consequences or trade-offs. It has been estimated that the total climate change mitigation potential of cost-effective NbS in the land use sector is around 11 gigatonnes annually (Gt CO_2e yr-1) of avoided emissions or enhanced sinks of CO_2. These would be derived principally from protecting intact forests, wetlands and grasslands; managing working timberlands, croplands and grazing lands; and restoring native ecosystems. While important, the cooling potential of NbS over the short-term is, therefore, relatively small compared to that which needs to be achieved through decarbonisation of the global economy[111]. It is, however, the case that NbS are already available for deployment, at relatively low cost compared with developing carbon capture and storage technologies. Hence NbS can provide a contribution towards the goal of net-zero carbon emissions but should not deflect attention from the challenge of decarbonisation.

NbS can also support human adaptation to climate change. As examples, restoring and protecting coastal ecosystems can provide some defence against coastal flooding and storm surges; sources of food and income from biodiversity can provide nutritional and financial security when crops or usual sources of income fail during climate extremes; and NbS can help build adaptive capacity and empowerment within local communities.

NbS can also enhance the ability of biodiversity itself to adapt to climate change, by increasing ecosystem diversity and resilience, by moderating local microclimates, and by facilitating species migration by increasing connectivity in fragmented landscapes.

According to United Nation's estimates, it will take at least $700 billion to reverse human destruction of the natural world[112]. Drawing together various studies, it has been estimated that the protection of coastal ecosystems could benefit upwards of 500 million people globally, bringing benefits of over $100 billion per annum[113]. Directly relating the costs and benefits of biodiversity to the ways that businesses and economies are run through national and corporate accounting procedures might help achieve the full potential of NbS.

4.2 Changing behaviour

Transformational change is required if biodiversity losses are to be averted or reversed[114]. This has to address the key human drivers – growth in global trade, an expanding human population, rising consumption and increasing uncoordinated urbanisation – that have acted on the biosphere since the middle of the last century[115,116]. A biosphere with limited capacity for renewal and to absorb waste cannot sustain perpetual economic growth[117].

As one example of the scale of the challenge, conservation assessments at both the regional and global scales recommend that at least 50% of the planning domain should be under some form of conservation management to ensure the long-term persistence of biodiversity patterns and processes. Such a radical target could only be achieved through re-setting values, norms and behaviours of individuals and institutions[118].

Central to the challenges and opportunities for biodiversity is the role of indigenous and traditional peoples who own, manage, use or occupy over a quarter of the land surface of the world. Much of that is particularly important for biodiversity, including 35% of the area that is formally protected, and around 35% of other land areas with very low human intervention[119]. Indigenous people and local communities therefore need to be at the heart of decisions to identify, manage and designate new areas for protection, recognising that these may already be under their purview[120].

More importantly, indigenous peoples frequently have a special relationship with the land and coastal areas over which they exercise stewardship, seeing themselves and nature inextricably linked. Land management is often based on factors such as culturally specific world views, including the health of the land, caring for country and reciprocal responsibility. Additionally, the lands overseen by indigenous peoples and local communities (farmers, pastoralists, herders and others) play a unique role, on behalf of broader global society, in sustaining remaining varieties of wild and domesticated biodiversity[121].

Land managed by indigenous peoples and local communities is increasingly under pressure from resource extraction, transport and energy infrastructure and other causes. The resultant impact on biodiversity is felt by local populations. The global response to the decline in biodiversity, therefore, must ensure the rights of indigenous peoples and local communities – including land and resource tenure rights – are strengthened and protected[122]. It must also engage with communities and civil societies as well as at the national and intergovernmental level[123]. This will require governance approaches that are equitable, integrative, inclusive, informed and adaptive[124]. Rights-based approaches (recognising the links between biodiversity and human rights and the role of human rights in catalysing transformative change) might have an important role to play. That could include recognition of the right to a safe and healthy environment; ensuring rights, responsibilities, knowledge and practices of indigenous peoples are assured; and ensuring inclusivity and fairness in participation, benefit-sharing and in the governance of nature.

Different human societies are believed to have collapsed over the millennia as a consequence of environmental degradation – from factors including deforestation, soil erosion, over-hunting and alien species introductions[125]. Humanity is, however, endowed with qualities capable of foregoing short-term gains and cooperating to address major societal challenges. These include the desire and capacity to cooperate with non-kin; the potential to show compassion to other animals and even plants; the aptitude to non-genetically transfer learned behaviour; and to communicate and inspire through metaphors and symbols[126]. Humans also have the ability to envision future events beyond their personal experience, and prepare accordingly.

Applying such qualities to the problem of biodiversity loss will require ingenuity and imagination. Only through using a suite of behavioural approaches, will generalised awareness and concern about natural resource management and conservation translate into radically altered individual behaviours which are sustainable in the way that they relate to nature.

CASE STUDY 9

Changing behaviour

Social marketing takes existing behaviours as a given and focuses on identifying barriers to behaviour change and designing specific incentive-based programmes to overcome these. Social marketers use commercial marketing techniques and social media aimed at different segments of stakeholders. Social marketing has been successful in achieving behaviour change in the health, social development and waste management sectors and could be applied to natural resource management and conservation[127].

4.3 Goals

The main premises of the evidence base and the magnitude of the threat to biodiversity are not in dispute globally. At the United Nations Summit on Biodiversity in September 2020, political leaders representing 78 countries from all regions together with the European Union committed in the *Leaders' Pledge for Nature*[128] to reversing biodiversity loss by 2030. That pledge expressly stated, "Science clearly shows that biodiversity loss, land and ocean degradation, pollution, resource depletion and climate change are accelerating at an unprecedented rate," and, accordingly, that "we are in a state of planetary emergency...driven in large part by unsustainable production and consumption".

Currently, there is a significant opportunity presented by international discussions on the Post-2020 Global Biodiversity Framework coordinated by the United Nations Convention on Biological Diversity. This framework "sets out an ambitious plan to implement broad-based action to bring about a transformation in society's relationship with biodiversity and to ensure that, by 2050, the shared vision of living in harmony with nature is fulfilled". The approach contained in the framework is complementary to, and supportive of, the 2030 Agenda for Sustainable Development and takes into account the long-term strategies and targets of other multilateral environment agreements[129].

A number of actors are already working at scale and with vision to propose solutions to address the biodiversity crisis. Each of these ideas have their challenges arising from the underlying science, the practicalities of implementation, or both. To demonstrate the scale and breadth of thinking, conceptual approaches include: Calling for protection of a significant percentage of global land and sea (e.g. Half-Earth Project[130] or A Global Deal For Nature[131]); reforming the global political economy (such as Whole Earth[132]); and specifically targeting particular types of ecological habitat (like the 30x30 ambition to create a network of highly protected marine areas[133]).

If current initiatives and momentum to reverse biodiversity decline are not to stall in the same way as their predecessors (such as the "Aichi Biodiversity Targets" under the Strategic Plan for Biodiversity 2011 – 2020[134]), considerably more flesh will need to be put on the bones of the necessary practical actions. This must begin with a far higher prominence being given to biodiversity at global, regional and local levels in the choices made across all areas of policy, not only in relation to the environment.

There are actions which can, at the same time, enhance biodiversity, deliver economic prosperity and bring greater equity. Indeed, the World Economic Forum recently concluded that transformative changes to reduce human impact on nature and its services could present business opportunities worth US$10 trillion per year and could create 395 million jobs by 2030[135]. Equally, to arrest the decline in biodiversity, there are hard policy trade-offs to take in influencing how societies and individuals live and behave in the modern world.

Ours is the first generation that understands in detail the damage that it is causing to biodiversity – and the last with the time to make a difference.

Chapter 5: Strategy and vision for biodiversity

An overarching strategy and vision for biodiversity should include the following:

TIMESCALES	
Immediate action and long-term vision	**Recovery pathways** – urgent measures over the next ten years (by 2030) to halt and start to reverse the decline in biodiversity
	Long term equilibrium – by 2050, biodiversity should be valued, managed and utilised in a viable and equitable way so that it can sustain planetary functions and human wellbeing
VALUATION	
New approaches to valuing and accounting for biodiversity	**International institutions** – in ways that can be incorporated in treaties, conventions, legislation and markets
	Countries and businesses – so that biodiversity is addressed in national and corporate accounting procedures
	Sustainability – so that economies no longer decouple economic growth from the long-term sustainability of the biosphere
	Multiple values – not excluding or devaluing the intrinsic and relational values of nature, or the values perceived by historically marginalised groups
CROSS-SECTORAL SOLUTIONS	
That build resilience through addressing the biodiversity, climate and other linked crises in a coordinated manner	**Governance frameworks** – at the appropriate international, regional and local levels to enable and facilitate actions to reverse biodiversity loss. This should include recognising and strengthening the right of indigenous peoples and local communities effectively to manage and protect their land and resources
	Land use – pathways to increase agricultural yields sustainably and incentives to protect and restore natural habitats elsewhere
	Trade – traceability in supply chains and explicit transparency around the negative and positive impacts of production on biodiversity
	Influencing consumers – behavioural and marketing approaches to ensure that purchasing decisions recognise and respond to consequences for biodiversity
	Working with nature – locally appropriate use of nature-based solutions to mitigate and build resilience to climate change
GLOBAL MONITORING NETWORK	
To strengthen countries' attainment of biodiversity targets, assist with regional and global assessments and support conservation planning	**Building human and technical capacity** – to monitor biodiversity in regions currently lacking the resources to track rates of change at the necessary resolution
	Establishing a global knowledge and information system – to support open data production and sharing, and to assist in the rapid detection and forecasting of trends to support conservation policy
	Harnessing technologies for monitoring biodiversity – on the ground, from the air, and from space.

Dedication to Dame Georgina Mace FRS (1953 – 2020)

This publication is dedicated to Dame Georgina Mace FRS who worked tirelessly through her research and advocacy for the causes of biodiversity and the environment.

Georgina Mace's research covered a range of topics that related to the trends and consequences of biodiversity loss and ecosystem change. She developed the criteria for measuring species extinction risk that are now used by the International Union for Conservation of Nature for their regular Red Lists of Threatened Species. Georgina also identified the factors that cause different species to be more or less vulnerable to extinction. She developed approaches to understanding climate change impacts and how this varies between species and in different ecosystems.

A second area of her research concerns ecosystem services and natural capital accounting, which she became interested in through her work on the Millennium Ecosystem Assessment and the UK's National Ecosystem Assessment. Georgina had been especially concerned with evaluating the links between biodiversity and ecosystem services, incorporating ecosystem services into biodiversity targets and examining trade-offs amongst ecosystem services. Most recently, she developed a new approach to measuring the loss of natural capital, using a risk register.

For her services to environmental science, Georgina was awarded an OBE in 1998, a CBE in 2007 and made a DBE in 2016.

At the time of her death on 19 September 2020, Georgina was fully committed to the Royal Society's Biodiversity Programme and critical to shaping this work as a member of the Steering Group. She is greatly missed by all those involved with this project and the wider environmental science communities.

Annex A: Acknowledgments

STEERING GROUP MEMBERS	
Chair: Professor Yadvinder Malhi CBE FRS	Professor of Ecosystem Science, School of Geography and the Environment, University of Oxford
Professor Andrew Balmford FRS	Professor of Conservation Science, Department of Zoology, University of Cambridge
Professor Sir Ian Boyd FRS	School of Biology, University of Saint Andrews
Professor Diane Coyle	Bennett Professor of Public Policy, University of Cambridge
Professor Sandra Díaz ForMemRS	Professor of Community and Ecosystems Ecology, National University of Córdoba and CONICET, Argentina
Professor Sarah Harper CBE	Clore Professor of Gerontology, University of Oxford
Professor Dame Georgina Mace DBE FRS	Professor of Biodiversity and Ecosystems, University College London (until September 2020)
Professor Dame Linda Partridge DBE FRS	Biological Secretary and Vice-President, the Royal Society
Dilys Roe	Principal researcher and team leader (biodiversity), Natural Resources Group, International Institute for Environment and Development
OTHER ACADEMIC CONTRIBUTORS	
Melissa Kemp	Assistant Professor, Department of Integrative Biology, The University of Texas at Austin
Professor William Sutherland	Miriam Rothschild Professor of Conservation Biology, University of Cambridge
PROJECT TEAM	
Mike Edbury	Science Policy Consultant
Emma Woods	Head of Policy, The Royal Society

Annex B: Biodiversity essays

All essays are being published at:
royalsociety.org/topics-policy/projects/biodiversity

Chapter 1: What biodiversity is

How biodiversity is described, the patterns and trajectory of biodiversity change and causes of this.

Emergent and vanishing biodiversity, and evolutionary suicide by Simon A Levin, James S. McDonnell Distinguished University Professor in Ecology and Evolutionary Biology, Princeton University; Director of the Center for BioComplexity in the Princeton Environmental Institute

Amazonia's Future: Eden or Degraded Landscapes? by Thomas E Lovejoy, United Nations Foundation

Past and future decline and extinction of species by Christopher N Johnson, School of Natural Sciences and Australian Research Council Centre of Excellence for Australian Biodiversity and Heritage, University of Tasmania

Chapter 2: Why biodiversity matters

The role of biodiversity and its benefits and importance to people.

The Economics of Biodiversity: the Dasgupta Review by Professor Sir Partha Dasgupta FRS, Frank Ramsey Professor Emeritus of Economics, University of Cambridge

Plural valuation of nature matters for environmental sustainability and justice by Berta Martín-López, Social-Ecological Systems Institute, Faculty of Sustainability, Leuphana University of Lüneburg

Chapter 3: Biodiversity loss and other key challenges of our times

Pressing topical issues for biodiversity and their social, cultural and political contexts.

Preserving global biodiversity requires rapid agricultural improvements by David Tilman, Department of Ecology, Evolution and Behavior, University of Minnesota; and Bren School of Environmental Science and Management, University of California; and David R. Williams, Sustainability Research Institute, School of Earth and Environment, University of Leeds

Consumption patterns and biodiversity by Jianguo Liu, Center for Systems Integration and Sustainability, Department of Fisheries and Wildlife, Michigan State University

Demographic trends and policy options by John Bongaarts, Distinguished Scholar, Population Council

Chapter 4: Securing a better future for biodiversity: societal goals and resilience

Future opportunities for promoting biodiversity alongside other global political objectives, together with policy trade-offs.

Why efforts to address climate change through nature-based solutions must support both biodiversity and people by Nathalie Seddon, Professor of Biodiversity, Director of the Nature-based Solutions Initiative, Department of Zoology, University of Oxford

Behaviours for conserving biodiversity by R.M. Cowling, Distinguished Professor, African Centre of Coastal Palaeoscience, Nelson Mandela University

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