The Economics of Biodiversity: The Dasgupta Review

Abridged Version

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Foreword

We are facing a global crisis. We are totally dependent upon the natural world. It supplies us with every oxygen-laden breath we take and every mouthful of food we eat. But we are currently damaging it so profoundly that many of its natural systems are now on the verge of breakdown.

Every other animal living on this planet, of course, is similarly dependent. But in one crucial way, we are different. We can change not just the numbers, but the very anatomy of the animals and plants that live around us. We acquired that ability, doubtless almost unconsciously, some ten thousand years ago, when we had ceased wandering and built settlements for ourselves. It was then that we started to modify other animals and plants.

At first, doubtless, we did so unintentionally. We collected the kinds of seeds that we wanted to eat and took them back to our houses. Some doubtless fell to the ground and sprouted the following season. So over generations, we became farmers. We domesticated animals in a similar way. We brought back the young of those we had hunted, reared them in our settlements and ultimately bred them there. Over many generations, this changed both the bodies and ultimately the characters of the animals on which we depend.

We are now so mechanically ingenious that we are able to destroy a rainforest, the most species-rich ecosystem that has ever existed, and replace it with plantations of a single species in order to feed burgeoning human populations on the other side of the world. No single species in the whole history of life has ever been so successful or so dominant.

Now we are plundering every corner of the world, apparently neither knowing or caring what the consequences might be. Each nation is doing so within its own territories. Those with lands bordering the sea fish not only in their offshore waters but in parts of the ocean so far from land that no single nation can claim them. So now we are stripping every part of both the land and the sea in order to feed our ever-increasing numbers.

How has the natural world managed to survive this unrelenting ever-increasing onslaught by a single species? The answer of course, is that many animals have not been able to do so. When Europeans first arrived in southern Africa they found immense herds of antelope and zebra. These are now gone and vast cities stand in their stead. In North America, the passenger pigeon once flourished in such vast flocks that when they migrated, they darkened the skies from horizon to horizon and took days to pass. So they were hunted without restraint. Today, that species is extinct. Many others that lived in less dramatic and visible ways simply disappeared without the knowledge of most people worldwide and were mourned only by a few naturalists.

Nonetheless, in spite of these assaults, the biodiversity of the world is still immense. And therein lies the strength that has enabled much of its wildlife to survive until now. Economists understand the wisdom of spreading their investments across a wide range of activities. It enables them to withstand disasters that may strike any one particular asset. The same is true in the natural world. If conditions change, either climatically or as a consequence of a new development in the never-ending competition between species, the ecosystem as a whole is able to maintain its vigour.

But consider the following facts. Today, we ourselves, together with the livestock we rear for food, constitute 96% of the mass of all mammals on the planet. Only 4% is everything else – from elephants to badgers, from moose to monkeys. And 70% of all birds alive at this moment are poultry – mostly chickens for us to eat. We are destroying biodiversity, the very characteristic that until recently enabled the natural world to flourish so abundantly. If we continue this damage, whole ecosystems will collapse. That is now a real risk.

Putting things right will take collaborative action by every nation on earth. It will require international agreements to change our ways. Each ecosystem has its own vulnerabilities and requires its own solutions. There has to be a universally shared understanding of how these systems work, and how those that have been damaged can be brought back to health.

This comprehensive, detailed and immensely important report is grounded in that understanding. It explains how we have come to create these problems and the actions we must take to solve them. It then provides a map for navigating a path towards the restoration of our planet's biodiversity.

Economics is a discipline that shapes decisions of the utmost consequence, and so matters to us all. The Dasgupta Review at last puts biodiversity at its core and provides the compass that we urgently need. In doing so, it shows us how, by bringing economics and ecology together, we can help save the natural world at what may be the last minute – and in doing so, save ourselves.

David Attenborough

Preface

The present monograph is an abridged version of *The Dasgupta Review on the Economics of Biodiversity* (the *Review*) that I prepared at the invitation, in Spring 2019, of the then Chancellor of the Exchequer of the UK Government.

*

Economics, like I imagine other scientific disciplines, normally moves in incremental steps, and always without a central guide. Much like practitioners of other disciplines, we economists work with models of those features of the world we want to study in detail. That involves keeping all else in the far background. Models are thus parables, some say they are caricatures, which is of course their point.

Economics is also a quantitative subject. Finance ministers need estimates of tax revenues if they are to meet intended government expenditure; environment ministers today cannot but ask how much farmers should be paid to set aside land for 'greening' the landscape, and whether fossil-fuel subsidies should be eliminated; health ministers look to convince cabinet colleagues that investment in health is good for economic growth; and so on. Which is why economic models are almost invariably cast in mathematical terms.

That is also why the models that appear in economics journals can appear esoteric, unreal, and even self-indulgent. Many would argue as well that to model human behaviour formally, let alone mathematically, is to tarnish the human experience, with all its richness. And yet, economists in governments, international organisations, and private corporations find those models and their adaptations essential for collecting and analysing data, forecasting economic trajectories, evaluating options and designing policy. Perhaps, then, it should be no surprise that those same models go on to shape the conception we build of our economic possibilities. In turn, our acceptance of the economic possibilities those models say are open to us encourages academic economists to refine and develop them further along their tested contours. And that in turn further contributes to our beliefs about what is achievable in our economic future. The mutual influence is synergistic.[1]

That has had at least one unintended and costly consequence. Not so long ago, when the world was very different from what it is now, the economic questions that needed urgent response could be studied most productively by excluding Nature from economic models. At the end of the Second World War, absolute poverty was endemic in much of Africa, Asia, and Latin America; and Europe needed reconstruction. It was natural to focus on the accumulation of produced capital (roads, machines, buildings, factories, and ports) and what we today call human capital (health and education). To introduce Nature, or *natural* capital, into economic models would have been to add unnecessary luggage to the exercise.[2]

[1] It will be asked who is represented in the collective 'we' and 'our' that I am using here. It is not everyone in the world, and certainly not restricted to those who agree with the claims I am making about the mutual influence of academic economic models and a general reading of economic possibilities. The group I have in mind is not fixed by designation but through invitation – for example, people who read this Review – to consider why and how we need to break the cycle and revise the conception we hold of humanity's place in the biosphere.

[2] The significance of the years immediately following the Second World War for the economics of biodiversity will become clear below. I am referring to the evolution of economic thinking in the West. However, to the best of my knowledge the economic models that shaped state policy in the Soviet Union, and the ones developed by prominent academics in Latin America, also did not include Nature. The terms Nature, natural capital, the natural environment, the biosphere, and the natural world are used interchangeably.

Nature entered macroeconomic models of growth and development in the 1970s, but in an inessential form.[3] The thought was that human ingenuity could overcome Nature's scarcity over time, and ultimately (formally, in the limit) allow humanity to be free of Nature's constraints. But the practice of building economic models on the backs of those that had most recently been designed meant that the macroeconomics of growth and development continued to be built without Nature's appearance as an essential entity in our economic lives. Historians of science and technology call that feature of the process of selection 'path dependence'.[4] That may be why economic and finance ministries and international organisations today *graft* particular features of Nature, such as the global climate, onto their models as and when the need arises, but otherwise continue to assume the biosphere to be *external* to the human economy. In turn, the practice continues to influence our conception of economic possibilities for the future. We may have increasingly queried the absence of Nature from official conceptions of economic possibilities, but the worry has been left for Sundays. On week-days, our thinking has remained as usual.[5]

The *Review* is both long and technical; in boxes, annexes, and starred chapters, it is even mathematical. I knew it would be so even as I began working on it; so I have all along had it in mind to write a shortened, non-mathematical monograph based on it. But I never expected the resulting monograph to be an easy read; it could not be, because the economics of biodiversity is a very hard subject.

My reader is the *concerned citizen*. She is someone who has watched television documentaries on the state of the biosphere and has read reports in newspapers and magazines on the extent to which Earth is being degraded and biodiversity is being lost. What she wants now is an explanation for how and why we have come to this pass, and she wants to know how to translate that explanation into recommendations. She is curious to know what sustainable development should mean; what criteria governments and private companies should use when choosing investment projects; what rules private investors such as herself should use to compare alternative asset portfolios; what she should insist be the practices of companies producing the goods and services she purchases and consumes; whether the social returns on investment in family planning and reproductive health to meet the unmet needs of millions of the world's poorest women are so low that the European Union assigns less than 1% of their international aid budget to them; and so on. Depending on the context, I call her the 'social evaluator', or the 'citizen investor'. She recognises that her perspective as a citizen is different from the one she assumes as she goes about her daily life. And she wants to understand why this is so. She is perplexed that her economist neighbour insists that markets can eliminate these problems if only the government would set appropriate taxes, subsidies, and regulations, but that without sustained economic growth all that humanity has achieved will be lost and poverty will be on the rise. She feels her neighbour is on a wrong track, but doesn't know how to argue with him. My reader is someone willing to work hard with me to understand how to counter her economist neighbour.

Biodiversity is the diversity of life. We will find that the economics of biodiversity is the economics of the entire biosphere. So, when developing the subject, we will keep in mind that we are *embedded* in Nature. We show (and the *Review* confirms formally) that although the difference in conception is analytically slight, it has profound implications for what we can legitimately expect of the human enterprise. The former viewpoint encourages the thought

[3] See, for example, the special issue in the *Review of Economic Studies* (1974) on the economics of exhaustible resources.

[4] A clear statement is in P. A. David, 'Clio and the Economics of QWERTY', *American Economic Review*, 75(2), 332-337.

[5] Over the years the absence of Nature's essentiality from macroeconomic models of growth and development has been remarked upon by scholars outside the mainstream of economic thinking and practice. But while it is all too easy to criticise existing practices, it is a lot harder to develop alternative models of comparable analytical depth and empirical reach to ones that have been honed by years of patient work. That may be why the criticisms have not been taken seriously by mainstream economists.

that human ingenuity, when it is directed at advancing the common good, can raise global output indefinitely without affecting the biosphere so adversely that it is tipped into a state far-removed from where it has been since long before human societies began to form; the latter is an expression of the thought that because the biosphere is bounded, the global *economy* is bounded.

In the chapters that follow, the natural world is studied in relation to the many other assets we hold in our portfolios, such as the vehicles we use for transport, the homes in which we live, and the machines and equipment that furnish our offices and factories. But like education and health, Nature is more than a mere economic good. Nature nurtures and nourishes us, so we will think of assets as durable entities that not only have use value, but may also have intrinsic worth. Once we make that extension, the economics of biodiversity becomes a study in portfolio management. Which is why I call the concerned citizen the 'citizen investor'.

Nature has features that differ subtly from produced capital goods. The financier may be moving assets around in his portfolio, but that is only a figure of speech. His portfolio represents factories and ports, plantations and agricultural land, and mines and oil fields. Reasonably, he takes them to be immobile. In contrast, Nature is in large measure mobile. Insects and birds fly, fish swim, the wind blows, rivers flow, the oceans circulate, and even earthworms travel. Economists have long realised that Nature's *mobility* is one reason the citizen investor will not take the market prices of natural capital to represent their social worth even when markets for them exist. We study the wedge between the prices we pay for Nature's goods and services and their social values (their social values are called 'accounting prices') in terms of what economists call 'externalities'. Over the years, a rich and extensive literature has identified the measures that can be deployed (the forces of the law and social norms) for closing that wedge. The presence of the wedge is why the citizen investor will insist that companies disclose activities along their entire supply chain. Disclosure serves to substitute for imperfect market prices.

But in addition to mobility, Nature has two properties that make the economics of biodiversity markedly different from the economics that informs our intuitions about the character of produced capital. Many of the processes that shape our natural world are *silent* and *invisible*. The soils are a seat of a bewildering number of processes with all three attributes. Taken together the attributes are the reason it is not possible to trace very many of the harms inflicted on Nature (and by extension, on humanity too) to those who are responsible. Just who is responsible for a particular harm is often neither observable nor verifiable. No social mechanism can meet this problem in its entirety, meaning that no institution can be devised to enforce socially responsible conduct.

It would seem then that, ultimately, we each have to serve as judge and jury for our own actions. And that cannot happen unless we develop an affection for Nature and its processes. As that affection can flourish only if we each develop an appreciation of Nature's workings, the monograph ends with a plea that our education systems should introduce Nature studies from the earliest stages of our lives, and revisit them in the years we spend in secondary and tertiary education. The conclusion we should draw from this is unmistakable: if we care about our common future and the common future of our descendants, we should all in part be naturalists.

My education in what is the substance of the *Review* began in the late 1970s in conversations with Karl-Göran Mäler. He encouraged me to develop my ideas on the links between rural poverty and the state of the local environmental resource-base in the world's poorest countries, a subject that was then notably absent from mainstream development economics and remained absent until well into the 1990s. I was further encouraged by Lal Jayawardena, Director of the World Institute of Development Economics Research (WIDER), Helsinki, who invited Mäler and me in 1988 to establish a programme at his institute on the environment and emerging development issues.[6]

But it wasn't until 1991 when, as the newly appointed Director of the Beijer Institute of Ecological Economics, Stockholm, Mäler asked me to serve as Chair of the Institute's Scientific Advisory Board, that we were able to pursue the programme jointly with ecologists. The Institute's mandate made it possible, which was unusual at that time, for ecologists and economists to conduct a regular series of workshops in ecological economics. In this, Mäler and I were aided greatly by the intellectual authority of Kenneth Arrow, Bert Bolin, Paul Ehrlich, and Simon Levin. The Institute's activities have continued with the same exacting standard under Carl Folke, who assumed the Directorship when Mäler retired.

As these developments were confined to Continental Europe, it was natural for us to imagine regional networks of ecological economists in developing countries. That was made possible by a grant from the MacArthur Foundation, Chicago. It enabled Mäler and me in 1999 to establish the South Asian Network for Development and Environmental Economics (SANDEE) and simultaneously the journal *Environment and Development Economics* (Cambridge University Press). Our idea was to offer not only encouragement, but also financial help and a journal based in the West where university teachers of economics in developing countries could publish their research findings. We were able soon after to help colleagues in Eastern and Southern Africa and in Latin America to establish their own networks.[7]

Mäler and I received further help. This time from Miguel Virasoro, Director of the Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, who invited us in 2001 to create a programme in ecological economics at ICTP. We used the opportunity to invite economists in our newly formed networks to the Centre, so that they could prepare their findings for publication with help from members of the journal's editorial board. The *Review* has been much influenced by the rich body of work by colleagues in those networks.

The economics of biodiversity requires attention to local socio-ecological details. I was introduced to the idea of social capital and its relevance for ecological economics at the biannual retreat that Ismail Serageldin convened for an advisory panel he had constituted in the mid-1990s at the Sustainable Development Vice Presidency of the World Bank.[8] My understanding of the subject has been deepened at the annual teaching workshop that SANDEE has organised since its inception, from discussions with my fellow lecturers Rabindranath Bhattacharya, Randall Bluffstone, Enamul Haque, Karl-Göran Mäler, Pranab Mukhopadhyay, M.N. Murty, Mani Nepal, Subhrendu Pattanayak, Priya Shyamsundar, E. Somanathan, and Jeff Vincent, and participants from Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka, too numerous to mention individually. On the science of complexity, I have learnt enormously from discussions over a period of fifteen years with fellow members of the Scientific Advisory Panel of the Programme on Complex Systems at the James S. McDonnell Foundation, St. Louis, and from the Foundation's successive Presidents, John Bruer and Susan Fitzpatrick.

Before beginning work on the *Review*, I asked Simon Beard, John Bongaarts, Simon Levin, Tom Lovejoy, and Peter Raven to prepare essays for me on subjects I knew to be essential but on which I was inexpert. The ideas they developed in their papers are reflected in the present work.

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[6] The programme's proceedings were published in P. Dasgupta and K.-G. Mäler, eds., *The Environment and Emerging Development Issues*, Vols. I and II (Oxford: Clarendon Press, 1997), and P. Dasgupta, K.-G. Mäler, and A. Vercelli, eds., *The Economics of Transnational Commons* (Oxford: Clarendon Press, 1997).

[7] Resource Accounting Network for Eastern and Southern Africa (RANESA) and the Centre for Environmental Economics and Policy in Africa (CEEPA), Pretoria; and Latin American and Caribbean Environmental Economics (LACEEP) and the Tropical Agricultural Research and Higher Education Center (CATIE), Costa Rica. SANDEE is based at the International Center for Integrated Mountain Development (ICIMOD), Kathmandu.

[8] The Panel's proceedings were published in P. Dasgupta and I. Serageldin, eds. (2000), *Social Capital: A Multifaceted Perspective* (Washington, DC: World Bank).

The Review and this monograph have been much influenced also by Scott Barrett and Aisha Dasgupta, who assumed the lead in collaborative works that form the basis of some of the central ideas here.

During the *Review*'s preparation, I gained enormously from correspondence and discussions with Inger Andersen, Robert Aumann, Scott Barrett, Ian Bateman, Simon Beard, Simon Blackburn, Caroline Bledsoe, John Bongaarts, Stephen Carpenter, William Clark, Mary Colwell, Diane Coyle, Aisha Dasgupta, Shamik Dasgupta, Zubeida Dasgupta, Paul Ehrlich, Carl Folke, Patrick Gerland, Roger Gifford, Lawrence Goulder, Ben Groom, Andy Haines, Geoffrey Heal, Cameron Hepburn, Girol Karacaoglu, Phoebe Koundouri, Pushpam Kumar, Tim Lenton, Simon Levin, Justin Lin, Tim Littlewood, Jane Lubchenco, Georgina Mace, Robert Macfarlane, Shunsuke Managi, Eric Maskin, Henrietta Moore, Tid Morton, Ilan Noy, Gustav Paez, Charles Perrings, Stuart Pimm, Peter Raven, Martin Rees, Fiona Reynolds, Marten Scheffer, Ingmar Schumacher, V. Kerry Smith, Denise Spinney, Will Steffen, Nicholas Stern, Thomas Sterner, William Sutherland, Nicola Tagart, Alistair Ulph, Ruut Veenhoven, Jeff Vincent, Robert Watson, Gavin Wright, Anastasios Xepapadeas, Menahem Yaari, and Aart de Zeeuw.

I am especially grateful to HM Treasury for enabling Sandy Sheard to assemble an exceptionally gifted team who have helped me think through the economics of biodiversity. Drawn from across the public sector and based in HM Treasury, they have provided me with invaluable support over the course of the *Review*, including Mark Anderson, Heather Britton, Abbas Chaudri, Dana Cybuch, Rebecca Gray, Haroon Mohamoud, Robert Marks, Emily McKenzie, Diana Mortimer, Rebecca Nohl, Felix Nugee, Ant Parham, Victoria Robb, Sandy Sheard, Sehr Syed, Thomas Viegas, Ruth Waters, and Lucy Watkinson. They have gathered evidence from a wide range of experts from around the world, arranged for me to meet many of them, supported my Advisory Panel, prepared a wealth of case studies, edited the *Review*, and made vital contributions to drafting elements of the *Review* itself. Even more, they queried every intellectual move I made; to a professor, there can be no greater reward.

Above all, I am grateful to Carol Dasgupta, on whom I have tested pretty much every idea in the *Review*. Her suggestions on what to emphasise and what is superficial have been invaluable. The present monograph reflects the impact of her comments and those of Paul Ehrlich.

The influence of Amiya Dasgupta, Kenneth Arrow, Paul Ehrlich, Peter Raven, John Rawls, and Robert Solow on the way I frame economics has become increasingly evident to me.

Partha Dasgupta
St John's College, Cambridge

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Part I
The State We Are In and Why

1 Managing Our Assets

We are all asset managers. Whether as farmers or fishers, foresters or miners, households or businesses, governments or communities, we manage the assets to which we have access, in line with our motivations as best as we can. But the best each of us is able to achieve with our portfolios may nevertheless result in a massive collective failure to manage the global portfolio of all our assets. The analogy of each person in a crowd trying to keep balance on a hanging bridge and bringing it crashing down speaks to that possibility. The *Review* has been prompted by a growing body of evidence that in recent decades humanity has been degrading our most precious asset, the natural environment, at rates far greater than ever before. Simultaneously, the material standard of living of the average person in the world is far higher today than it has ever been; indeed, we have never had it so good.[9] In the process of getting to where we are, though, we have degraded the biosphere to the point where the demands we make of its goods and services far exceed its ability to meet them on a sustainable basis. That suggests we have been living at both the best and worst of times.

It is a commonplace assertion that economic development should be so directed that it is sustainable (Box 1). But the idea of sustainable development cannot be applied unless we have an understanding of what a sustainable dependence on Nature requires of us.[10] Here we study the natural world in relation to the many other assets we hold in our portfolios, such as the vehicles we use for transport, the homes in which we live, and the machines and equipment that furnish our offices and factories. But like education and health, Nature is more than a mere economic good. Nature nurtures and nourishes us, so we will think of assets as durable entities that not only have use value, but may also have intrinsic worth. Once we make that extension, the economics of biodiversity becomes a study in portfolio management.

To be sure, not every object of Nature has a positive value for us. Pathogens and pests damage not only our health and that of our crops and animals, they also destroy pristine forests and fisheries, so we try to suppress them when they arise. That their emergence is an immanent feature of Nature's processes does not alter our attitude to them, for we too are an emergent feature of those processes. We will confirm that environmental degradation is making their appearance in the human economy more frequent. COVID-19 is only the most recent arrival.

Pollution is a by-product and waste product of our activities – they too have negative value. Conservation of mass means that the waste we create has to be deposited somewhere. The discharge contributes to the degradation of the natural environment. Acid rains damage forests; carbon emissions into the atmosphere trap heat; industrial seepage and discharge reduce water quality in streams and underground reservoirs; sulphur emissions corrode structures and harm human health; and so on. The damage inflicted on each type of asset (buildings, forests, the atmosphere, fisheries, human health) should be interpreted as depreciation of that asset. Pollution is the reverse of conservation.

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[9] Recent books noting humanity's achievements include Micklethwait and Wooldridge (2000), Ridley (2010), Lomborg (2013), Norberg (2016), and Pinker (2018). Time series of subjective measures of well-being, such as happiness and life satisfaction, however, tell a different story (*Review*, Chapter 11).

[10] We use the terms Nature, natural world, natural environment, biosphere, and natural capital, interchangeably.

The *Review* demonstrates that in order to judge whether the path of economic development we choose to follow is sustainable, nations need to adopt a system of economic accounts that records an inclusive measure of their *wealth*. The contemporary practice of using gross domestic product (GDP) to judge economic performance is based on a faulty application of economics. GDP is a *flow* (so many market dollars of output per year), in contrast to *inclusive wealth*, which is a *stock* (the social worth of the economy's entire portfolio of assets). Relatedly, GDP does not include the depreciation of assets, for example the degradation of the natural environment (we should remember that 'G' in GDP stands for *gross* output of final goods and services, not output net of depreciation of assets). As a measure of economic activity, GDP is indispensable in short-run macroeconomic analysis and management, but it is wholly unsuitable for appraising investment projects and identifying sustainable development. Nor was GDP intended by the economists who fashioned it to be used for those two purposes. An economy could record a high rate of growth of GDP by depreciating its assets, but one would not know that from national statistics.[11] Below we show that in recent decades eroding natural assets has been exactly the means the world economy has deployed for enjoying what is routinely celebrated as 'economic growth', and that *sustainable* economic growth requires a different measure than GDP.

Depending on our circumstances, the portfolios of assets we manage differ widely. More than 50% of the world's population today are urban, and the figure is projected to rise to 70% by 2050. Urban living creates a distance between us and the natural world. Rural communities in low income countries are much closer to Nature than urban households in high income countries. Daily activities in rural Africa require goods and services extracted from the local landscape, in contrast to the daily lives in urban Europe, where people depend equally on, and extract more from, Nature but do so at several steps removed, often depending on natural resources from distant parts of the world. Many households in villages in Niger, in contrast to households in towns in Germany, do not have water on tap to drink, wash, or cook; nor do they have access to electricity. And their landscape is degrading through unsustainable use. One measure of resource degradation facing rural communities in low income regions is the increased time needed for household production. But exit toward a similar landscape is not always an option, for neighbouring villages also face increasing resource scarcity and out of necessity are not welcoming. Which is how crowding in the shanty towns of sprawling cities has become such a familiar sight.

In contrast, degradation of Nature in distant lands has little-to-no bite on the lives of people in high income countries; there are alternative sources of supply from other parts of the world, at least for now. Pendrill et al. (2019) for example have estimated that about one-sixth of the carbon footprint of the average diet in the European Union can be linked directly to deforestation in tropical countries.

The *Review* develops the idea of sustainable development by constructing a grammar for understanding our engagements with Nature – what we take from it, how we transform what we take from it and return to it, why and how in recent decades we have disrupted Nature's processes to the detriment of our own and our descendants' lives, and what we can do to change direction.

As this is a global Review, we often speak of the demands that humanity makes on Nature. But much of the time the *Review* looks closely at smaller scales and local engagement with Nature. Differences in the way communities are able to live tell us that people do not experience increasing resource scarcity in the same way. Food, potable water, clothing, a roof over one's head, clean air, a sense of belonging, participating with others in one's community, and a reason for hope are no doubt universal needs, but the emphases people place on the goods

[11] The United Nations' Human Development Index (UNDP, 1990) suffers from the same weakness.

and services Nature supplies differ widely. To farmers in South Asia and sub-Saharan Africa, it could be declining sources of water and increasing variability in rainfall in the foreground of global climate change; to indigenous populations in Amazonia it may be eviction not just from their home, but from their spiritual home; to inhabitants of shanty towns everywhere the worry could be the infections they are subjected to from open sewers; to the suburban household in the UK it may be the absence of bees and butterflies in the garden; to residents of mega-cities it could be the poisonous air they breathe; to the multi-national company it could be the worry about supply chains, as disruptions to the biosphere makes old sources of primary products unreliable and investments generally more risky; to governments in many places it may be the call by citizens, even children, to stem global climate change; and to people everywhere it would be to experience the consequences in myriad different situations to such forms of environmental problems as the COVID-19 pandemic. Degradation of Nature is not experienced in the same way by everyone.

Box 1

Sustainable Development Goals and the Idea of Sustainable Development

In September 2015, the United Nations General Assembly agreed on an agenda for sustainable development in member countries. Nations committed themselves to meeting 17 Sustainable Development Goals (SDGs) by 2030 (Figure 1). Reasonably, the quantitative targets to be met do not distinguish societal ends from the means to achieve them. Thus, in the chart below Goals 1-6 should be taken to be ends, whereas Goals 7, 9 and 17 are means to ends, and Goal 8 reflects both ends and means. The SDGs involve 169 socio-economic targets. To measure progress in meeting those targets, it was proposed to track more than 240 socio-economic indicators over the coming years (United Nations, 2015).

Figure 1 17 Sustainable Development Goals Adopted by All United Nations Member States in 2015

Source: United Nations (2015).

International agreement on the SDGs was a remarkable, even noble, achievement, for the Goals unpick features of lives that would enable us to live well. But there is a problem. The

Goals are not accompanied by an examination of whether, assuming they are achieved, they are sustainable. The Brundtland Commission (1987) defined sustainable development as "... development that meets the needs of the present without compromising the ability of future generations to meet their own needs". One should interpret it as a requirement that relative to their respective demographics, each generation should leave to its successor at least as large a productive base as it had inherited from its predecessor. For if it were to do so, economic possibilities facing the successor would be no less than those the generation faced when inheriting the productive base from its predecessor.

The *Review* shows that an economy's productive base is an inclusive measure of its wealth (here, we sketch the idea in Section 17). The Brundtland Commission's proposal could then be re-worded to say that development is sustainable if inclusive wealth increases. The founding text of the discipline of economics was titled 'The Wealth of Nations', not 'The GDP of Nations'. The notion of wealth the *Review* formulates is a lot more comprehensive than the one Adam Smith was able to articulate in his day, but his focus on assets was exactly right.

2 Biodiversity and Ecosystem Services

Biological diversity, or *biodiversity* for short, means the diversity of life in all its forms. It is not uncommon though to regard biodiversity to be the number of species of organisms that inhabit Earth. Today there are 8-20 million species of organisms, maybe more, with cells containing a distinct nucleus that houses genetic material in the form of chromosomes (such organisms are called eukaryotes). Only about 2 million eukaryotes have been recognised and named so far. There are in addition unknown and much larger numbers of archaea and bacteria, which do not have a cell nucleus (they are called prokaryotes). Our lack of knowledge, including whether viruses should be thought of as living organisms, is enormous.[12]

But biodiversity has further dimensions, including the genes these organisms contain and, as we will see presently, the functional characteristics of the ecosystems in which they live. The chemical reactions of Earth's plants, algae and many bacteria sustain life by converting sunlight and nutrients into food, useable energy, and the building blocks of life, as well as recycling waste. Those photosynthesising organisms are called *primary producers*. Their activities are often both silent and hidden from view, but they enable ecosystems to function and provide a multitude of services on which we rely. Which is why the economics of biodiversity is the economics of the biosphere.

The *biosphere*, which is the part of Earth occupied by living organisms, is a regenerative entity. Its rhythms such as those responding to the seasons, shape the regeneration patterns of the living world. Living systems in turn make use of the non-living, or abiotic, material in the biosphere and transform them; water, carbon, and nitrogen cycles are expressions of that. Because the ability to regenerate is a characteristic of living systems, regeneration of the biosphere is key to the sustainability of the human enterprise.

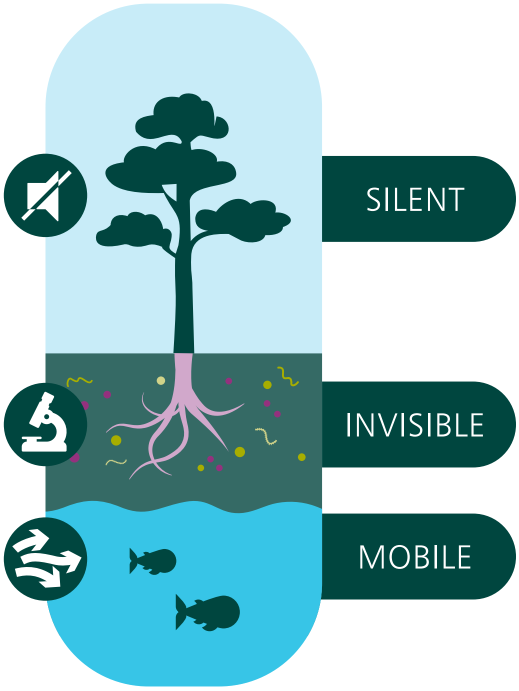
Movement is a pervasive feature of the biosphere. The wind blows, rivers flow, birds and insects fly, the oceans circulate, even continents are known to travel. The Antarctic ice sheet is weakened by activity everywhere; phosphorus-rich runoff from farms in north-central US contribute to transforming the estuary of the Mississippi River into a dead zone; fertilisers, and pesticides pollute the rivers and ground waters of the Indo-Gangetic Plain; emissions of soot

[12] Hubbell (2015), for example, notes that a recent estimate that there are between 40,000 and 53,000 tree species in the tropics is based on a very small sample of forest patches. Peter Raven has emphasised to us in correspondence the enormous uncertainty in our knowledge of the number of species, let alone tree species in the tropics. Moreover, the distribution of species numbers has a thick tail: a very large proportion of species are of small population size. Pimm and Raven (2019) contains a summary of what we know.

from kitchens in the Indian sub-continent affect the circulation patterns of the monsoons; fish in the North Sea eat micro-plastic originating in markets in the Bahamas; and so on.[13]

Less visible are the changes that take place when a plant dies and is converted into soil by the actions of organisms that also live and die. Mostly, these transformative processes are invisible to the naked eye. We do not see the bacterial mass residing beneath our feet, without which life as we know it would not exist. The activities they are engaged in are undertaken in silence to the human ear. These three features of Nature – *mobility*, *invisibility* and *silence* – are of profound significance to the economics of biodiversity (Box 2).

Figure 2 Nature's Properties



Ecosystems are constituents of the biosphere. They combine the abiotic environment with communities of plants, animals, fungi, and microorganisms to form combinations of life forms that control the multitude of natural processes shaping the world around us. Ecosystems are not defined in a sharp manner from rigid principles. Watersheds, wetlands, coral reefs, and mangrove forests are ecosystems, as are agricultural land, inland fisheries, freshwater lakes, rainforests, coastal fisheries, estuaries and the oceans.

Ecosystems are not tightly knit entities – they blend into one another. The Okavango River comes down from the hills of Angola, waters grasslands in northern Zimbabwe, and as the river loses its energy, grass gives way to shrubs and, even as the Okavango sinks into the ground, shrubs give way to the pebbly desert of the Kalahari. But there are ecosystems that have strong interactions among their own constituents and weak interactions across their boundaries, as in the visible breaks between the oases and deserts of Egypt. The boundaries may separate sharp differences in material composition, distribution of organisms, soil types, depth of a body of water, and so on.

Ecosystems differ in their spatial reach (the Amazon rainforest is an ecosystem, as is the collection of micro-organisms occupying the gut of a dolphin swimming in its rivers) and rhythmic time (minutes for bacterial colonies, decades for boreal forests). Some ecosystems cover regions (the Ganga-Brahmaputra river basin); many are volcanic islands (Micronesia);

[13] A new species of crustacean, discovered deep in the Marina Trench in 2014, has been appropriately named *Eurythenes plasticus* for the contents of its stomach (reported in *The New Yorker*, 18 May 2020, p. 15).

others involve clusters of towns (micro-watersheds in the Ethiopian highlands); yet others are confined to a village (village ponds in Barisal, Bangladesh).[14]

Each of us is an element in many ecosystems. We each contain microbial ecosystems. The biosphere is the largest ecosystem of which we are an element – it is our home. Being embedded within it, we are entirely dependent on it, not just for survival but for our well-being too. Nature's goods and services are the foundations of our economies. They include the *provisioning services* that supply the goods we harvest and extract (food, water, fibres, timber, medicines) and *cultural services*, such as the gardens, parks and coastlines we visit for pleasure, even emotional sustenance and recuperation. But Nature's processes also maintain a genetic library, preserve and regenerate soil, control floods, filter pollutants, assimilate waste, pollinate crops, maintain the hydrological cycle, regulate climate, and fulfil many other functions besides. Without those *regulating* and *maintenance services*, life as we know it would not be possible.[15]

Depreciation is the decline in the quantity or quality of an asset over time. In the case of ecosystems, depreciation is the difference between the rate at which it is harvested and its regenerative rate. If human extraction of an ecosystem's provisioning services exceeds its regenerative rate, the ecosystem depreciates. Depreciation caused by pollutants is the difference between the rate at which pollutants are discharged into the biosphere and the rate at which the biosphere is able to degrade them for assimilation in the land and waters. Sustainability of our engagement with Nature is thus ultimately about the functions of the biosphere, not just the living part of it.

Biodiversity is a *characteristic* of ecosystems. It enables ecosystems to flourish and supply the wide variety of services we have just alluded to. Drawing an analogy with human society, we could say biodiversity in an ecosystem resembles the extent to which people trust one another. A further analogy would be the diversity of human talents in an economy needed for it to thrive. From a financial perspective, just as diversity within a portfolio of financial assets reduces risk and uncertainty, so biodiversity increases Nature's resilience to shocks, and thereby reduces risks to the ecosystem services on which we rely. And drawing on an analogy with indivisible objects such as automobiles, biodiversity provides ecosystems with spare parts; it enables ecosystems to be resilient, to be able to adapt to changing circumstances and to be productive. Reduce biodiversity, and the health of ecosystems generally suffers.[16]

There is, however, a significant caveat to this idea of productivity. Modern agriculture enables us to produce food at rates per hectare unthinkable in the past. But it does so at the cost of biodiversity. Croplands as far as the eye can see are productive, but they are productive in mono crops and do not even house crop genetic diversity, let alone diversity of species and ecosystems. Land given over to ranching and animal grazing is productive too, but it is productive in terms of sheep and cattle. Plantations of oil palm and soya are also productive, but they are poor in biodiversity. The fields we see today replaced ecosystems that were once in varying degrees diverse in species – grasslands, wetlands, woodlands, tropical rainforests, swamps. Moreover, agricultural practices themselves cause biodiversity to be lost, both on and off site. Industrial fertilisers, insecticides and pesticides destroy soil biodiversity and cause even far-away estuaries to become dead zones. Tilling and ploughing destroy life in the soils (Box 2).[17] The underlying idea in modern agriculture is the substitution of one production input (industrial

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[14] Levin (1999) is a deep meditation on the processes that shape the evolving spatial characteristics of the biosphere. The author explains the significance for life of Nature's modular structure.

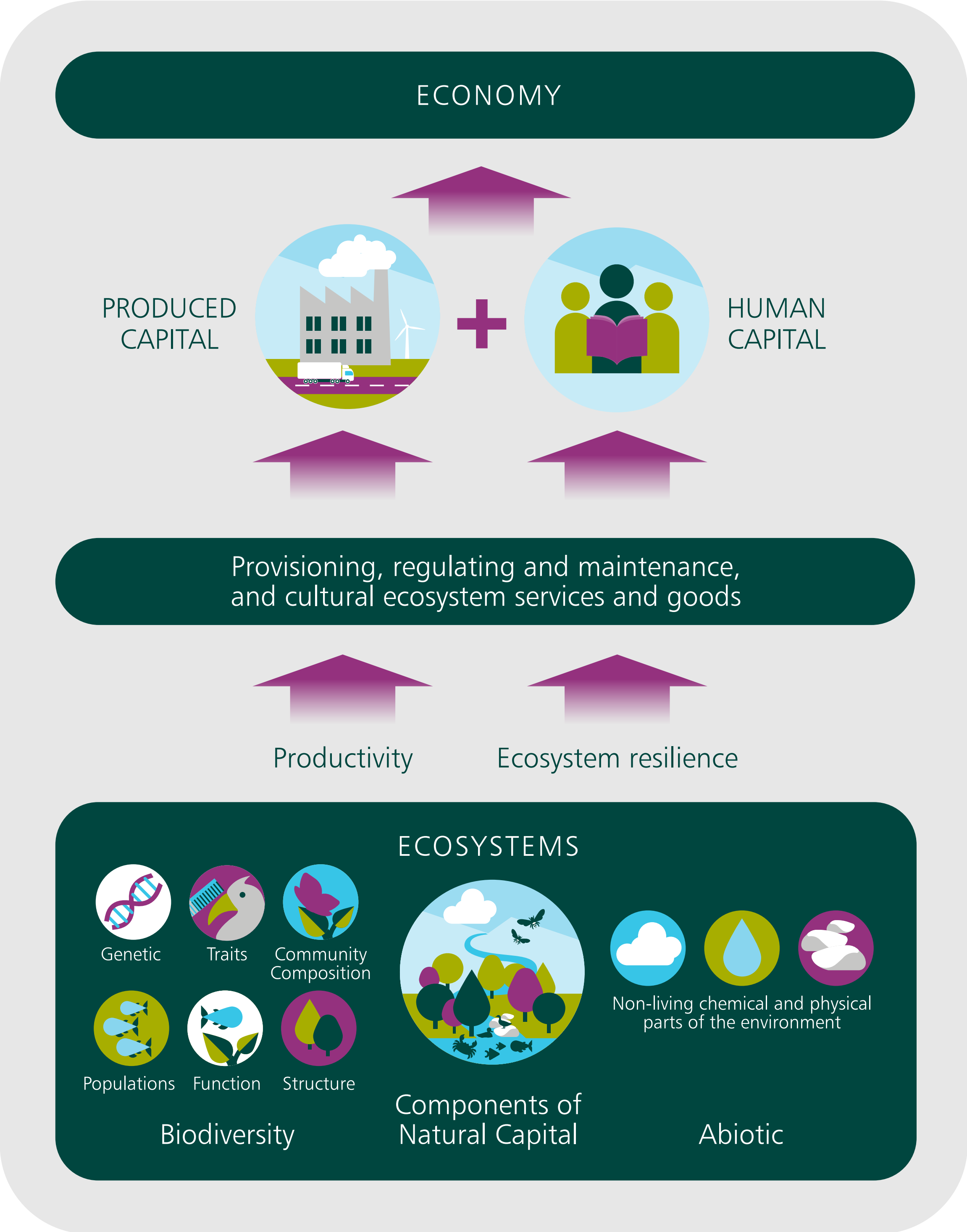
[15] The classification of ecosystem services into provisioning, cultural, and regulating and maintenance services follows the Common International Classification of Ecosystem Services (CICES), which is an adaptation of the classification constructed by the pioneering Millennium Ecosystem Assessment (MA, 2005 a-d).

[16] The scientific literature on this is huge. The interested reader should consult the *Review* (Chapter 2), which reports findings on the role of biodiversity in ecosystem functions.

[17] We are indebted for discussions with organic farmer Tid Morton of Norfolk, UK, on what ploughing does to the soils.

fertilisers) for another (soil nutrients). Our demand for food, water, timber, fibre, minerals, and the dams that are built to supply water and produce electricity visibly destroy biodiversity. By tearing the landscape apart, mining and quarrying are also significant factors in biodiversity loss. Substitution of produced capital (roads, buildings ports, machines) for natural capital (ecosystems) has not only characterised our investment activities but also shaped our conception of economic progress.

Figure 3 Links From Biodiversity to the Economy



Box 2
The Soils

The soils, called the pedosphere by ecologists, appear far less in public discourses on biodiversity than terrestrial and marine ecosystems. Beach, Luzzadder-Beach, and Dunning (2019) call the soils, "dark matter biodiversity". The soils are approximately half air and water, 45% minerals and 5% organic matter. Of that 5%, only 10% is life, but that 10% contains some of the greatest biodiversity in the biosphere. By one estimate, the soils contain nearly 80% of terrestrial carbon, with an inevitable accompanying estimate that up to 25% of our uncertainty in the flux of global carbon is traceable to soil erosion.

Soil organisms include earthworms, nematodes, arthropods, protozoa, fungi and bacteria, but by far the most abundant are fungi and bacteria. These organisms form food webs which drive soil ecosystem processes, including nutrient cycling, carbon sequestration, nitrogen storage and water purification, and are important components of global cycling of matter, energy and nutrients. Advances in molecular genetics have revealed the enormous diversity of fungi and bacteria associated with plant roots. They play diverse roles, for example, in promoting plant growth through enhancing plant nutrition and protecting plants from herbivores and pathogens (Orgiazzi et al. 2016). By one set of estimates, more than 25% of the Earth's species live only in the soil or soil litter.

The 2016 Global Soil Biodiversity Atlas was the first attempt to map life in soil at a global scale (Figure 4). Biodiversity in soil is highest in tropical rainforests and lowest in deserts. Soil has historically been the world's largest carbon sink. However, recent studies have suggested that soil could shift to become a net emitter of carbon, due to climate-change driven increases in respiration by organisms that derive their nutrition from plants and animal matter (Lugato, Leip, and Jones, 2018).

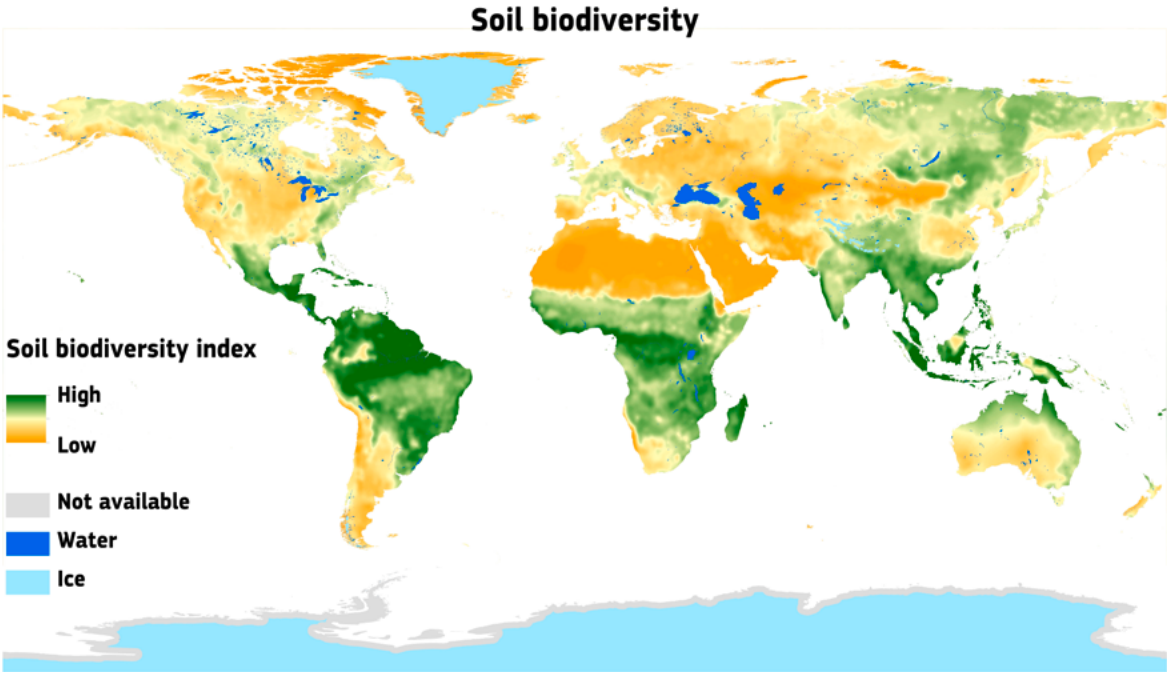
The soils also supply most of the water needed by plants and for terrestrial biodiversity. Soil water makes up 65% of the world's fresh water, is the source of 90% of global farm output, and provides over 99% of our food calories (Pimental and Burgess, 2013). The dynamics in the soils start from plants, which shed leaf litter on soil surface and the narrow band of soil that is influenced by root secretion and soil microorganisms. The enormous network of fungi that connect tiny roots ('rootlets') to a wider array of soil nutrients and water help to fix nitrogen (a regulating service). Nitrogen is a macronutrient, vital in the food chain.

The soils are also a major reservoir for medicines (a provisioning service). Pepper et al. (2009) have reported that over 75% of antibacterial agents and 60% of new cancer drugs approved between 1983 and 1994 had their origins in the soils, as did 60% of all newly approved drugs between 1989 and 1995.

When threats to soil biodiversity are mapped, areas at high-risk often correspond with areas of highest soil biodiversity (Figure 4). A risk index was constructed by combining eight factors that place soil health under risk: loss of above-ground diversity; pollution and nutrient overloading; over-grazing; intensive agriculture; fire; soil erosion; desertification; and climate change (Orgiazzi et al. 2016).

If soil biodiversity were completely lost, the land-based food system would cease to function. Wagg et al. (2014) found a strong linear relationship between all measured ecosystem functions and indicators of soil biodiversity. Reductions in soil biodiversity contribute to several environmental problems, such as an excessive nutrient load (i.e. eutrophication) of freshwater bodies, reduced above-ground biodiversity and global warming. Declines in soil biodiversity cause declines in performance of essential processes.

Figure 4 Soil Biodiversity Index



Source: Orgiazzi et al. (2016).

The Millennium Ecosystem Assessment (MA, 2005a-d) found that 15 of the 24 ecosystem services that were assessed were in decline. The recent global assessment by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES, 2019) reported a decline in 14 of 18 categories of Nature's goods and services since 1970. Both global reviews found our extraction and harvest of provisioning services has increased, while the supply of regulating and maintenance services has declined. A corresponding decline in cultural services has also been recorded by the assessments.

There is thus a tension between our demand for provisioning services on the one hand and our need for regulating, maintenance, and cultural services on the other. The distinction between *drawing on* Nature and *depending on* Nature is all-important here. Tensions between the two became manifest in recent centuries, but at the global scale it did so only gradually. As we confirm below, it has become acute since the middle of the 20th century. The biosphere's regulating and maintenance services are the underpinnings of human societies, which is why increases in the material standard of living will come to naught if those underpinnings are broken irreparably.

3 Nature's Complexities

Ecosystems are self-regulating, but only within bounds. The biosphere provides regulating and maintenance services as *joint products* and ecosystem processes are *complementary* to one another. Disturb a process sufficiently and the other processes are affected, adversely. Lovejoy and Nobre (2018), for example, have observed that the Amazon rainforest generates half of its rainfall by recycling moisture 5 to 6 times as air masses move from the Atlantic across the basin to the West. The authors have estimated that at 20-30% further deforestation, central, southern and eastern Amazon would experience diminished rainfall and lengthier dry seasons, and that this would tip the rainforest into savannah vegetation. That shift can be expected to affect wind patterns, altering farming conditions as far away as central USA.

Such a chain of events, resulting in an ecosystem tipping over from one broad mode of behaviour into another very different mode, can start with fragmentation. Studies have found that habitat fragmentation reduces biodiversity by impairing important ecosystem functions and altering nutrient cycles. Striking examples arise when river systems are fragmented with dams: fragmentation destroys the life cycles of fish species (Box 3). In a long-standing research programme in the Amazon rainforest, Laurance et al. (2002), Laurance et al. (2011) and Lovejoy and Hannah (2019) have observed that fragmentation caused by networks of roads affect forest microclimates, tree mortality, carbon storage, and fauna. The intensity of what the authors call 'edge effects' is influenced by such factors as the ages of an ecosystem's edges (or boundaries) and the number of nearby edges. One way to read this is to say that *the productivity of an ecosystem is greater than the sum of the productivities of its broken parts*. Mathematicians say ecosystem processes are *non-linear*.

Fragmentation exposes species to harsh environmental conditions, including fires, diseases, and invasive species. That amounts to a reduction in an ecosystem's ability to withstand disturbances without breaking down – it becomes less resilient. Decline in resilience would accompany a loss in biodiversity, so there is mutual causation at work. Paleo-biologists have found fragmentation of natural habitats to be a good early-warning sign of biodiversity loss and ecosystem collapse. Chance events that would previously have been absorbed by the ecosystem that has lost its resilience can trigger a sudden, dramatic change and loss of its integrity.[18]

Shallow bodies of water such as garden ponds offer a good illustration of synergies among Nature's processes. A major reason ponds tip from a crystalline state to a eutrophic state is the inflow of phosphorus from fertilisers applied to lawns. If the rate of inflow is small enough, ponds remain crystalline, but not otherwise. Freshwater lakes suffer from a similar fate when phosphorus seeps into them from farms. Accumulation of small pressures (regular runoff into a lake) can tip a lake into a eutrophic state.[19]

The time involved in such dramatic shifts (they are called 'regime shifts' by ecologists) differs enormously, depending on the character (e.g. size) of the ecosystem. It could take decades for a rainforest to tip over into a savannah, whereas grasslands have been known to tip into shrub in years; and garden ponds have been known to tip into a eutrophic state in a matter of hours (Figure 5). Reversing direction is costly because an ecosystem's history is imprinted in its current state: ecosystems have memory.[20] One can help to bring an ecosystem back to a state *near* to where it had previously been, but only at a cost. The phenomenon is known as 'hysteresis'. Examples abound: eutrophic ponds can only be brought back to a crystalline state at a cost; a rainforest that has become savannah cannot be brought back – the move is to all intents and purposes irreversible. Thus, *restoration is costlier than conservation*, other things equal.[21] The institutions, physical infrastructure, and social practices we have fashioned since establishing agriculture some 11,000 years ago also display hysteresis. They have been shaped under broadly speaking stable biospheric conditions. Abrupt changes to settled conditions are costly because the investments we had made in the past are hard to reverse. In the world of finance, this phenomenon is commonly known as 'stranded assets', such as investments in structures for oil and gas extraction which become obsolete in the transition to renewable and low-carbon energy.

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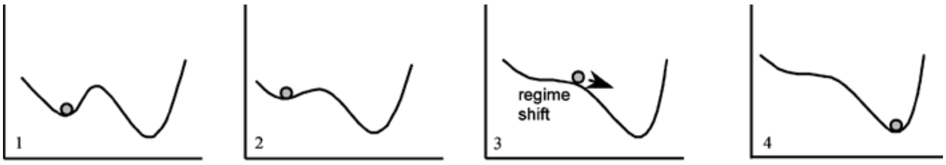
[18] It is now becoming widely acknowledged that fragmentation of ecosystems is associated with the spread of zoonotic viruses, that is, viruses that cross from animals to humans. Tropical rainforests have great biodiversity. Deforestation creates fragments. Often the viruses come from edges of fragments, which is where humans first encounter the forest animals. It is thought that COVID-19 crossed from bats to humans through an intermediary animal. Daily and Ehrlich (1996) is an excellent early study of the connection between biodiversity loss and the frequency and intensity of pandemics.

[19] See Carpenter, Ludwig, and Brock (1999). A body of water that is so rich in nutrients and animals that algae grow and are degraded by bacteria to the point where oxygen is severely depleted is said to be in a eutrophic state.

[20] A rough analogy would be our inability to forget consciously what we have learnt, making it impossible to return to a previous state of mind.

[21] Being ecosystems ourselves, we also harbour multiple stability regimes. The old adage about human health that 'prevention is better than the cure' is based on that same feature.

Figure 5 Multiple Stability Regimes



clear-water lakes	phosphorous accumulation in agricultural soil and lake mud	flooding, warming, overexploitation of predators	turbid-water lakes
coral-dominated reefs	overfishing, coastal eutrophication	disease, bleaching hurricane	algae-dominated reefs
grassland	fire prevention	good rains, continuous heavy grazing	shrub-bushland
grassland	hunting of herbivores	disease	woodland
kelp forests	functional elimination of apex predators	thermal event, storm, disease,	sea urchin dominance
pine forest	microclimate and soil changes, loss of pine regeneration	decreased fire frequency, increased fire intensity	oak forest
seagrass beds	removal of grazers, lack of hurricanes, salinity moderation, spatial homogenization	thermal event	phytoplankton blooms
tropical lake with submerged vegetation	nutrient accumulation during dry spells	nutrient release with water table rise	floating-plant dominance

Source: Folke et al. (2004). *Permission to reproduce from Annual Reviews, Inc.*

Box 3
Damming Rivers

Fragmentation can prevent migratory populations from conforming to their behaviour over the life cycle. That translates into species extinction. Dams are a major contributor to freshwater biodiversity loss. The construction of high dams is favoured by national economic planners because they expand irrigation, supply energy and offer protection against floods. One problem is that they also disrupt the hydrology of freshwater ecosystems by fragmenting them.[22] Fragmentation obstructs migration routes, which are essential for spawning and feeding – it limits dispersal.

Freshwater habitats cover only 0.8% of Earth's surface, nevertheless one-third of described vertebrates, including approximately 40% of fish species, are found in them. Barbarossa et al. (2020) have constructed a connectivity index of river water by combining species occurrence ranges with the hydrology and location of dams. Fragmentation can then be read as reduction of the index. The authors report that the approximately 40,000 high dams that currently exist worldwide have altered 50% of the volume of river water, by either regulation of water flow or fragmentation, and that the pending construction of some 3,700 more high dams will raise the figure to over 90%.[23] Current measures of fragmentation are highest in

[22] There are other problems too, for example, that communities are displaced, often without consultation or compensation.

[23] High dams are defined as dams that are taller than 15 metres. The figure of 40,000 for the number of existing high dams worldwide is probably an underestimate, but it pays to work with conservative figures even when they correspond to massive disruptions.

the US, Europe, South Africa, India and China, but increases in fragmentation due to future dams are estimated by the authors to be especially high in the tropics, with declines in the connectivity index of some 20-40% in the Amazon, Niger, Congo and the Mekong Basin.

If high dams are environmentally damaging, they would appear to be uneconomic even if environmental concerns were set aside. Ansar et al. (2014) reported findings from a study of large hydropower dams for which they could find reliable data. The authors' sample of 245 projects initiated in the period 1934 to 2007 covered 65 countries. Construction costs on average were found to have been *double* the figures projected in their original feasibility studies, reducing the realised rates of return on most to below what are available from government bonds (4-5% annually). Smaller-scale dams, and fish ladders that allow fish to pass around dams, have been found to reduce risks to fisheries through fragmentation.

4 Classifying and Valuing Assets

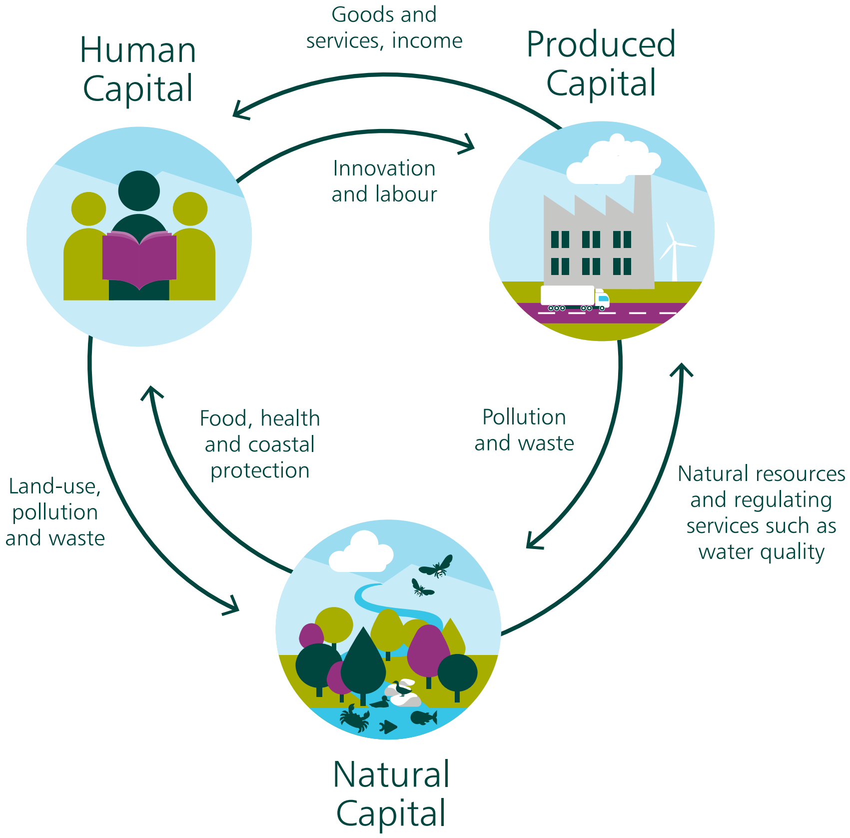
Assets are durable. Durability, of course, does not mean everlasting, but unlike services, assets are not fleeting. It is tempting to call all assets *capital goods*, a term that has proved to be so attractive that it now stretches to include knowledge ('knowledge capital'); the law, the market system, and financial institutions ('institutional capital'); mutual trust, social norms, and group solidarity ('social capital'); culture and personal norms ('cultural capital'); even religion ('religious capital'). Economists have been more reticent; they confine the use of the term to assets that are measurable.[24] In the past, economists reserved the term 'capital goods' even more stringently than they do now, for they only included assets that are material (tangible) and alienable (i.e. whose ownership is transferable). Roads, buildings, machines and ports are ready examples. As patents held by a firm are part of the firm's asset base, they appear in its balance sheet. So intangible and alienable assets are also included on the list of capital goods. Taken together, they are called *produced capital*.

The range of capital goods in the economist's lexicon has broadened over the years to include intangible but non-alienable assets such as health, education, aptitude and skills, which, taken together, form *human capital*. Economists today include human capital as a category of capital goods because they have discovered ways to measure its value – not only to the individuals who acquire it, but also to society at large.

In the past decades, economists have developed methods for measuring the value individuals place on natural resources; so we now have a third category of capital goods: *natural capital*. The methods can be involved, for natural capital ranges over plants (they are tangible and alienable), pollinators (they are tangible and often non-alienable), the view from one's sea-front home (it is intangible and alienable) and the global climate (it is intangible and non-alienable).

[24] See Arrow (2000) and Solow (2000) for strong criticisms of the increasing practice of regarding social capital as capital. This does not make social capital unimportant: it is a central feature of effective institutions, as we discuss below.

Figure 6 Interaction Between the Capitals



As the *Review* explores reasons for the growing disparity between private incentives and public aspirations, we pay particular attention to the wedge between market prices of capital goods, especially the market prices of natural capital, and what should be called their 'social worth', or alternatively, their 'social scarcity value'. Economists call them *accounting prices*. A capital good's accounting price is the contribution an additional unit of it would make to societal well-being (or more narrowly, the common good).[25] Being durable, capital goods offer their services over their lifetime. So the accounting price of a capital good reflects the contribution its flow of services over its lifetime makes to social well-being. Box 4 shows that absolute values of ecosystems (they are a form of natural capital) have no meaning; only comparisons of values tell us something.

Box 4
Absolute Values Are Meaningless

Absolute values of portfolios carry no information; only portfolio comparisons do. The value of a marginal change to the biosphere is meaningful because it is presumed that humanity will survive the change to experience it, but the matter is different when it comes to valuing Nature as a whole. It may be because growth and development economists ignored our place in the natural world, environmentalists some years ago were tempted to value the whole of Nature, to show that it is of great economic worth. In a widely cited publication in *Science*, the authors estimated that the global flow of the biosphere's services was, towards the end of the 20th century, worth US$16-54 trillion annually, with a point estimate of US$33 trillion (Costanza et al. 1997). As that figure was larger than global GDP in the mid-1990s, we were meant to appreciate the economic significance of natural capital.

[25] Accounting prices are also called 'shadow' prices.

The estimate is a case of misplaced quantification. As the authors recognise, if Nature is destroyed, life would cease to exist. But then who would then be here to receive US$33 trillion of annual benefits if humanity were to exchange its very existence for them? Economics, when used with care, is meant to serve our ethical values. The language it provides helps us to choose in accordance with those values. Despite recognising this, the authors of the paper imply that the biosphere is valuable *because* it can be imputed a large monetary value. That is to get things backward.[26]

Measurement problems are also rife in estimating the *stock* of many kinds of natural capital (fisheries stocks in their national waters are generally not recorded by governments), but it is far better to work with rough and ready figures than to ignore whole swathes of capital goods by pretending they do not exist. Unfortunately, the macroeconomic theories of growth and development that have shaped our beliefs about economic possibilities and the progress and regress of nations do not recognise humanity's dependence on Nature. The *Review* corrects that mistake.[27]

Accounting prices reflect an accommodation between economic futures that are both socially desirable and socio-ecologically possible, which means they reflect social scarcity values of capital goods. There are cases where market prices approximate accounting prices, but for reasons we explore below (Section 7), many forms of natural capital simply do not have markets – they are free to the user. So special methods have to be devised. There is now a wide range of methods for doing that, from asking people to state their willingness to pay for restoring a degraded beach (that is, estimating an 'amenity value' of Nature), to asking them to declare the value they attach to protecting the migratory route of snow geese (that is, estimating what people may regard as an 'intrinsic value' of Nature), to inferring the value of an ecosystem service from the contributions they make to the production of goods and services whose social scarcity values can be estimated (that is, estimating the 'use value' of Nature's services), such as the contribution of forests as habitat for pollinators that support crop production.

Valuation methods that involve estimating the use value of Nature by determining the productivity of its processes involve a blend of ecological and economic reasoning: The accounting value of a lake fishery can be approximated by the market value of catch over time; the social costs of air- or water-borne pollution can be estimated at least in part by measuring the losses to human health attributable to it; the minimum value of restoring a watershed can be inferred from the cost of building a water treatment plant; and so on.[28]

To date, estimates of accounting values of natural capital have, for the most part, not included the health benefits green spaces that ecosystems confer on us. They have remained even further from including the mental health benefits we derive from green spaces. However, the importance of including health benefits in natural capital accounts is increasingly recognised, and there are an emerging number of studies attempting to elicit values (White et al. 2016). Humans cannot survive without the rich biodiversity of microbiota that exist on our skin and in our guts, urogenital tracts and airways. They influence our susceptibility to disease and play an important role in our health under changing environmental conditions. We are ecosystems ourselves, with exchanges taking place constantly between bacteria, viruses, fungi, archaea, and protozoa in the natural environment and those in our bodies. We need contact with sources of

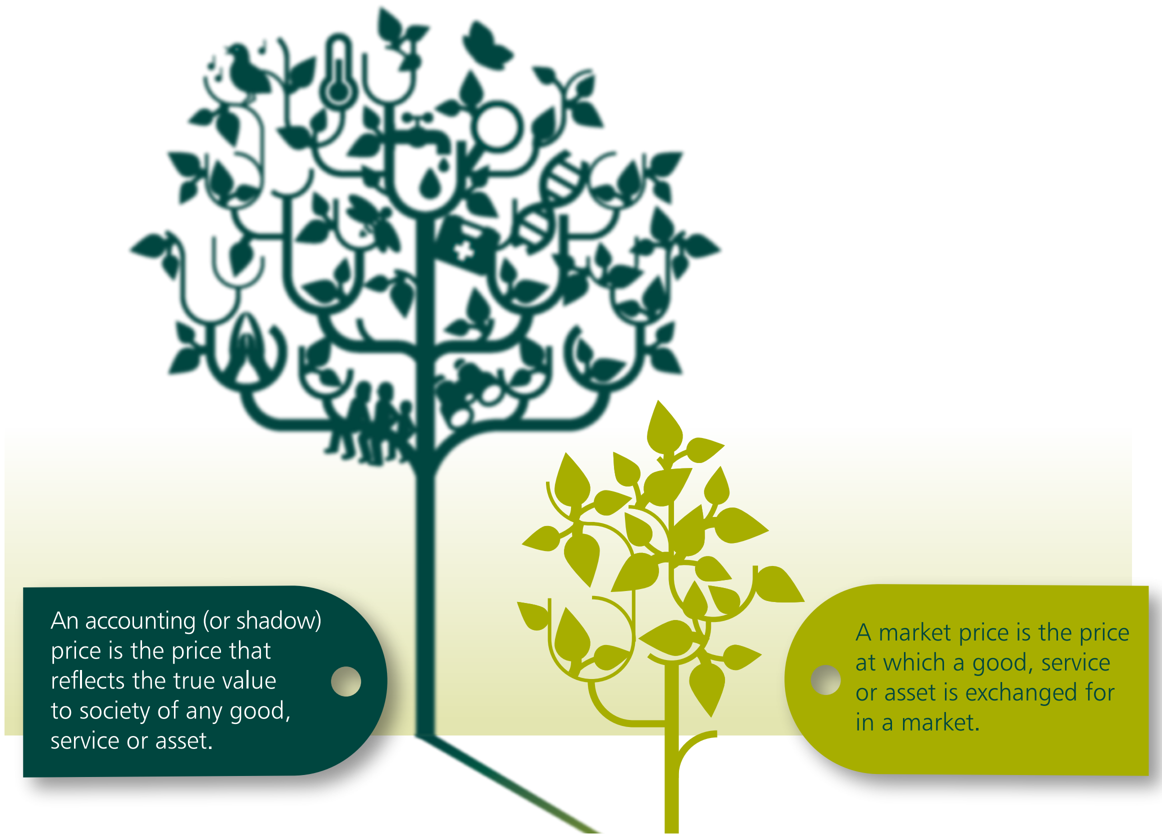
[26] Formally we have a case where the value of an entire something has no meaning, and is therefore of no use, even though the value of changes to that same thing – expressed as differences – not only has meaning, but also has use.

[27] The absence of Nature is also prominent in the economic growth and development models that inform economics and finance ministries and central banks.

[28] Excellent accounts can be found in the treatise by Freeman (2003) and the collection of essays in Haque, Murty and Shyamsundar (2011). Kareiva et al. (2011) and Vincent (2011) contain clear accounts of valuation methods that estimate the productivity of natural capital in providing ecosystem services.

diverse microbiota. Loss of biodiversity can and does have an impact on our health (e.g. weaker resistance to disease). Studies suggest that macro-biodiversity (e.g. plants and trees) in urban environments is associated with microbe diversity and in turn with a healthy human microbiome, known to be linked to a wide range of health outcomes (*Review*, Chapter 11). There is evidence too that repeated contact with Nature contributes not only to long term hedonic well-being (happiness, pleasure), but to life satisfaction as well. A series of large-scale European studies based on data from national surveys has found that living in an area with more green space is associated with less mental distress than otherwise. A longitudinal study covering over 10,000 UK residents found that living in greener urban space was associated with greater life satisfaction (White et al. 2013)[29].

Figure 7 Market Prices and Accounting (or Shadow) Prices



What about knowledge, institutions and social capital – are they not assets as well? They are, but as with biodiversity, measurement problems abound (try, for example, to compare the value to a nation of 'good governance' with the real estate value of its capital city). So we call them *enabling assets*, their worth is reflected in accounting prices. Enabling assets bestow value to an economy's capital goods. Even if the composition of capital goods is the same in two societies, the one where people trust one another with reason would be found to be wealthier than the one where people are distrustful of one another. Mutual trust is an enabling asset: other things equal, the accounting price of, say, scientific journals in a country at peace would be higher than in a country torn by civil strife. Likewise, other things equal, a more biodiverse ecosystem is more productive in terms of the regulating and maintenance services it supplies. So biodiversity is also an enabling asset.

The relationship runs the other way also. Knowledge in the sciences, technologies, and the arts and humanities (they are all enabling assets) is created and acquired, but it is created and

[29] See *Review* (Chapter 11), for the distinction between measures of hedonic well-being and life satisfaction.

acquired by people (human capital) in combination with produced capital (libraries, laboratories) and natural capital (raw materials and ecosystem services). Institutions are also created by people, as is mutual trust, which is the glue that holds communities together. Financial capital facilitates exchange (among people and across time), so it too is an enabling asset.

There are therefore three categories of capital goods in our classification and a wide range of enabling assets. Enabling assets may not be measurable, but that does not matter: they enable human societies to function well, and that *can* be measured. Accounting prices reflect that worth.

5 The Global Economy in the Anthropocene

World population in 1950 was around 2.5 billion and global output of final goods and services (i.e. global GDP) at 2011 prices was around 9 trillion international dollars (i.e. dollars at purchasing price parity, PPP).[30] The average person's annual income was around 3,300 dollars PPP, a high figure by historical standards. Since then the world has prospered beyond recognition. Life expectancy at birth in 1950 was 46; today it is around 73. The proportion of the world's population living in absolute poverty (currently 1.90 dollars per day) has fallen from nearly 60% in 1950 to less than 10% today (World Bank, 2019).[31] In 2019, the global population had grown to over 7.7 billion even while global GDP per capita had risen to around 16,000 dollars PPP (at 2011 prices). The world's output of final goods and services was a bit above 120 trillion dollars PPP (at 2011 prices), meaning that globally measured economic activity had increased more than 13-fold in only 70 years, a rate of increase that had never remotely been experienced before (Figure 8).

This remarkable achievement has, however, come alongside a massive deterioration of the biosphere's health. In a review of evidence from the past 11,000 years (Earth scientists call the period the Holocene), Waters et al. (2016) tracked the human-induced evolution of soil nitrogen and phosphorus inventories, and carbon dioxide and methane in sediments and ice cores. They report that time series of a broad class of global biogeochemical signatures display a flat trend over millennia until some 250 years ago, when they begin a slow rise that continues until the middle of the 20th century, when they show a sharp and accelerating rise. The trends in global economic activity over the past 70 years that we have summarised above and displayed in Figure 8 match these findings. The authors proposed that the mid-20th century should be regarded as the time we entered the Anthropocene.[32] Annex 1 presents a way of defining the Anthropocene through the idea of 'planetary boundaries'.

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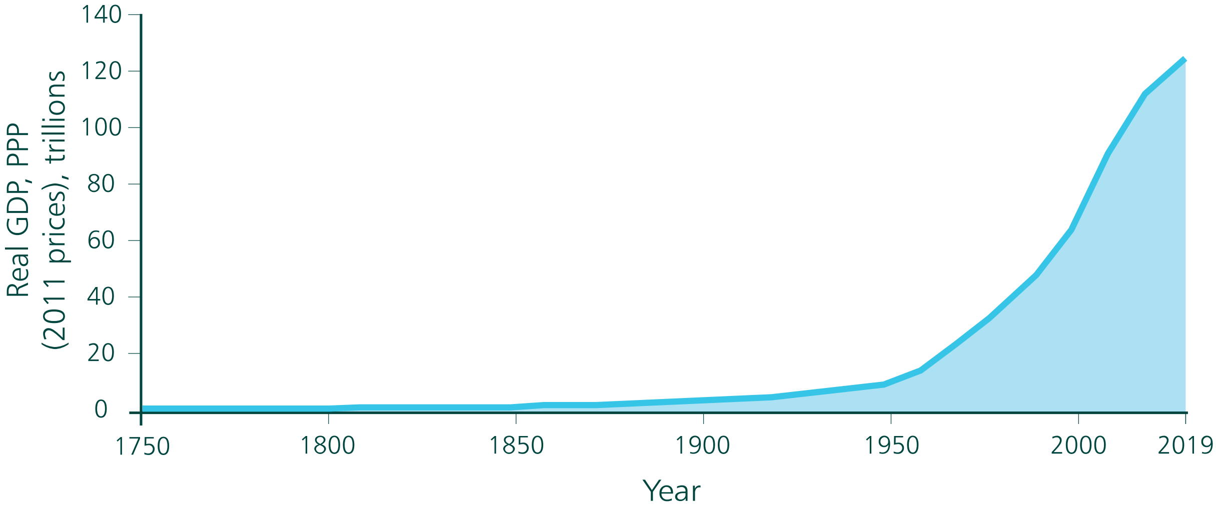
[30] In constructing international dollars (i.e. dollars at *purchasing price parity*, PPP), the official exchange rates of various currencies with respect to the US dollar are converted to bring the purchasing power in the regions on par with one another. In what follows, 'dollars' mean 'international dollars'.

[31] Global poverty is likely to have risen sharply in 2020 due to the COVID-19 pandemic, partially reversing some of the improvement over recent decades. In October 2020, the World Bank suggested that the number of people living in extreme poverty would likely increase from 88 million to 115 million in 2020 (World Bank, 2020a).

[32] The term 'Anthropocene' was popularised by Crutzen and Stoermer (2000) to mark a new epoch in which humans dominate the biosphere. The Anthropocene Working Group has proposed that the immediate post-war years should be regarded as the start of the Anthropocene (Voosen, 2016).

Figure 8 Global Real GDP Since 1750



Source: Our World in Data based on World Bank (2020a), Maddison (2018), Bolt et al. (2018) and Review calculations.

Perhaps the most visceral sign of environmental degradation is species extinction. Uncertainties in the rates at which species are becoming extinct mirror our lack of knowledge of the number of species in existence (recall the range 8-20 million, possibly more, for eukaryotes, Section 2). The figures presented in Box 5 reflect these uncertainties, but explain why the Holocene is the period when Earth began experiencing its sixth mass extinction.

Box 5
Species and Population Extinction

Largely as a result of human activities – land- and ocean-use change in all its varieties – species and the component populations of still-extant species are becoming extinct far more rapidly than in the past. Current extinction rates of species in various orders are estimated to have risen to 100-1,000 times the average extinction rate over the past tens of millions of years (the 'background rate') of 0.1-1 per million species per year (expressed as E/MSY), and are continuing to rise.[33] To illustrate in absolute terms, 1,000 species would become extinct every year if the number of species was 10 million and 100 E/MSY was the current extinction rate. Despite the uncertainties, the figures put the scale of humanity's presence in the biosphere in perspective. The figures also tell us why Earth scientists and ecologists say we are witnessing the *sixth* great biological extinction since life began.[34]

Judged by what is known about relatively well-studied groups (terrestrial vertebrates, plants), some 20% of species could become extinct within the next several decades, perhaps twice as many by the end of the century. It is estimated that 84 mammal species have become extinct since 1500 and 32 species of mammal have gone extinct since 1900 (IUCN, 2020; Pimm and Raven, 2019).

In a survey of population data on nearly 30,000 species of terrestrial vertebrates, Ceballos, Ehrlich, and Raven (2020) have estimated how many are on the brink of extinction. Their criterion was populations with fewer than 1,000 individuals. By this measure, 515 species are on the brink, representing 1.7% of the vertebrates on the authors' survey list. If extinction

[33] See De Vos et al. (2014), Pimm et al. (2014), and Ceballos, Ehrlich, and Ehrlich (2015).

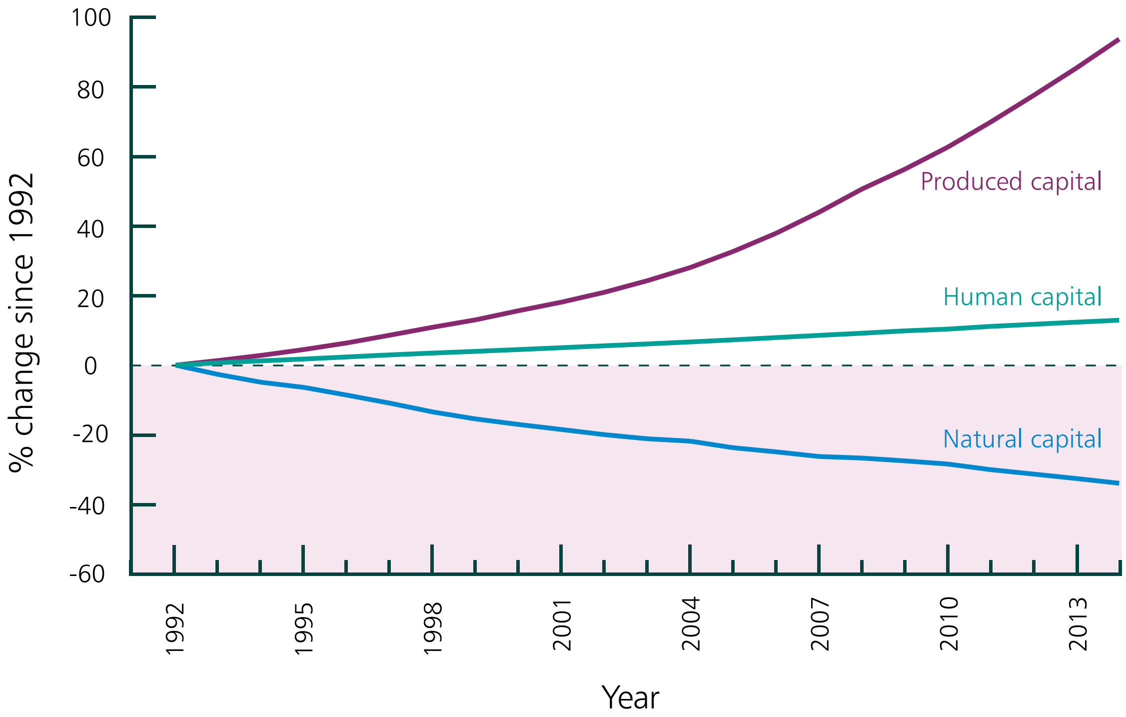
[34] The Sixth Extinction has also been called the Holocene Extinction, which began at the end of the last glacial period some 11,000 years ago, the signature being provided by the extinction of large land mammals. Kolbert (2014) is a narrative on the mass extinction under way.

follows at the same rate, the population of terrestrial vertebrates will halve in about 40 years. But the rate is likely to increase at an accelerated rate, for several reasons. First, human pressure on the biosphere is increasing (see below); second, the distribution of those species on the brink of extinction coincides with hundreds of other endangered species, surviving precariously in regions with high human impact; and third, close ecological interactions among species tend to move other species toward annihilation – extinction breeds extinction. Assuming all species on the brink have experienced similar trends, the authors estimate that more than 237,000 populations of those species have vanished since 1900.

Trends in biogeochemical signatures and species extinctions are consistent with those in the global stock of natural capital. Managi and Kumar (2018) tracked the accounting values of produced capital, human capital, and natural capital over the period 1992 to 2014 in 140 countries.[35] In their work, renewable resources include forest resources (stocks of timber and a selected group of non-timber resources), fisheries (stocks were estimated from past records of catch), agricultural land (cropland and pasture land); while non-renewable resources cover fossil fuels and a selected set of minerals. Figures for the social cost of carbon (a negative accounting price) of greenhouse gas emissions were used to address future losses from global climate change.

Figure 9 displays the authors' estimates of global accounting values per capita of the three classes of capital goods over the period 1992 to 2014. It shows that the value of produced capital per capita doubled and human capital per capita increased by around 13%, but the value of the stock of natural capital per capita declined by nearly 40%.

Figure 9 Global Wealth Per Capita, 1992 to 2014



Source: Managi and Kumar (2018).

[35] The value of produced capital was obtained from official national accounts. Data limitations meant that natural capital was limited to minerals and fossil fuels, agricultural land, forests as sources of timber, and fisheries. Market prices were used to value them. The accounting value of human capital was based on methods that economists have devised for valuing education and health.

6 Unsustainable Economic Development

As the biosphere is a regenerative entity, it pays to let our imagination roam and regard it to be a gigantic version of a lake fishery (forests would be an equally good metaphor)[36]. If the stock of fish is low, the lake provides ample nutrients for the fish population to grow, which is a way of saying that the fishery is a regenerative resource. But because the lake is of finite size, it is able to provide a limited flow of nutrients. Even though the fish population increases initially, nutrients per unit of fish population decline, so the population eventually attains a size determined by the lake's carrying capacity and fluctuates around it. If fish-harvesters enter the scene, the fish population will decline, but so long as each period's harvest is kept within bounds, the fishery can survive indefinitely. That is a sustainable fishery. But if fishers harvest at a rate that is consistently above the fishery's regenerative rate, it is doomed. That is an unsustainable fishery.

The biosphere is finite in extent, so the flow of goods and services it provides is bounded. We may liken our activities to those of the fishers in our parable, but unlike them we inhabit the lake, we are not external to it. We take goods and services from our planet and we deposit our waste into it: material has to balance. What we take from our planet over a period of time *and* put back in as waste is known as our *ecological footprint*. And so the footprint not only includes the goods and services we harvest and extract from the biosphere, it also includes the rate at which the biosphere is able to treat our waste. The full set of provisioning, regulating, maintenance, and cultural services comes into play here. We may use the economist's lexicon and call our ecological footprint the *demand* we make of the biosphere.[37]

In a classic paper, Ehrlich and Holdren (1971) used the term *impact* to refer to what we have just called 'ecological footprint' and 'demand'. The authors decomposed humanity's impact on the biosphere in terms of our activities and the efficiency with which we are able to transform the biosphere's supply of goods and services into our activities. Reasonably, they took global GDP to be a measure of human activities and observed that it is the play of technology (and institutions, although the authors did not speak of the latter explicitly) that determines the efficiency with which we convert the biosphere's goods and services into GDP.

But global GDP is the product of human population size and global GDP per capita. So we have three factors to reckon with: population size; per capita GDP, and the efficiency with which we convert the biosphere's goods and services into GDP; and the extent to which the biosphere is transformed by global waste products. The factors are of course not independent of one another and are, in any case, the outcome of our choices. Fertility rates both influence and are influenced by our standard of living, and both influence and are influenced by the technology and institutions we devise and bring into play. It is nevertheless useful to work with this three-way breakdown of our ecological footprint. It enables us to identify trade-offs. For example, it says that if the efficiency factor remains unchanged, the trade-off between population size and the living standard is of an inverse form: doubling the global population needs to be matched by halving global GDP per capita if humanity's ecological footprint is to remain unchanged.

Human population has been growing, as has global GDP per capita. Efficiency has also increased, but not to the extent needed to counter the growth in population numbers and GDP per capita (Box 6). Figures 10 and 11 show that both have grown in recent centuries in much the way of global GDP (Figure 8): a slow rise at the start of the industrial revolution and a sharp increase that has itself been increasing since the mid-1950s.

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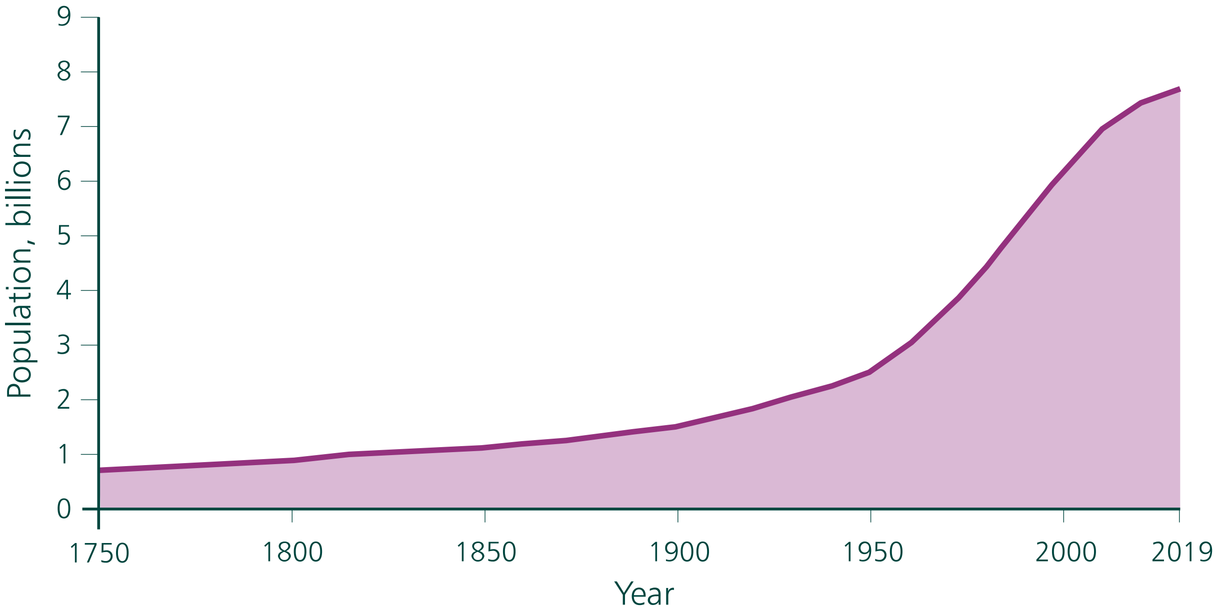
[36] This and the following section are based on A. Dasgupta and Dasgupta (2017) and Barrett et al. (2020).

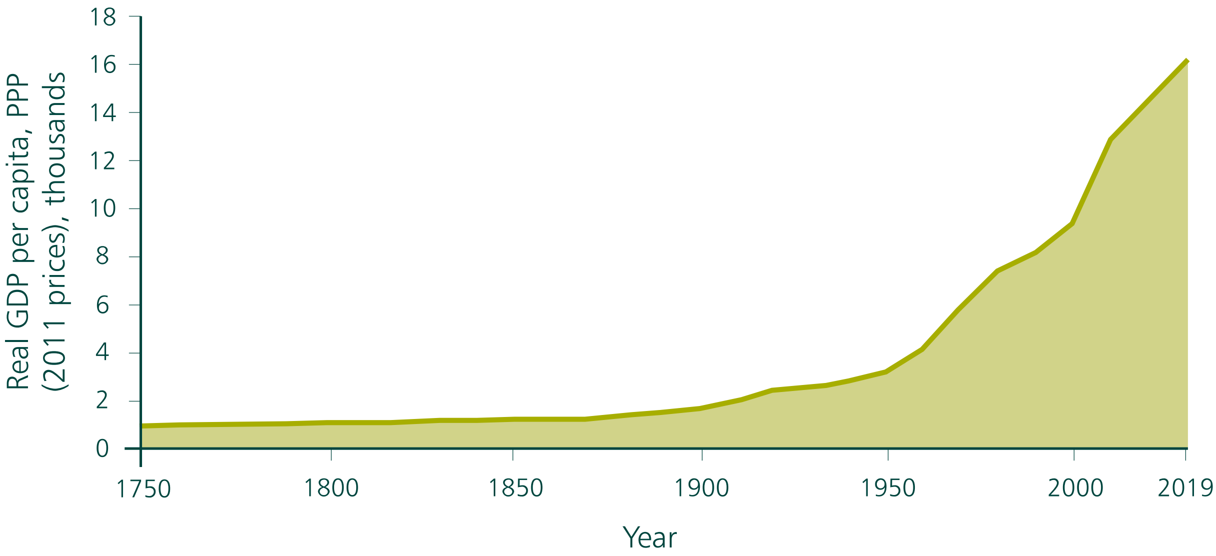
[37] That material must balance was the insight in Kneese, Ayres and d'Arge (1970) and Mäler (1974). The *Review* puts the material balance condition to work to show that economic output cannot be made to grow indefinitely. We return to this point in Section 11.

Figure 10 Global Population Since 1750



Source: Maddison (2010), UNPD (2019) and Review calculations.

Figure 11 Global Real GDP Per Capita Since 1750



Source: Our World in Data based on World Bank (2020a), Maddison (2018), Bolt et al. (2018) and Review calculations.

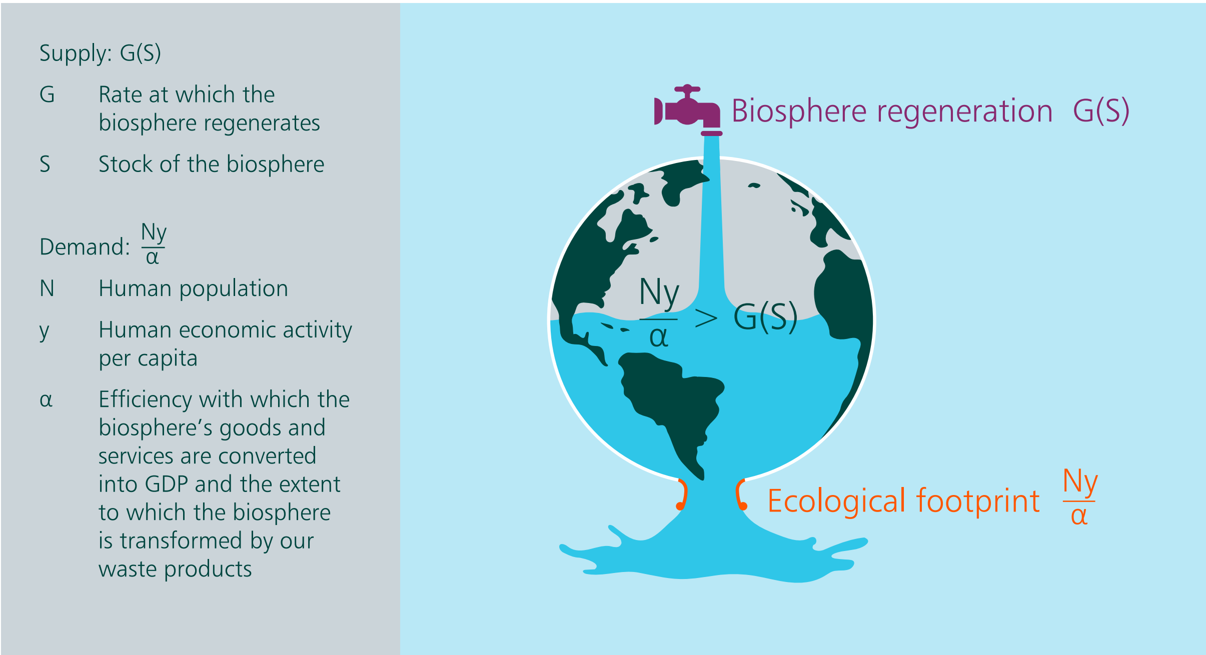
Recall Figure 8, which showed the growth in global real GDP since 1750. It can be interpreted as saying that, assuming the efficiency factor has not matched GDP growth, the global ecological footprint (i.e. human global impact) has been increasing. But we cannot tell whether the footprint exceeds the biosphere's ability to regenerate itself. That question has been studied in a bold programme of research by the Global Footprint Network (GFN). They have estimated that the ratio of our demand from the biosphere to its regeneration rate increased from 1 in the late 1960s to 1.6 in 2020 (Wackernagel and Beyers, 2019; Lin et al. 2020).[38] The authors speak of 1.6 figuratively as the number of Earths needed to satisfy our current demand on a sustainable

[38] Their estimate is that the ratio was less than 1 previously. The methods deployed by GFN to estimate the ratio can be found in their annual publications. Wackernagel and Beyers (2019) presents a non-technical account of the findings. It should be noted that the 2020 estimate (1.6) was slightly lower relative to 2019 due to the falls in economic activity due to COVID-19 induced lockdowns around the world.

basis. The exact figure is of little significance, what matters is that the evidence that now has been collected from a wide range of investigations (Section 5 and Annex 1) says that in recent decades the gap between demand and supply has been widening and will continue to widen unless humanity is able to reverse the trends in its demands. We borrow from Barrett et al. (2020) and call the gap between the global ecological footprint and the biosphere's regenerative rate the *Impact Inequality* (Figure 12).

In a healthy biosphere, humanity could, on reasonable utilitarian grounds, choose to draw it down somewhat and use the goods and services Nature supplies not only for consumption but also for accumulating produced capital (roads, buildings, machines, ports) and human capital (health, education, aptitude). That is what we have been doing over millennia and is what economic development has come to mean among many people.[39] That was a legitimate formulation of economic development when our ecological footprint was less than the biosphere's ability to supply goods and services to meet that demand at a sustainable rate. Today the matter is different.

Figure 12 The Impact Inequality



There are therefore four avenues available to humanity for transforming the Impact Inequality into an Impact Equality. They involve finding ways to:

(i) reduce per capita global consumption;[40]

(ii) lower future global population from what it is today;

(iii) increase the efficiency with which the biosphere's supply of goods and services are converted into global output and returned to the biosphere as waste; and

(iv) invest in Nature through conservation and restoration to increase our stock of Nature and its regenerative rate.

Box 6 formalises this and uses empirical findings of our recent economic experiences to estimate how fast the efficiency with which we are able to transform the biosphere's goods and services

[39] Barbier (2011) is an excellent historical account of that process.

[40] For simplicity of exposition, we are equating global output with global consumption.

into GDP has to be if the SDGs are to be met by 2030.[41] We find that the rate at which it must increase vastly exceeds the rate it has been achieved in the recent past.[42] As there is enormous waste in our use of provisioning services (global food waste alone, from source to final consumption, is an astonishing 30% or thereabouts[43]), there is scope for efficiency gains. There is also waste attributable to the wide range of subsidies we pay ourselves for the use of Nature's services. Many of the biosphere's goods and services (e.g. water, fossil fuels) thus come with a *negative* price tagged to them. Globally, Nature's subsidies amount to an annual US$4-6 trillion, or approximately 5-7% of global GDP (Box 9).

There are, however, limits to the extent our global demand can be reduced by being more efficient in our consumption of goods and services (see Section 12 on technological advances). Which is why our crude estimates say we must also invest in Nature and attend to two problems that are rarely addressed in the economics of growth and climate change: finding ways to reduce global per capita consumption (the required redistribution measures would be enormous) and hastening the demographic transition in countries and regions where larger families are the norm. We study the contours of these two neglected problems first (Sections 7-9).

Box 6
The Impact Inequality and the UN's Sustainable Development Goals

We denote humanity's global impact on the biosphere by I and the biosphere's regenerative rate by G. Both I and G are estimated in terms of the accounting values of the biosphere's goods and services, expressed, say, in real (international) dollars per year. I does not have to equal G, for, continuing to use the parable of fisheries, the difference between the two would automatically be accommodated by a change in the biosphere's stock. We write the latter as S. Declines in S are to be read as deterioration of the health of the biosphere. For vividness, we could imagine that every ecosystem is valued at its accounting price, and S is the sum of the accounting values of all the ecosystems on Earth. S is a stock, expressed in real (international) dollars. As with the example of fisheries, G depends on S, so we write that dependence as $G(S)$. But as S is bounded, so is G bounded.

N denotes global population, y global GDP per capita, and α a numerical measure of the efficiency with which we are able to convert the biosphere's goods and services into the final products we produce and consume. Global GDP is then N times y, which we write as Ny. The larger is α, the smaller is the demand we make on Nature for the same level of GDP.[44] Conversely, the larger is Ny, the larger is the demand we make on Nature for the same level of α. We may then express I as Ny/α and thereby write the fundamental inequality at the core of the economics of biodiversity as

$$I = Ny/\alpha > G(S) \qquad (1)$$

[41] Box 6 contains the one bit of technical material in this abridged version of the *Review*. Readers can skip it without losing the thread of the argument. We have prepared it for readers who are curious to learn how mathematical arguments advance our quantitative understanding of socio-ecological possibilities for the future.

[42] COVID-19 can be expected to set the SDGs even further back than our computations.

[43] This is only a very rough estimate; there is a lack of information at some stages of production, See FAO (2019).

[44] A simple illustration would be installing double glazing in homes. α would increase because the same warmth would be enjoyed at a reduced dependence on electricity or gas.

Expression (1) is the global Impact Inequality (Figure 12).[45]

Figures 10 and 11 revealed that *Ny* has been increasing in recent decades at an unprecedented rate; Figure 9 revealed that *S* has been declining in recent decades; and MA (2005) and IPBES (2019) have confirmed that *G* has also been declining in recent decades. The Global Footprint Network has found that the gap between *I* and *G* has been rising in recent decades to the point where the ratio of *I* to *G* in 2019 was 1.7. In recent decades, *S* has declined even as the gap between *I* and *G* has grown. The estimates of the character of modern economic growth that we have collated here now allow us to ask whether the United Nations' SDGs for 2030 were ever realisable.

As a simple exercise, we assume that global GDP at constant prices will continue to increase at its average annual rate since 1970, of 3.4%. Managi and Kumar (2018) estimated that the value of per capita global natural capital declined by 40% between 1992 to 2014. That converts to an annual percentage rate of decline of 2.3%.[46] But world population grew approximately at 1.1% in that period. It follows that the value of the stock of natural capital *S* declined at an annual rate of (2.3-1.1)% = 1.2%. Because there are no estimates of the form of the *G*-function, we assume for simplicity that *G* is proportional to *S.* So *G* can also be taken to have declined at an annual rate of 1.2%. As we have seen, the GFN has estimated that *I*/*G* increased from 1 in 1970 to 1.7 in 2019, which implies that it increased at an average annual rate of 1.1%. The estimates for the annual percentage rates of change of *Ny*, *G*, and [*Ny*/α]/*G* enable us to calculate that α had been increasing at an annual percentage rate of 3.5% in the period 1992 to 2014.

Suppose we want to equalise *Ny*/α and *G* in year 2030, that is, reduce the ratio of [*Ny*/α] to *G* from its current value of 1.7 to 1 in 10 years' time. That would require that the ratio of *Ny*/α to *G* should decline at an average annual rate of 5.4%. Assuming *Ny* continues to grow at 3.4% annually and *G* continues to decline at 1.2% (i.e. business is assumed to continue as usual), how fast must α rise? The answer is an annual rate of 10.0%. As that is a huge hike from the historical rate of 3.5%, it suggests we must look at other policies if the SDGs are to be sustainable.

Suppose *Ny* was to remain constant from now to year 2030 and draconian steps were taken by us over our demands to limit the rate of deterioration of the biosphere to 0.1% a year. A simple calculation shows that the required increase in α is an annual (5.4+0.1)% = 5.5%. Even that is almost a 60% increase of the 3.5% rate at which α has been increasing in recent decades. These are crude estimates, but they serve to illustrate the point that increases in efficiency alone are highly unlikely to be able to close the gap between I and G in the next decade.

The Impact Inequality also points to the error in imagining that perpetual economic growth is possible in the long run. It is significant that a mechanical engine that converts heat into work at 100% efficiency is a theoretical impossibility. The biological counterpart is that it would not be possible even theoretically to convert our further waste into a state that makes no further demands on the assimilative services of the biosphere; for if we were able to do that, we would be able to break free of Nature. That impossibility places a bound on α, meaning that no matter how ingenious we can be, global output (*Ny*) must also be bounded.

[45] The expression for global impact *Ny*/α in equation (1) could be thought to be saying that, for any given value of α, *N* and *y* are in inverse relation to each other – for instance, that if *N* was to double then *y* would have to halve if global impact *Ny*/α was to be held constant. Arithmetically that would be correct, but the thought could be misconstrued. The reason is that *N* and *y* are not independent of one another: we humans have not only mouths, but hands and brains too. Thus, *y* is a function of *N*. The *Review* (Chapter 4*) presents a complete capital model from which 'trade-offs' between *N* and *y* can be estimated at various stages of economic development. Dasgupta and Dasgupta (2021) have constructed simple methods that can be deployed on the model to calculate trade-offs between *N* and *y* that are consistent with sustainable development.

[46] The interested reader can follow the arithmetic steps in the corresponding Box in the *Review* should she wish to do so.

7 Rich and Poor, Consumption and Population

How does ecological footprint vary with income?[47] Figure 13 shows that although the higher a country's income, the greater is its footprint, that footprint increases with income less than proportionately. It seems our impact on the biosphere increases with affluence, but the efficiency with which we transform the biosphere's goods and services into the market value of final goods and services also increases with affluence. But that poses a cruel dilemma: other things equal, egalitarian objectives such as those enshrined in the SDGs may clash with the global need to reduce our ecological footprint.[48]

Figure 13 Ecological Footprint and Income

Source: World Bank data on GDP per capita in 2018 (thousands, constant prices in 2017 international dollars), and estimates from the Global Footprint Network on ecological footprint per capita (in global hectares), and Review calculations.

The World Bank groups countries into four income categories: (i) high income, with an average per capita GDP of around 52,000 dollars PPP; (ii) upper-middle income (average around 17,500 dollars PPP); (iii) lower-middle income (average around 6,800 dollars PPP); and (iv) low income (average around 2,500 dollars PPP). Table 1 presents the distribution of incomes, population sizes, and total fertility rates (TFR) across the four groups.[49]

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[47] This section is based on A. Dasgupta and Dasgupta (2017).

[48] This can be confirmed from Figure 13. Suppose all countries were to enjoy the average income of the world, around 16,000 international dollars. The global ecological footprint would be larger than the sum of the footprints of all countries at the current distribution of incomes.

[49] A region's total fertility rate (TFR) is the average number of births per woman over her reproductive years (taken to be 15-49). As a rule of thumb, 2.1 is taken to be the fertility rate at which a region's population would remain constant in the long run. That is the 'replacement fertility rate'.

Table 1 Income and Population Shares

Countries (income; dollars PPP)	GDP (2019 prices; trillion)	% global GDP	% global population	Total Fertility Rate (TFR)
High	64	47	16	1.6
Upper-middle	50	47	37	1.9
Lower-middle	20	15	38	2.8
Low	2	1	9	4.6

Source: World Bank (2020a). Figures rounded.

The figures are revealing. A little over 15% of the world's population produces nearly 50% of global GDP, while just under 10% of the world's population produces 1%. The majority of the world's lowest income countries are in sub-Saharan Africa. Comprising around 14% of the world's population, the region represents only a bit more than 3% of the world economy.[50] Estimates from the Global Footprint Network suggest that sub-Saharan Africa's ecological footprint is a mere 6% of the global footprint. So sub-Saharan Africa cannot remotely be held responsible for the global environmental problems we face today; that responsibility falls squarely on today's high income countries and increasingly the lower-middle income and upper-middle income countries.

8 Addressing the Impact Inequality, 1: Global Consumption

In recent decades, there has been a significant increase in our global demand for provisioning services, in particular food, timber, fibres, biofuel, and water. This has affected the ability of ecosystems to provide the regulating and maintenance services on which our economies ultimately depend. For example, land used for agriculture increased by over 100 million hectares between 1980 and 2000 across the tropics, with half of this land directly converting the tropical forests that regulate climate and prevent soil erosion. In our oceans, fishery catch has more than quadrupled since 1950. Data on our current and predicted future use of provisioning services of crops, fibre, biofuels, timber, water, fish and aquaculture tell a similar story of escalating demands. If we are to avoid exceeding the limits of what Nature can provide on a sustainable basis while still meeting the needs of the human population, consumption and production patterns will need to be restructured fundamentally.

Food production is the most significant driver of terrestrial biodiversity loss. But humanity also comes with an entourage. Land is used to produce food for our pets (cats and dogs). A recent assessment of the demand for pet food found that its production uses 0.8-1.2% of global agricultural land, which is approximately twice the land area of the UK (Alexander et al. 2020). But that is nothing in comparison with our love of meat products. Livestock in 2016 occupied 3.28 billion hectares of global agricultural land (67%). This figure does not include the approximately 35% of crop production for livestock feed (Foley et al. 2011). If that were included, the proportion of agricultural land devoted to livestock would become 77%.[51] If we reckon that agricultural land replaced what were once woodlands and forests, grasslands and shrubs, wetlands and swamps, and include in our calculation the discharge of waste accompanying food production and consumption, we begin to appreciate the magnitude of the tension between our demand for provisioning services, in particular food production, and our need for regulating and maintenance services.

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[50] The slight discrepancy between these figures and the corresponding ones in Table 1 is explained by the fact that there are a handful of lower- and upper-middle income countries in sub-Saharan Africa (e.g. South Africa, Kenya, Namibia and Botswana).

[51] See Klein Goldewijk et al. (2017), and Poore and Nemecek (2018).

As the global population grows, the problem of producing sufficient food in a sustainable manner will only intensify. There is also significant waste (Box 7): as noted earlier, approximately one-third of food produced is lost or wasted (FAO, 2014, 2019). This is more than just ironic; even as more than 10% of the world's population go to bed hungry each day, food remains under-priced for the wealthy.

Box 7
Food Loss and Waste

Short term macroeconomics fuels profligacy: we are encouraged to consume so as to prevent the employment rate from falling. There is a need to break the link between consumption that is damaging of the biosphere and employment, because we know employment improves well-being (*Review* Chapter 11). Three major types of footprint of food loss and waste are quantifiable: greenhouse gas (GHG) emissions, pressures on land, and pressures on water. They all have an impact on biodiversity. Production of food which is never consumed has significant environmental impact: GHG emissions from the production of lost and wasted food amount to 8% of total GHG emissions, making food waste the third largest carbon emitter in the world, behind the US and China (Hanson and Mitchell, 2017).

The extent of food loss and waste along supply chains varies depending on global context: loss is substantial in handling, storage and transport stages in regions where these are difficult to achieve. At the global level, approximately one-third of food produced is lost or wasted (FAO, 2019), that is, a land area the size of India and Canada together is used to grow food that is never consumed. For aquatic food, post-harvest loss is a particular problem for small-scale fisheries. Large quantities of fish are lost in transport and storage, especially where access to electricity for cold storage is a difficulty. Post-harvest losses were estimated at 10% of global capture fishery and aquaculture production in 2005 (Béné et al. 2007).

Meeting environmental objectives by reducing food loss and waste requires an understanding of not only where food waste occurs in the supply chain, but also the footprints of commodities that are wasted and the costs of interventions to reduce waste at different points. To reduce the land footprint, for example, policies need to aim to reduce animal product waste because 60% of the land footprint of food loss and waste is for livestock production. Some countries have achieved significant reductions in food waste. In 2015 to 2018, the UK saw a 7% reduction in food waste (480,000 tonnes), mainly through working in partnership with food retailers and tackling waste at the household stage (WRAP, 2020). Globally, however, food waste remains gigantic.

9 Addressing the Impact Inequality, 2: Global Population

Global population grew sharply in the years following the mid-20th century, because the substantial reductions in death rates traceable to advances in medicine and public health practices were not matched by reductions in fertility rates. Table 1 shows that fertility rates are lower in richer groups of countries. The table also shows that low income countries, the bulk of which are in sub-Saharan Africa, stand out for their high fertility rates.[52]

In 2018, women in sub-Saharan Africa on average have around 4.7 births over the course of a lifetime, in contrast to a global average of 2.4. Even the latter figure is above the replacement fertility rate – approximately 2.1. The fertility rate in South Asia differs considerably across regions: the fertility rate in Bangladesh, which has welcomed voluntary participation in family

[52] The remainder of this section owes much to discussions with John Bongaarts, John Cleland, Aisha Dasgupta, Paul Ehrlich, and Peter Raven.

planning programmes, is today only a bit over 2; in India it has fallen to 2.2, whereas in Pakistan it is 3.5.[53] In contrast, the fertility rate in China today is 1.7.

Recall though that the global ecological footprint depends on the *absolute* population size. A population can be stable, but if large it would have a big footprint, other things equal, and could bring the biosphere into disrepair. That is why the replacement fertility rate is not as significant a notion of 'fertility transition' (the transition from high fertility rates to the replacement rate) in the economics of biodiversity as it is in demography. The economics of biodiversity encourages us to look for transitions that dip below the replacement fertility rate before tending toward it. As Table 1 shows, high income and upper-middle income countries, seen as groups, display that feature.

Peering into population projections by expert demographers is a necessary exercise in the economics of biodiversity. The United Nations' current median projection of world population in year 2100 is around 10.9 billion, with a 95% certainty range 9.4-12.7 billion (UNPD, 2019). More than three-quarters of the increase from today's 7.7 billion is expected to be in sub-Saharan Africa, where population in 2100 is projected to rise from around 1.1 billion today to 3.8 billion with 95% certainty that it will be in the range 3.0-4.8 billion (Figure 14). But attempts to raise incomes there, even to the current global average income (approximately 17,000 international dollars), in the face of a near-3 billion rise in numbers, will require an increase in the region's annual output from 4.3 trillion international dollars to about 68 trillion international dollars at today's prices. That rise, assuming that it is possible, is likely to have adverse consequences for the region's ecology, contributing to societal conflicts there and greater attempted population movements both within the region and out of it (Juma, 2019).

There are alternative projections to those made by the United Nations Population Division (UNPD). Vollset et al. (2020) have projected global population for 2100 based on two assumptions that are notably different from UNPD (2019): (i) sharper declines in fertility rates in countries that have already undergone a fertility transition; and (ii) earlier declines in fertility rates in low income countries. The authors' central projection of global population in 2100 is 8.8 billion, with a 95% prediction interval of 6.8-11.8 billion. Their forecast for sub-Saharan Africa is an increase by approximately 2 billion from today's 1.1 billion, which is fewer by 700 million than the median projection in UNPD (2019). As a median global population of 8.8 billion in 2100 is lower than even the lower bound of 9.4 billion in UNPD's 95% prediction interval, the publication created much media interest.

In fact, differences between the two sets of projections for global population become significant only after 2070. Until then, there is less than 5% difference between the two.[54] And that matters far more than their differences for 2100. Nature responds to the demands we make of it, it does not calculate rates of change in demands, nor rates of change of rates of change in demands. When ecosystems tip over into unproductive states, the shift cannot usually be reversed (in exceptional circumstances it can be, but only at great cost). Globally, if a few more planetary boundaries (Annex 1) are breached by year 2070, differences in population projections for year 2100 will count for little.

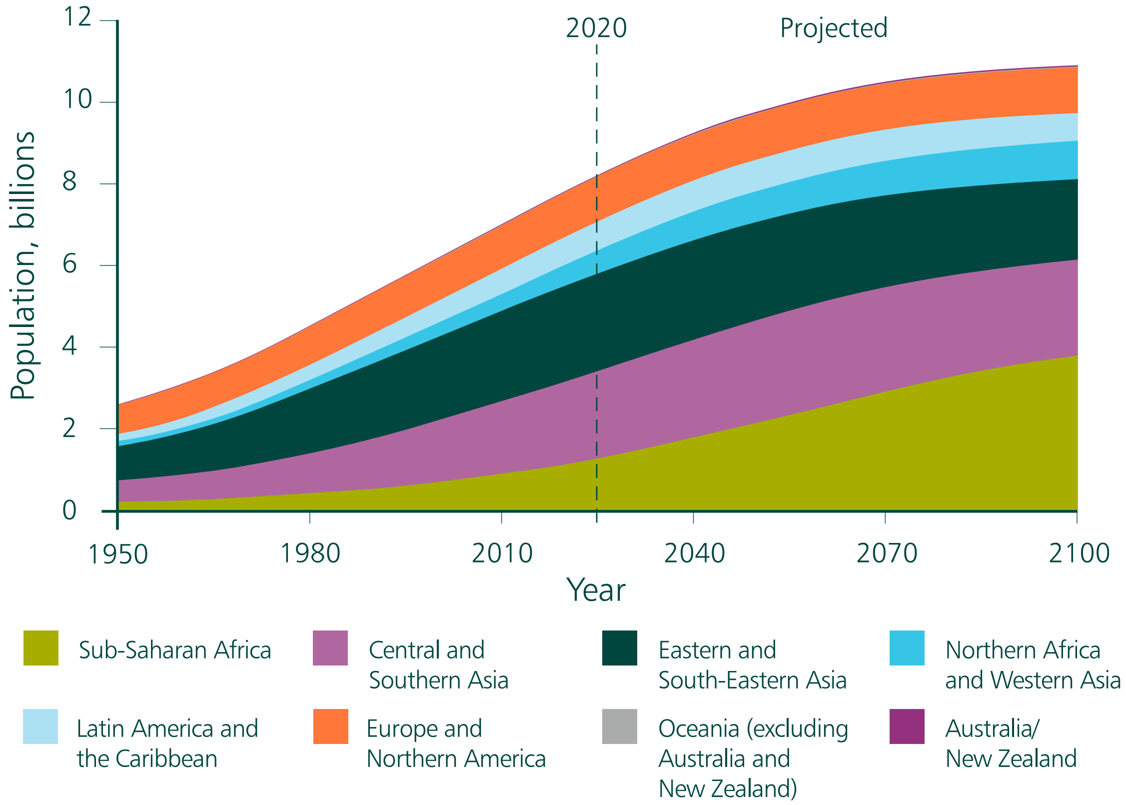
The SDGs are reticent about population, and yet it is difficult to imagine that they can be regarded to be sustainable without addressing the subject (given the role population plays in our demands on Nature), even if the target year was to be postponed a decade or more beyond 2030. It has been argued that the goal to restrict the increase in mean global temperature to 2°C from that in the pre-industrial revolution era is unlikely to be met unless population growth

[53] In 1970 (i.e. before the partition of Pakistan into two states), the total fertility rate was high in both Bangladesh and Pakistan – 6.9 in Bangladesh and 6.6 in Pakistan – but by 2000 it had dropped to 3.2 in Bangladesh but was 5.0 in Pakistan (A. Dasgupta, 2020). For further discussion of the role family planning played in reducing birth rates in Bangladesh, see *Review* (Chapter 9).

[54] We are grateful to Patrick Gerland of the United Nations Population Division for clarifying this for us.

is reduced substantially (O'Neill et al. 2010), and yet even the recent 2015 Paris Agreement on climate change made no mention of population, nor of the lack of family planning facilities for many of the world's poorest women. Today, less than 1% of international aid from the EU to Africa is devoted to family planning. Box 8 collates what is known of the magnitude of unmet need for family planning.

Figure 14 Total Population Size by Region, Estimates and Projections, 1950 to 2100



Source: UNPD (2019).

Box 8
Family Planning and Reproductive Health

Over the years, female education has been seen by development experts as the surest route to women's empowerment, including choice over fertility. All governments recognise the importance of women's education for empowering women, yet even today around 30% of females between 15 and 24 years of age in low income countries are illiterate (World Bank, 2020a). Family planning and reproductive health programmes, in contrast, are affordable by governments even in low income countries. They offer an effective route for governments to empower women (they are what today many would call a 'low-hanging fruit'); yet they remain low on the development agenda. It is a paradox.

By providing access to subsidised contraceptive commodities and services, family planning and reproductive health programmes were successful in accelerating fertility declines in East Asia and Latin America in the 1960s to 1980s. Cleland et al. (2006) estimated that their promotion in countries with high fertility rates had the potential to avert more than 30% of maternal deaths and nearly 10% of childhood deaths. The rationale for vigorously expanding the content and reach of such programmes today also lies in the more than 215 million women in developing, mainly low income, countries who have reported they want to prevent pregnancy but are not using modern contraception. Among them, over 150 million use no method of contraception and nearly 65 million rely on traditional methods (UNPD 2020). The Guttmacher Institute (2020) estimated that there were some 110 million pregnancies in low and middle income countries annually that were unintended. The institute also estimated that if all unmet needs for modern contraception were satisfied in developing countries, there would be a nearly 70% decline in unintended pregnancies, amounting to around 35 million a year. Meeting unmet needs for contraception would reduce pregnancy-related deaths by 70,000. Many unintended pregnancies end in abortion, a significant proportion of which are performed under unsafe conditions.

In addition to reducing unintended pregnancies, use of contraceptives among women enhances their own health and that of their children by spacing births and providing greater opportunity for education. Guttmacher Institute (2020) estimated that more than 2.5 million infants in low and middle income countries die each year in the first month of life. Access to community-based modern family planning and reproductive health programmes is a means for women to have greater control over their lives and for improving the chance of having healthy babies. If the benefits of modern family planning and reproductive health programmes are high, the costs are low. By one estimate (Guttmacher Institute, 2020), expanding and improving services to meet women's needs for modern contraception in developing countries would cost under US$2 a year per person. As routes to fertility transitions, investment in community-based family planning and reproductive health programmes should now be regarded as essential.[55]

10 Environmental Externalities

Why and how have we come to over-extend our demands on the biosphere to such an extent? One set of explanations, much studied in recent years by environmental economists, focuses on human short-sightedness and our inability to choose actions that are in our own personal interests. Behavioural psychology has studied and confirmed systematic biases in our reading of the world and in the personal choices we make – the goods we consume and the risks we take (Box 11).

The findings are illuminating, but they do not help to explain why our overshoot has increased so rapidly in recent decades, to the point where some parts of the biosphere have tipped over into unproductive ecosystems and some parts are probably not far from tipping points (Annex 1). In order to have an uncluttered problem to examine, we therefore imagine that people are capable of reasoning judiciously. The problem then is to explain why reasoned choices at the individual level can nevertheless result in a massive failure of collective reasoning. For that, we look into features of the biosphere that create the dissonance.

As noted earlier, mobility, invisibility, and silence are pervasive features of regulating and maintenance services. That makes it difficult for others to *observe* or *verify* the use someone makes of them or what that someone does, perhaps inadvertently, to weaken them. Property rights to Nature's processes are thus difficult to define and difficult to enforce even when they have been instituted. By property rights we do not only mean private rights, we include collective rights (e.g. community rights and state rights). The inability of societies to honour property rights even when they can be defined gives rise to *externalities*, which are the unaccounted-for consequences for others, including future people, of actions taken by one or more persons. The qualifier 'unaccounted-for' means that the consequences in question follow without prior engagement with those who are affected, or without due consideration for future people. *Environmental* externalities, for that is what we are focusing on here, are prevalent because we do not have to pay for many of our biosphere's services. Being free, we demand too much; that

[55] Of the many publications that have reported the benefits that family planning services provide to poor households, see especially Cleland et al. (2006), Bongaarts (2011, 2016), Miller and Babiarz (2016), and Guttmacher Institute (2020).

is, we demand more than is in our collective interest. In Box 9, we confirm, moreover, that some ecosystem goods and services come not at zero price but at a *negative* price. Put simply, it *pays* to exploit the biosphere, and government subsidies play a part in that.

Box 9
Nature Subsidies

Governments almost everywhere amplify adverse environmental externalities by paying people more to exploit the biosphere than they do to protect it. These payments have been called *perverse subsidies*. Examples include subsidies to agriculture, water, fossil fuels, fisheries, energy and fertilisers. These subsidies encourage over-extraction and harvesting of the biosphere. Government subsidies for exploiting Nature are extensive in size. Recent estimates suggest that direct subsidies that are harmful to biodiversity total around US$500 billion per year, and when taking into account environmental externalities, the conservative estimate of the total cost of subsidies is much larger, at around US$4 to US$6 trillion globally per year for the sectors mentioned above (OECD, 2017b; Andres et al. 2019; Coady et al. 2019). The figures dwarf the size of public finance devoted to conservation and restoration and sustainable use of the biosphere. For example, domestic public finance associated with the conservation and sustainable use of biodiversity totals around US$68 billion per year globally (OECD, 2020). Estimates of aggregate finance flows toward biodiversity (including those from both public and private sources) range from around US$78 billion to US$143 billion per year (equivalent to around 0.1% of global nominal GDP in 2019)[56] (*Review,* Chapters 8 and 20).

Two types of externalities may be contrasted: *unidirectional* and *reciprocal*. We introduce them, and then review various types of institutions that societies have created to reduce them (Sections 11-13).

Figure 15 Reciprocal and Unidirectional Externalities

[56] See Deutz et al. (2020) and OECD (2020).

10.1 Unidirectional Externalities

An externality is unidirectional when an agent (or a group of agents) inflicts an unaccounted-for damage or confers an unaccounted-for benefit on another (or others). An example of unidirectional harm is a company discharging toxic chemicals into waterways; an example of a unidirectional benefit is the protection enjoyed by downstream dwellers against landslides afforded by the wooded property of the landowner upstream.

Unidirectional externalities find their greatest expression in our engagements with our descendants. To explain, consider that our consumption levels affect what we are able to leave behind for them. It is customary to argue that people have a right to judge for themselves how much to save for their children, that parents are in any case best placed to reach answers to that question.[57] The argument runs as follows: people care about their children, and know that their children in turn will care about their grandchildren, that their grandchildren in turn will care about their great-grandchildren, and so on. By recursive reasoning, thoughtful parents would care about all their descendants. So, when parents reflect on how much they should bequeath to their children, they are guided by all their descendants' well-being. Voluntary participation in free and fair markets would enable parents to express that extended care, while relying on their own resources.

One problem with the argument (there are other problems as well) is that even if parents are able to internalise the well-being of their own descendants, they would not take into account the positive externalities they confer on, nor the negative externalities they inflict on, *other* parents and *their* descendants. As so many of our biosphere's regulating and maintenance services are free, each one of us experiences (even if at an unconscious level) an urge to exploit them at rates that, from the perspective of our collective good, are too high.[58] And that amounts to each one of us discounting the benefits and burdens of our descendants at rates we would not countenance were we able to choose them collectively. Rates of discount in the market are therefore too high; accounting rates of interest – they are often called *social rates of discount* – would be lower. Economists point to an absence of adequate property rights to natural capital as the source of the problem.

10.2 Reciprocal Externalities

Under reciprocal externalities, each party inflicts an unaccounted-for harm or confers an unaccounted-for benefit on all others in a population. The population could be as small as a village community or as large as the world. One example of mutual harm is the carbon emissions of every household today; another is the biodiversity loss caused by our activities. An example of a mutual benefit would be the flip side, which would take place if nations undertook to fulfil their commitments to reduce carbon emissions or biodiversity loss. Gordon (1954) famously wrote that an asset that belongs to everyone belongs to no one. Hardin (1968) even more famously spoke of the "tragedy of the commons" to describe what can happen to a resource to which access is free. Because users are not charged nor required to limit their use, everyone uses it excessively.[59] This is not simply market failure, it is institutional failure writ large. When governments are unable to agree on ways to ensure that commitments they have made on reducing carbon emissions are complied with, it is a sign of failure in international governance; it is not market failure.

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[57] There are exceptions to this argument of course, investment in education being one.

[58] Anthropologists have observed that children consume meals at a faster rate when eating from a common plate than when eating from individual plates.

[59] What prevents us from depleting free resources immediately are the personal costs of extraction. On this, see Dasgupta, Mitra, and Sorger (2019).

Reduction in the prospective damage from climate change and biodiversity loss is akin to the production of *public goods*, which are neither rivalrous (access to a public good by any one group of people has no effect on the quantity available to others) nor excludable (no one can be excluded from access to the good). Markets would be expected to offer very little in the way of incentives for individuals in their private capacity to supply public goods: the benefit from supplying them would be shared with everyone, while the entire cost of production would be borne by the supplier. The term 'free riding' expresses the phenomenon exactly. That is why governments are urged by economists to reduce harmful externalities using pollution taxes, resource extraction fees, even prohibitions (e.g. establishing Protected Areas; issuing a fixed number of tradeable permits to pollute; and so on).

Globally, public goods appear in the form of such regulating and maintenance services as are embodied, for example, in the climate system. The ecosystems supplying those public goods differ from one another, which means different remedies are required if their supply is to improve. Consider that the world's rainforests are a seat of global public goods but fall within national jurisdictions. They thereby give rise to unidirectional externalities. If we are to preserve the world's rainforests, the global community should be prepared to pay the nations harbouring them to do that. In contrast, the world's oceans beyond the 200-mile exclusive economic zones are global public goods but are open access resources, giving rise to reciprocal externalities. Protection of the oceans should therefore be subject to international control (e.g. global taxation on ocean fisheries and transportation; extensions of Protected Areas, and so on). The public finances in the two cases would be different, but they could be made to relate to one another. The revenue collected from global fisheries and marine transportation could, for example, be used to cover, if only partially, the international payment for the protection of rainforests. In Part II, we explore the idea of a Global Marshall Plan for protecting the biosphere and, by extension, our prosperity and well-being also.

Box 10
Externalities and Rights

Although the failure to establish and protect property rights has traditionally been at the heart of the economics of externalities, the language of rights sits awkwardly there.[60] We are speaking of fundamental rights, not rights assigned to people or organisations because they are instrumental in advancing human well-being. But even fundamental rights need to be justified. As elsewhere in the economics of biodiversity, trade-offs have to be weighed if actions are to be judged. Rights short-circuit those complexities.

Perhaps the most striking, as well as the most sensitive, sphere where rights would seem to clash is reproduction. The 1994 International Conference on Population and Development reaffirmed the language of rights in the sphere of family planning and reproductive health. The Conference's conclusions read:

"Reproductive rights … rest on the recognition of the basic right of all couples and individuals to decide freely and responsibly the number, spacing, and timing of their children, and to have information and means to do so, and the right to attain the highest standards of sexual and reproductive health." (UNFPA, 1995: Chapter 7, Section 3)[61]

The qualifier 'responsibly' could be read as requiring couples to take into account the adverse environmental externalities their reproductive decisions may give rise to; but that

[60] The material in this Box has been taken from A. Dasgupta and Dasgupta (2017).

[61] Moral philosophers would argue that the evaluation of family planning programmes should include the quality of lives that will not be lived on account of the programmes. We avoid those difficult problems by assuming that thoughtful parents reach their fertility desires by taking into account the potential well-being of their offspring and, by recursion, the well-being of their dynasty. On this and related matters in population ethics, see Dasgupta (2019).

probably would be a stretched reading. Certainly, writings affirming the UN declaration have interpreted the passage and its intent more narrowly. For example, the fundamental right of individuals "to decide freely and for themselves whether, when, and how many children to have" is central to the vision and goals of Family Planning 2020 (FP2020). It is also pivotal in the reproductive health indicators of the UN's Sustainable Development Goals. In this vision, information and other services pertaining to family planning and reproductive health are rights, as is choosing one's family size. But it is not clear that the two sets of rights have the same force.

Rights are peremptory, which is why they are problematic. One way to overcome the problem is to place them in a hierarchy. That was the conclusion Rawls (1971) famously reached when framing his principles of justice.[62] But if note is taken of adverse externalities accompanying a person's actions, it is by no means clear whose rights are to trump. Which is why the language of rights sits awkwardly in the economics of biodiversity. In a world where the Impact Inequality holds, and holds strongly, it may seem reasonable to insist on the rights of future generations when an appeal is made to curb our impact on the biosphere. Sen (1982: 346), for example, has likened persistent pollutants to instruments of oppression: "Lasting pollution is a kind of calculable oppression of the future generation." But if additional births can be expected to contribute further to the discharge of persistent pollutants, why do a couple's reproductive rights trump the rights of future people not to be oppressed? That is the kind of ethical dilemma the language of reproductive rights misses.[63]

11 Socially Embedded Preferences

The previous section described externalities that travel in the material world. In fact, externalities are embedded in a larger space. The social world can be as powerful a carrier of externalities as the material environment. A common form in which they appear in the social world is in the way our relationships influence our preferences and wants. This is cause for hope that transitions to sustainable development are possible and with lower human costs than may be feared.

Conceptions of human behaviour that inform the economic models in use by government ministries view human agency as egoistic. In some aspects of behaviour we are surely that, but in other aspects we are socially embedded: we look to others when acting. Even in the latter, our motivation is not uniform. In some spheres of life we are *competitive*, in others we are *conformists*. The economics of biodiversity remains seriously incomplete when our innate sociability is not acknowledged; nor is policy well informed when we neglect our social embeddedness.[64] That consumption is the activity around which human relationships are built and maintained has been found time and again by historians and anthropologists in their studies of traditional societies. Feasts to mark occasions of significance (birth, puberty, marriage, death, harvests, and the annual renewal that is spring) are a recurrent theme in their writings. The epic poems of Homer and Vyasa are full of it. There is hardly a book in the *Odyssey* that does not have a line-after-line description of the roasting, carving, and communal eating of meat and drinking of wine. And no opportunity is lost in the *Mahabharata* for describing the extravagance with which the king entertains his kinsmen and guests to mark a sacrifice to the gods or to celebrate the establishment of a capital for his kingdom.

[62] In contrast, the 30 Articles in the United Nations' Declaration of Human Rights are not placed in a hierarchy. Blackburn (2001) uses the UN Declaration to demonstrate the weaknesses inherent in rights-based ethics.

[63] In recognisably exceptional circumstances, governments resolve the dilemma by creating a hierarchy of rights. In the current COVID-19 pandemic, many governments have insisted that the right not to be infected by others trumps the individual right to do as we please when it comes to wearing masks and keeping safe distance from our friends.

[64] A modern classic on the way others influence us and we influence others is Cialdini (1984).

Historians of consumption are aware that the act of eating food communally has been a salient feature of societies everywhere, and that feasts have bound societies together since time immemorial. What contemporary historians have sought to understand are the societal changes that led to the democratisation of eating meals together beyond the household unit. The feasts described in epic poetry are enjoyed only by the aristocrats; we are told nothing of how common people celebrated special occasions. The modern historian, in contrast, is at pains to understand the growth of inns, cafes and restaurants in the general development of societies in the West since the late Middle Ages and Early-Modern times.

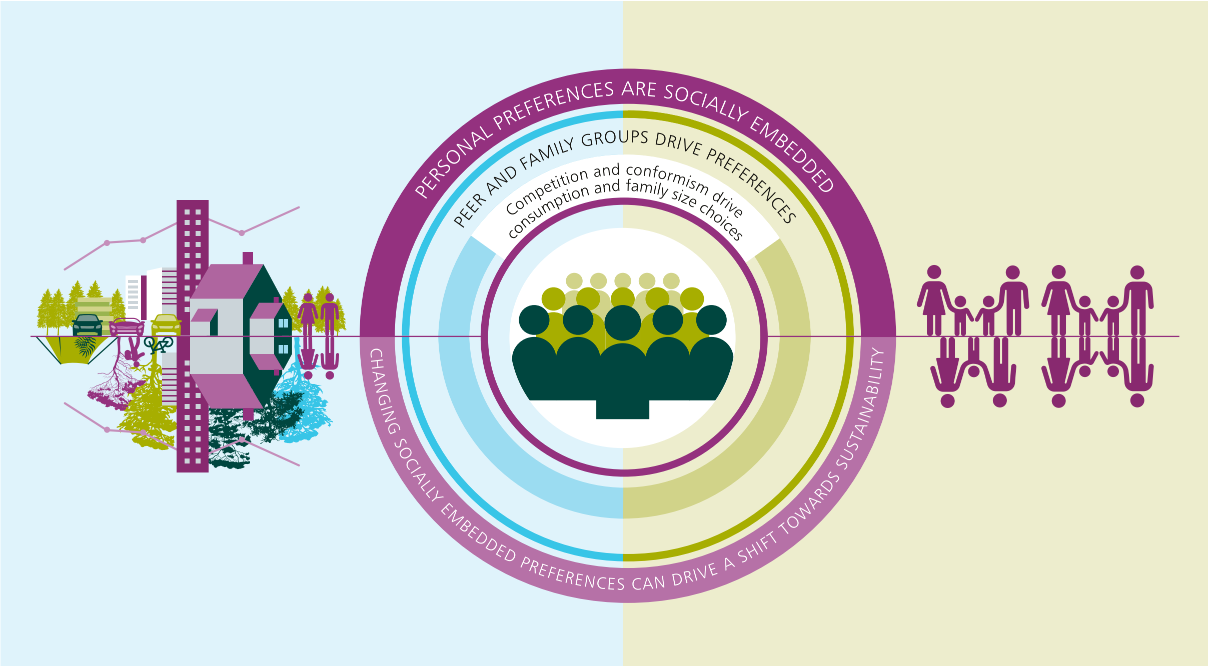
To date, socially embedded preferences have been uncovered mainly by historians, sociologists, and social and behavioural psychologists. What we have from social historians are narratives on the formation of tastes and changes in consumption practices over time (Trentmann, 2012, 2016); and what we have from large-scale surveys on stated happiness and life satisfaction is confirmation that our place relative to others matters to us (*Review*, Chapter 11).

The classic study of competitive preferences was Veblen (1925), who wrote of 'conspicuous consumption' to understand the Gilded Age among America's 19th century economic barons. That competitive preferences over consumption patterns leads to socially excessive consumption is well known, as evidenced by the term 'consumerism', which carries with it a pejorative note. People acknowledge the force of the 'rat races' they join in search of consumption experiences. Getting ahead of 'the Jones's' is a familiar expression. Competition can also drive consumption that is less degrading of the biosphere, for example in demand for more energy efficient appliances or electric cars.

Conformist preferences are different. They reflect the desire on our part to be like others, neither above nor below them. Conformism can direct us to be profligate, but we would be profligate only because others are profligate. So it may be difficult empirically to distinguish the two explanations for profligacy – competitiveness and conformism. Nevertheless, conformism is distinct from competitiveness. One reason is that if we were conformists we would be frugal in our consumption practices if others were frugal. Each practice – profligacy, frugality – could be held together by its own bootstraps, so to speak. So there is indeterminacy in the emergent behaviour in a society of conformists. That indeterminacy gives substance to a common observation that consumption patterns in the affluent West are wasteful, and worse, that they damage biodiversity and thereby our own wealth and well-being – the thought being that our practices have evolved in a socially damaging way. But the indeterminacy also offers hope that reductions in those forms of consumption that are damaging of the biosphere may cost far less in psychological terms than they would were the human person an egoist in all manners of consumption.

Fertility practices also are not influenced solely by private desires and wants, they are also shaped by societal mores. Reproductive behaviour is conformist when the family size a household desires conforms to the average family size in the community or, more broadly, in the world that households come into contact with. So long as all others aim at large families, no household will wish to deviate from the practice; if, however, all other households were to restrict their fertility, every household would wish to restrict its fertility. A society can thus get embedded in a self-sustaining mode of behaviour characterised by high fertility and stagnant living standards, even when there is another potentially self-sustaining mode of behaviour that is characterised by low fertility and rising living standards and which is preferred by all (Dasgupta and Dasgupta, 2017).

Figure 16 Socially Embedded Preferences



A study of contraceptive use in rural Kenya found that in communities with dense social networks and a poorly developed market economy, a woman would be unlikely to use contraceptive methods if contraception use in her network was low, whereas she would be likely to use such methods if contraception use in her network was high (Kohler, Behrman, and Watkins, 2001). Further support has been provided in a recent analysis of contraceptive uptake in Bangladesh (Munshi and Myaux, 2006). The study concerned women living in the same community but belonging to different religious groups. After controlling for individual differences in education, age, wealth, and the like, the study found that a woman's choice to use contraception depended strongly on the predominant choice made by other women in her religious group and was unaffected by the predominant choice made by women belonging to the other group. Family planning programmes that encourage community discussions on contraception and fertility preferences enable and empower women to both make and coordinate their choices.

Box 11
Behavioural Biases

Over the years behavioural psychologists have uncovered a number of systematic biases our choices are prone to. The biases on their own do not reflect socially embedded preferences – they are simply biases in the way we absorb information and respond to them. For example, the way choices are framed influences what we choose, so default options can have a powerful effect in shifting behaviour – referred to as 'nudging' (Thaler and Sunstein, 2008).

Researchers have found that even when people say they would like to use a green energy supplier, few do (Reisch and Sunstein, 2016). However, when a green energy supply was made the default, 69% of people in a trial of approximately 40,000 households ended up with one, compared to only 7% when it was not the default option (Ebeling and Lotz, 2015). To cite another example, hotels today routinely offer customers the default option of not requiring their bathroom towels to be changed each day.

Nudging people to do one thing rather than another can also be achieved through changing the environment in which people make their decisions. This includes cues in the physical environment, such as size, availability and position of objects or stimuli. For example, researchers have found when higher proportions of healthy and vegetarian cafeteria meals were made available, calorie intake and meat consumption were both reduced (Pechey et al. 2019).[65]

12 Technology and Institutions

Technology and institutions together influence the efficiency with which we are able to convert the biosphere's supply of goods and services into final products. They also influence the biosphere's ability to supply goods and services on a sustainable basis (e.g. bioengineering).

12.1 Synergies and Disharmonies

That institutions and technology influence one another is a commonplace observation. Institutions define the incentives that people have to do one thing rather than another, and incentives shape the production, dissemination and use of knowledge. A state that invests vigorously in life-saving technology and then applies it is able to transform society for the better. Likewise, technological possibilities shape institutions. Advances in mapping the geographical spread of natural capital and in methods to monitor its use can help enforce property rights. History is rife with examples where institutions and technology have influenced one another beneficially.

That each can be made at least partially to mitigate the other's failure has also been widely noted. Although degradation of the biosphere is frequently traced to institutional failure, people often express hope that progress in science and technology can put things right. The economics of climate change has encouraged that thought by focusing on the development of cheap renewable energy sources as substitutes for fossil fuels. Nature-saving technology – for example, substituting degradable waste for persistent pollutants and decarbonising the energy sector – are one class of ways in which technology can raise the efficiency with which the biosphere's goods and services are converted into final products. Institutional changes, such as improving the character and enforcement of property rights to natural resources points to another class of ways in which that efficiency can be raised. Establishing Protected Areas to conserve ecosystems; imposing pollution taxes or outright prohibitions; and removal of subsidies on resource extraction and agricultural production; are another class of institutional changes that can be brought about by public policy. Changes in behavioural norms, such as those that lead to a reduction in food waste, are yet another avenue (Section 19).

But there are problems. The incentives entrepreneurs have for developing technology are shaped by the systems of property rights in place. Entrepreneurs understandably innovate with a view to lessening the need for expensive factors of production, not cheap ones. We should then not be surprised that modern technologies are rapacious in their use of the biosphere's goods and services, many of which have a zero or even negative price. Remarkable post-war developments in sonar technology and advances in the technology for harvesting fish came about in large measure because ocean fisheries beyond national jurisdiction are free. Unbridled application of modern technology (e.g. the chainsaw) in clearing tropical rainforests has been made possible because governments have permitted it at a small price. Both forms of environmental destruction would have been avoided had institutions not failed. There is nothing good or bad

[65] It may be that what appears as irrational behaviour today has its roots in rational responses to problems our distant ancestors faced; that is, our behavioural biases may be relics of survival strategies in the distant past. For an exploration of this line of thinking for understanding the time-varying discount rates we humans have been found to deploy in our saving behaviour, see Dasgupta and Maskin (2005).

about technology per se. It is the use to which it is put that affects the efficiency with which we are able to convert the biosphere's goods and services into final products.

Box 12
Genetically Modified Crops

Changing the biological capabilities of crops offers the possibility of using marginal land for production, improving crop resistance to pathogens, obtaining higher yield on existing farmland, and enhancing nutritional quality. Genetically modified crops remain controversial, even though prominent scientific bodies such as the Nuffield Council on Bioethics (NCB, 2003) continue to affirm their salience in a world with growing food needs.[66]

There are numerous examples of how classic genetic modification and the newer, faster, and more precise technique of gene editing with CRISPR/Cas9 have conferred desirable traits on crops. One important example of transformational crop change through genetic engineering relates to rice: changing its primary metabolism to increase yield dramatically (C_4 rice). As rice makes up some 20% of global calorie intake, improvements to its growth efficiency have far-reaching consequences (Elert, 2014). Plants can carry out photosynthesis using a basic C_3 or C_4 molecule; the C_4 route is much more efficient. Yields of species currently using C_3 photosynthesis would be considerably higher if they could be re-engineered to use C_4. Rice is currently a C_3 plant, but a global research consortium has been working since 2009 to introduce genes from maize and change its photosynthetic pathway to C_4. The researchers estimate that rice yields could be improved by up to 50%, and that water use efficiency could be doubled (Rizal et al. 2012; Ermakova et al. 2019).

12.2 Our Bounded Economy

Contemporary conceptions of economic possibilities acknowledge that the biosphere is of finite size, capable of producing only a limited flow of goods and services. But they encourage the thought that if institutions are designed so as to create the right incentives, human ingenuity can overcome the bounds of a finite Earth. Formal models of macroeconomic growth assume that substitution possibilities between produced capital goods and technological advances can enable us to pursue economic growth indefinitely.

The economics of climate change and international negotiations over carbon emissions would seem to have gone further. There is an implicit suggestion there that GDP growth is the only viable route for (i) reducing carbon emissions, (ii) eliminating global poverty, and (iii) ensuring that development is sustainable.[67] That stance has given rise to a paradox: growth in global output is seen as necessary for providing the funds that will be needed for reducing our ecological footprint, even though the ways growth in global output have been achieved are known to increase the footprint.[68]

Our footprint is not only of the material we take from the biosphere but also the transformed material we deposit into it. What is requisitioned for human use has to be returned. The macroeconomic models of growth and development in use in economic and finance ministries and Planning Commissions, however, do not acknowledge that material must balance – from source to sink. Persistent pollutants such as plastics (bags and containers), nylon (fishing nets

[66] Zilberman, Holland, and Trilnick (2018) is an excellent summary statement.

[67] That would also appear to be the implicit assumption underlying the UN's SDGs (Box 1).

[68] Visions of a prosperous world in which Nature plays no part continue to thrive. Criticising the young climate activist Greta Thunberg for her speech at the United Nations in September 2019, the economics editor of Sky News wrote in *The Times* (27 September 2019: p. 30): "Eternal economic growth is not a phrase one spits out in derision; it's precisely what we should be aiming for."

and synthetic textiles), toxic chemicals (insecticides and pesticides), and metals and minerals (iron sulphide, mercury compounds) provide examples of waste that have adverse consequences for the soils and water bodies. Even (perhaps, especially!) biodegradable waste has to be accounted for. It does not do to imagine that if waste is biodegradable it leaves no footprint. If we overload Nature with such waste, the process of decomposition alters the biota, and that compromises other ecosystem services. Pharmaceuticals such as antibiotics and fashion products such as cosmetics contaminate the soils and water bodies. They have an adverse effect on the food we eat, the water we drink, and the air we breathe. Chemical fertilisers and waste from livestock emerge at the other end of farm production as waste, causing nutrient overload in streams and water bodies, disrupting the nitrogen cycle. Even the carbon dioxide emitted by our economies is a biodegradable waste: it is absorbed by primary producers for photosynthesis. But an overload compromises the ability of the biosphere to regulate climate. Global climate change will increasingly be a major cause of biodiversity loss (Lovejoy and Hannah, 2019). That will compromise the functional integrity of ecosystems. Rising concentration of carbon in the atmosphere is thus expected to bring about a chain of events that will radically alter the biosphere's workings. Regulating and maintenance services will move out of the bounds within which our economies and physiologies have evolved.[69]

Technological advances are taken in contemporary conceptions of economic growth to serve as the engine of economic growth. But those advances require investment in research and development. The conceptions carry with them the belief that even when GDP growth propels economies to higher and higher standards of living, further technological advances will require vanishing quantities of Nature's goods and services. The underlying assumption is that humanity will in the long run be able to break free of the biosphere. It is imagined that we are *external* to Nature. The *Review* develops the economics of biodiversity on an understanding that humanity is *embedded* in Nature. That viewpoint can be shown to imply that the human economy is bounded. The *Review* (Chapters 4 and 4*) appeals to ecological principles to argue that the efficiency with which the biosphere's goods and services can be transformed into our final goods and services will prove to be bounded no matter how ingenious we happen to be. We have to acknowledge that, if we are to reverse the Impact Inequality.

Models are now urgently needed that follow the ecological principles outlined in the global economic model in the *Review* (Chapter 4*), including data on natural capital. Empirical estimations of such models are needed to address the question of whether, and for how long, the redirection of consumption and investment that is now required is compatible with global GDP growth in the immediate future. The evidence presented in Section 5 implies that the possibility of global GDP growth generated by activities that cause depreciation of natural assets for an indefinite period into the future is highly unlikely. As does evidence that we have left the safety zones defining two of the nine planetary boundaries identified by scientists (Rockström et al. 2009) and are perilously close to leaving the safety zone of two further boundaries (Annex 1). Protection and restoration of the biosphere should now be a priority; otherwise the global footprint will continue to increase.

Making forecasts of technological progress involves peering into an uncertain future. In order to identify desirable reforms to contemporary institutions, it pays to look instead for pointers within our experience. In the following two sections we study the character of local institutions that have been found to reduce externalities.

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[69] On an example of the latter – the effect of climate change on our sporting abilities – see Smith et al. (2016).

Figure 17 The Economy is Embedded in the Biosphere

13 Payments for Ecosystem Services (PES)

For unidirectional externalities, payments by beneficiaries to those holding property rights to ecosystems is an arrangement resembling market operations. Named 'Payments for Ecosystem Services' (PES), the underlying idea is simple enough. The Amazon rainforest is recognised as Earth's lungs. If the government in Brazil is convinced that razing the Amazon is necessary for economic development in the country, should the rest of the world not pay an annual fee to Brazil to protect the forest? If a wetland on a landowner's range is a sanctuary for migratory birds, shouldn't bird lovers pay the landowner not to drain it for other uses? The cases here involve ecosystems that produce a public good but are located in private jurisdictions. PES involves negotiations, so it is not like customers accepting prices in the supermarket.

PES is based on the principle that beneficiaries of ecosystem services should pay to preserve and restore them. The systems have been much influenced by the fact that landowners manage their property in ways that are not necessarily (perhaps not even usually) compatible with the provision of ecosystem services. Modern agricultural practices are a notable example (Section 2). Designers of PES systems therefore grapple with finding ways in which landowners and land managers are to be compensated for providing those services.

As the tropics are rich in biodiversity and many of the world's poorest countries are in the tropics, it has been a natural thought to build PES programmes among low income communities. A PES system in which the state plays a positive role is attractive for wildlife conservation and habitat preservation. Property rights to grasslands, tropical forests, coastal wetlands, mangroves, and coral reefs are often ambiguous in low income countries. The state may lay claim to the assets ('public property' being the customary euphemism), but if the terrain is difficult to monitor, inhabitants who continue to reside there can be expected to live off its products. Inhabitants are therefore key players. Without their engagement, the ecosystems could not be protected. Meanwhile flocks of tourists visit the sites on a regular basis. An obvious thing for the state to do is to tax tourists and use the revenue to pay local inhabitants to protect their landscape from poaching and free-riding. Local inhabitants would then have an incentive to develop rules and regulations to protect the site. An alternative would be to hand over the right to charge tourists to the local inhabitants themselves.

There are two aspects of especial interest in PES systems in low income countries. One is its contribution to poverty reduction, the other to biodiversity conservation. Unfortunately, the findings are mixed on both counts (Zilberman, Lipper, and McCarthy, 2008; Pattanayak, Wunder, and Ferraro, 2010). There are situations where the system would be bad for poverty reduction and distributive justice. Many of the rural poor in low income countries enjoy Nature's services from assets they do not own. Even though they may be willing to participate in a system of property rights in which *they* are required to pay for ecosystem services provided by landowners (as Pagiola, Rios, and Arcenas (2008) reported in their careful study of a silvo-pastoral project in Nicaragua), it could be that the economically weaker among them are made to pay a disproportionate amount. Some may even become worse off than they were previously. One could argue that in those situations the state should pay the resource owner instead, using funds obtained from general taxation. Who should pay depends on the context.

Box 13
Experience With PES Programmes

PES programmes differ in the types and scale of the demand for ecosystem services, the payment source (i.e. who makes the payment), the type of activity for which payment is made, the measure used to judge the quality of the service for which payment is made, and of course the size of the payment. The effectiveness of a PES programme depends crucially on its design.

In one variant, as in the case of CAMPFIRE in Zimbabwe, the state awards inhabitants of an ecosystem (e.g. an open range in the savannah) the right to charge for the services it provides those who are interested (safari for eco-tourists). In another variant, the state pays restoration costs for the benefit of citizens. The now-revived Ganga Action Plan of the Government of India to restore the river Ganges is an example. The Colombian government's policy to pay for the conservation of biodiverse forest to maintain natural capital and enhance livelihoods post-conflict is yet another example.

Then there are variants at smaller scales. The Trumpington Meadows development, involving a local chapter of the Wildlife Trust (an NGO), local farmers, and property developers on the southern fringe of Cambridge (UK), has established 1,200 new homes while creating a Nature reserve that spans 60 hectares – 80% of which constitutes wildflower meadows. New species have already colonised the Nature reserve, while some of the species present prior to development can still be found in the new meadows. In still another variant, a concerned citizen initiates a Trust to which individuals and government contribute to restore an ecosystem of value to local people. Just two kilometres from New Zealand's Houses of Parliament, Zealandia – a conservation project covering 225 hectares – has reintroduced over 20 species of native wildlife, some of which have been absent from mainland New Zealand for more than 100 years. In addition to providing a space in which city-dwellers can easily experience their surrounding natural environment, Zealandia's example has spawned numerous community conservation initiatives (Lynch, 2019).

And then there are examples where a farmer unilaterally 'wilds' their land so as to provide ecosystem services (carbon capture and wildlife experiences), financed in part by government subsidy and in part by tourists.[70] In each of these examples, it is the beneficiary who pays for the ecosystem service. That could seem a trite observation, but the law could in principle have been so designed that suppliers of ecosystem services are required to pay potential beneficiaries if the services are not provided!

Today, there are literally hundreds of PES schemes around the globe. China, Costa Rica, and Mexico, for example, have initiated large-scale programmes in which landowners receive payment for furthering biodiversity conservation, carbon sequestration, landscape amenities, and hydrological services. These are multiple objectives, and in practice a PES system may have to be designed to target more than one. That creates problems. A system could be aimed at reducing fragmentation of an ecosystem but has to check that it does not lead to an increase in disease transmission among populations; it could be aimed to improve a habitat for birds even while increasing the watershed's supply of other ecosystem services; its purpose could be to increase both carbon sequestration and hydrological services; it could be designed to reduce local poverty while promoting Nature conservation; and so on. Multiple goals add to design challenges.[71]

14 Common Pool Resources (CPRs)

Ecosystem size matters. The atmosphere as a sink for pollution embraces all humanity; it is a global common. In contrast, a grazing field is typically contained within the perimeters of a village's jurisdiction. The economics of climate change has explored institutional arrangements that are potentially available for curbing carbon emissions. They all involve nations as players.[72] In contrast, it is possible, even desirable, for the inhabitants themselves to manage geographically confined ecosystems. One reason is that it is a lot easier to institute community fines (even social sanctions) for overusing village grazing fields or rainforest patches than it is for governments to set a tax on them. Fewer jurisdictions are involved in negotiations and monitoring people's activities is much easier when it is undertaken by community members themselves than when it is undertaken by a government official sent from outside. Moreover, knowledge of the local ecology is held by those who work on, and live in and around, the commons. Local participatory democracy offers a mechanism by which that knowledge can inform the way resources are used. Taken together, they suggest that as the basis of cooperation over the use of a geographically confined ecosystem, *mutual* enforcement would be more reliable than enforcement by external agencies such as governments.

Confirming this is not easy. In an exceptional study on the quality of forest management in the central Himalayas, Somanathan, Prabhakar, and Mehta (2005, 2009) used satellite images and field surveys on what was a natural experiment in governance to find that crown cover was no less in places that were governed by village councils than it was in areas managed by the state, but expenditure on governance was an order of magnitude higher in the latter. The authors also reported that relative to unmanaged commons, crown cover in broad-leaved forests was higher in village-managed commons, but was not appreciably different in pine forests. It did not go un-noted by the authors that under the user rules, broad-leaved forests provided more benefits to community members than pine forests. As in any management problem, individual incentives and monitoring costs matter.[73]

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[70] In her book, *Wilding*, Isabella Tree provides a vivid account of the way she transformed her agricultural farm into a Nature reserve (Tree, 2018).

[71] Perrings (2014) provides a fine, extended discussion of differences among PES systems.

[72] Barrett (2003, 2012) are key publications on why climate negotiations have so far failed.

[73] Baragwanath and Bayi (2020) report a similar finding on a site in the Brazilian rainforest. Deforestation was significantly less in land inside a territory where inhabitants had been given collective property rights than in land outside the border.

We are talking here of the role social norms play in sustaining cooperation among resource users. Anthropologists and political scientists observed a different world from the one Hardin (1968) had considered when describing the tragedy of the commons. He had alluded to grazing fields from a distance, whereas those scholars studied grazing fields in the village economies they had visited. They discovered that spatially confined ecosystems such as woodlands, water sources, grazing fields, mangrove forests, and coastal fisheries are often common property, but are regarded as property of the *community*. Access to them by outsiders is not permitted without the community's consent. To contrast spatially confined common-property resources from the open access resources Hardin had in mind, scholars have named the former, *common-pool resources* (CPRs). A rich, striking literature has found that communities restrict their use of CPRs using a wide range of measures (see below), held together by social norms of conduct. The norms are effective because community members have an incentive to impose them on one another. Hardin had not appreciated that there are common property resources which are not open to all, so his analysis came under criticism (Feeny et al. 1990; Ostrom, 1990). That local ecosystems in low income countries are communally held is not a happenstance. Annex 2 discusses the reasons.

Because CPRs are seats of non-market relationships, transactions involving them are not mediated by market prices, which is why their fate usually goes unreported in national economic accounts. An extensive empirical literature identifies community practices over the use of CPRs that differ in their complexity, depending on both geography and history. Because mutual enforcement, not external enforcement (e.g. by the state), is the way rules and regulations are imposed on the use of CPRs, it pays to read examples.

In an early study of communitarian allocation rules over the use of standing timber in the Swiss Alps, Netting (1981) found that village councils marked equivalent shares for community members, who in turn drew lots for the shares. Sanctions were imposed on those who took more firewood than their entitlements. In summer months, cattle owners were entitled to graze as many animals on the communal alps as they were able to feed from their private supply of hay during the preceding winter. That way the total number of animals was kept roughly in line with the fodder potential of the village meadows. Netting traced the origins of such communitarian arrangements on the Alps to the 15th century.

From his study of communitarian allocation rules over water and grazing land in South Indian villages, Wade (1988) reported that villages downstream had an elaborate set of rules for regulating the use of water from irrigation canals. Fines were imposed on those who violated the rules. Most villages had similar arrangements for the use of grazing land.

In a study of the Kuna tribe in Panama, Howe (1986) described an intricate set of sanctions imposed on those who violate norms of behaviour designed to protect a common source of fresh water. In a study of sea tenure in northern Brazil, Cordell and McKean (1985) uncovered a system of codes that served to protect the fishery. Violations of the codes were met with a range of sanctions that included both shunning and the sabotaging of fishing equipment. And so on.

Are CPRs important to rural people? In a pioneering study on the significance of CPRs, Jodha (1986) found in a sample of semi-arid districts in Central India that the proportion of income among rural families that is based directly on CPRs is 15-25%. Cavendish (2000) arrived at even larger estimates than Jodha from a study of villages in Zimbabwe: the proportion of income based directly on CPRs was found to be 35%, the figure for the poorest quintile being 40%.

CPRs not only supply households with a regular flow of ecosystem services and tangible goods (water, fuelwood, fibres, building material, fruit, medicines, honey, fish), they also offer protection against agricultural risks. CPRs are sometimes the only assets to which the otherwise disenfranchised have access. In a study of households on the margin of the Tapajos National Forest in the Brazilian Amazon, Pattanayak and Sills (2001) found that households made more trips into the forest for non-timber products when times are hard. In an early study, Hecht, Anderson, and May (1988) described the importance of *babassu* products among the landless in Maranho, Brazil. Extraction from the plants offers support to the poorest of the poor, most especially women. The authors reported that *babassu* products are an important source of cash income in the period between agricultural-crop harvests. Falconer (1990) offered a similar picture in the West African forest zone.

The downside of communitarian institutions is that, like so many other institutions, they suffer from inequities. That women may be excluded from CPRs has been recorded in the study of communal forestry in India (Agarwal, 2001). Entitlements from CPRs have also been known to be based on private holdings, that is, richer households have been found to enjoy a greater proportion of benefits. Beteille (1983), for example, drew on examples from India to show that access to CPRs is often restricted to the elite (e.g. caste Hindus). Cavendish (2000) reported that in absolute terms richer households in his sample of villages in Zimbabwe took more from CPRs than poor households. In an early review, McKean (1992) noted that benefits from CPRs are frequently captured by the elite.[74] Agarwal and Narain (1999) exposed the same phenomenon in their study of water management practices in the Gangetic plain. The state can play a powerful role here. It can engage with communities so as to eliminate social inequities. Well-functioning states do that in other contexts (e.g. ensuring fair elections). We argue below that it has an important, albeit indirect, role in the management of CPRs. But to do that it pays to study conditions that are necessary for people to trust one another and have confidence in their institutions to protect that trust. As would be expected, these issues are vital to the economics of biodiversity.

15 The State, Communities and Civil Society

Institutions are overarching entities. People engage with one another *in* institutions. Collective action would prove to be impossible in an institutional vacuum. It is then natural to ask: *under what contexts would a group of people wishing to engage with one another enjoy the mutual trust they need in order to fulfil the obligations they undertake*?

Outside the family, three contexts suggest themselves: (i) the people are trustworthy; (ii) the group is able to appeal to an external agency to enforce agreements; and (iii) group members are able to converge on norms of behaviour that mutually enforce agreements.[75]

Economic models of the marketplace are built mostly on (ii), where the external enforcer is usually taken to be the state, its coercive weapon being the law and the force required to enforce the law. Although the models rely on (i) only minimally, it is not as rare in the world as we may suspect. Evolutionary psychologists have found that communal living, role modelling, education, and receiving rewards and punishments (be it here or in the afterlife) help us to acquire a general favouring of pro-social behaviour. People are trustworthy in varying degrees. When we resist the temptation to go take a closer look at an exotic plant in the woods it is not necessarily because others will rebuke us for trampling over fragile Nature, it can be because we do not want to disfigure it. The problem is that although pro-social disposition is not foreign to human nature, no society could rely exclusively on it. How is one to know the extent to which someone is trustworthy? If the personal benefits from betraying one's conscience are large enough, almost all of us would betray it. Most people have a price, but it is hard to tell who comes at what price.

People everywhere have tried to establish institutions in which they have an incentive to cooperate. The incentives differ in their details, but they have one thing in common: *those who*

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[74] See also Bromley (1992) and McKean (1992) for wide-ranging reviews of CPR management schemes.

[75] Daily routines within the family are usually carried out without thought because of mutual affection among members.

break agreements without cause suffer punishment.[76] In contrast to (i), where the punishment is meted out by *self*-censorship, in (ii) it is meted out by a source external to the person (the state, tribal chieftain, village head), and in (iii) it is meted out in the community by *mutual* censorship, requiring as it does social norms of behaviour. The evidence of people's doings that are required if (ii) is in play is based on *verification* (e.g. judgments in law courts). In contrast, (iii) requires that people are able to *observe* one another's behaviour, otherwise social norms would have nothing to work on.

Trust in others and confidence in the institutions of government and markets that enable people to engage with one another for mutual advantage is called *social capital*.[77] It is, however, common to regard society as comprising three classes of institutions: households, markets and state. The economics of climate change was initially framed explicitly with that three-way classification. The idea of social capital illuminates a fourth class of institutions, comprising *communities* and *civil society*. They both play an essential role in enabling people to engage with one another without the direct involvement of either markets or the state.

Social capital is the seat where individuals and organisations can be held to account by the public. Reputation is a form of enabling asset that private firms are eager to acquire. Firms today try with varying success to purchase reputation (Bakan, 2020), but in previous times it was acquired by behaving in ways that build their reputation. For that to be a viable route, consumers have to coordinate on norms of doing business with firms. Word of mouth used to be a common method of coordination. Today social media is a powerful platform. In Part II, we will suggest that the public and private financial institutions both have large roles to play in directing private investment toward projects that protect and restore Nature and their sustainable use.

Communities and civil society – the 'third estate', as they are sometimes called – carry somewhat different connotations. It is not a travesty to think of 'communities' as institutions that work outside the state (they mostly evolved in traditional societies when there *was* no state, at least not in the contemporary sense) to manage, for example, their local ecosystem.[78] That can be contrasted with 'civil society', which we may think of as comprising institutions that engage actively with the state, for example, to create a place for services that the state is either unwilling or unable to provide and, more generally, to make the state function better (that can be a cause of friction between the two of course).

Nor are communities and civil society without their own deficiencies. As noted in the previous section, communities can harbour large inequities (e.g. between men and women; between castes, ethnic groups, and so on) and civil society can degenerate into mere special interest groups; worse, street gangs. For simplicity, we amalgamate the pair and regard social arrangements overseen by communities and civil society as *communitarian institutions*.

The state has the enormous advantage over communitarian institutions in the ability to mobilise resources. It can finance projects that these institutions on their own would not be able to, and it can coordinate their activities for their mutual benefit. The biosphere is spatially

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[76] Offering rewards for good behaviour is the flip side, but for obvious reasons the rewards are more in the form of prestige, not money.

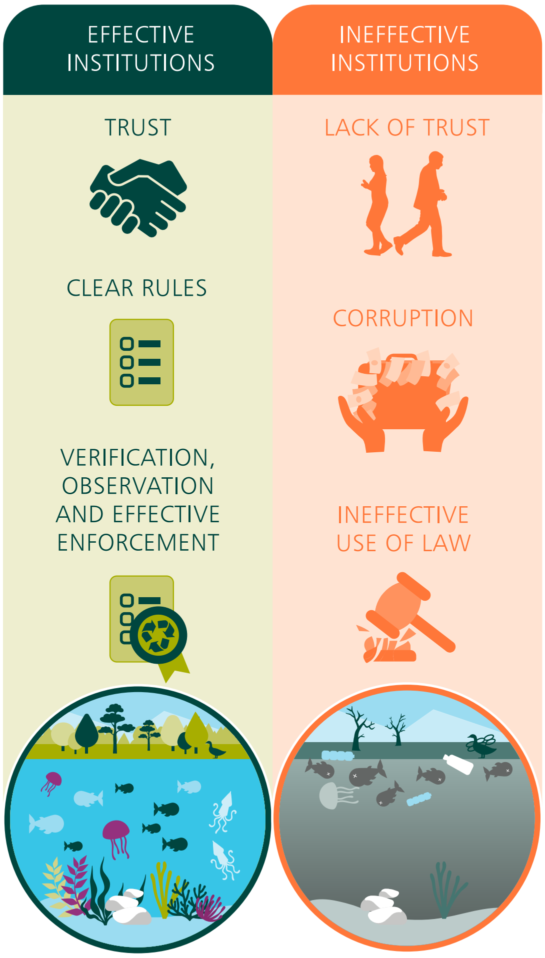
[77] The literature is enormous. Contributions that have direct bearing on the issues studied here include Coleman (1988), Putnam (1993), Fukuyama (1995), and Granato, Ingelhart, and Leblang (1996). Dasgupta and Serageldin (2000) is a collection of both theoretical and empirical essays on the subject. The way the notion of social capital has been framed here and in the *Review* is not quite the same as it has been proposed in the above works, nor is it framed the same way even among them, but ambiguity is not a hindrance in so complex a notion; it is instead a help, as it enables us to avoid a protracted discussion on what social capital means.

[78] That depends, of course, on how far back one looks back. In an essay on the world in Homer's songs, Finley (2002: 89) wrote: "The world of Odysseus was split into many communities like Ithaca. Among them, between each community and every other one, the normal relationship was one of hostility, at times passive, in a kind of armed truce, and at times active and bellicose." Finley would seem here to be using 'community' to refer to the social fabric of an entire island kingdom.

so heterogeneous that knowledge of its ecosystems' particular traits are held only by their inhabitants. On the other hand, the inhabitants' knowledge of the circumstances of the outside world may be very limited, which is yet another reason the state has a vital role. The illustrations in Box 14, however, point to extensive government failure to aid communities to protect and preserve their local ecosystems.

Effective institutional structures are therefore *polycentric*.[79] We explain the idea below, but it is a commonplace in the notion of a mixed economy, in which competitive markets supply private goods and services, and a central authority supplies public goods and services (including application of the law and measures that brings about a fair distribution of assets among people). The price system is the hallmark of markets. It serves not only to coordinate the choices people make, it simultaneously aggregates diffused information across the economy.[80] That system, however, cannot serve to protect and preserve biodiversity because Nature's processes do not satisfy a number of technical conditions that are required for markets to function well. Two conditions are especially important: (i) Nature is mobile, meaning that it is impossible to establish private property rights to many of its processes (silence and invisibility reinforce the problems); and (ii) production and consumption possibilities involving the biosphere (in other words, *all* production and consumption possibilities!) are characterised by non-linearities. Communitarian institutions fill the hole created by the inability of markets to function well.

Figure 18 Effective and Ineffective Institutions

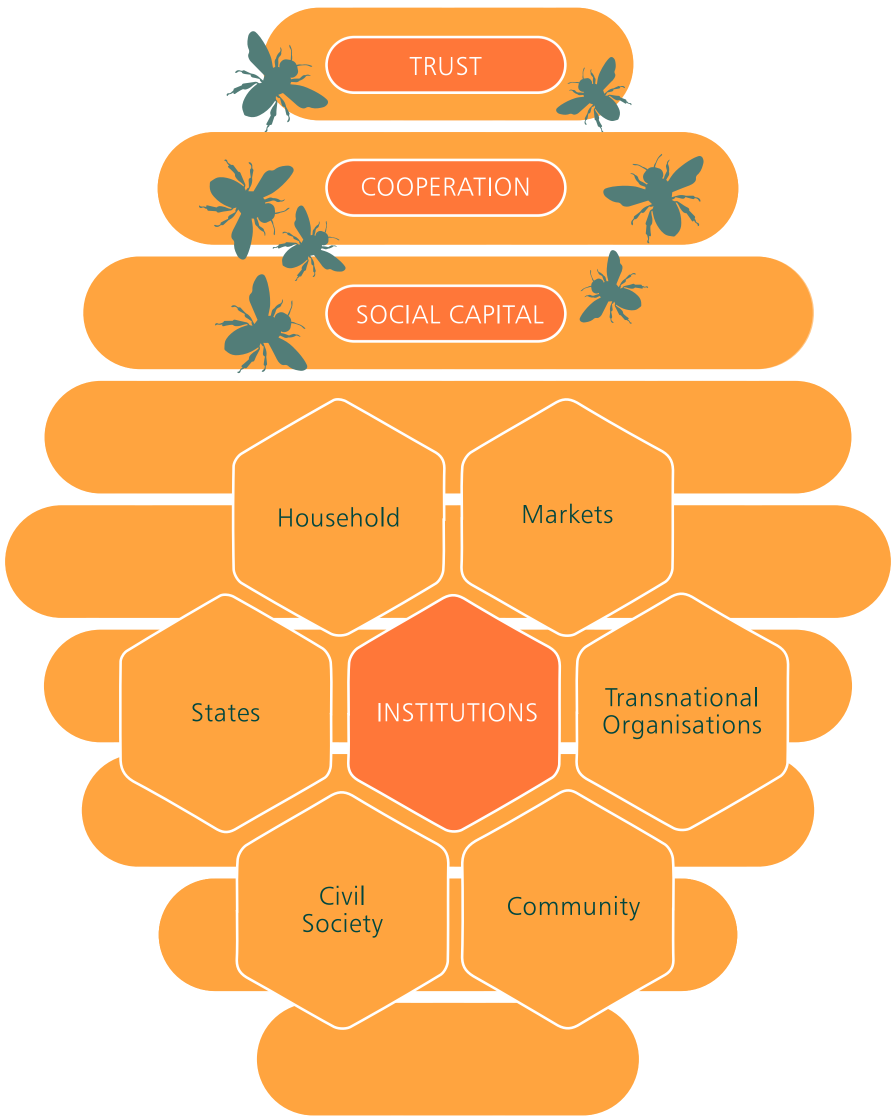


[79] Ostrom (2010) popularised the term.

[80] For a fine exposition of the place of the price system in a well-functioning economy, see Stiglitz (1989).

Polycentric structures that are best placed to protect and promote biodiversity are thus *layered* institutions: global, regional, national, and community based. Each layer requires an authority at the apex to achieve coordination below and with other layers laterally. In the contemporary world, there is thus an enormous role for government and non-government organisations (NGOs) to help build or rebuild local institutions through which communities could get to realise the advantages of informed collective management under changing times. Such help would involve, among other things, devising clearly defined rules concerning the allocation of burdens and benefits, rules whose compliance can be observed (hopefully verified also) by the others who are involved. Figure 19 adds communitarian institutions to the customary triad of households, markets and the state for classifying institutions within a nation. States on their own are not capable of curbing transnational externalities. The management of global public goods, such as the benefits we all enjoy from tropical rainforests and the oceans, and the harms we all suffer from wildlife trafficking and pandemics, requires transnational institutions. Part II highlights humanity's collective need today for an enhanced version of supra-national institutions.

Figure 19 Society's Institutions



Box 14
The Fragility of Trust

Collective undertakings are of necessity built on trust and confidence in others. The law is able to function only when citizens trust one another to abide by the law and have confidence in government to enforce the law. In turn, those responsible for law enforcement have to believe that not to discharge their responsibility will prove costly for them, say, come the next election. Communitarian management of CPRs is also built directly on trust. The mechanism that provides incentives to members to abide by their agreement and so enjoy the benefits of cooperation involves the use of social norms. But social norms can prove effective only when individuals trust one another to act in accordance with the norms. Mutual trust is self-confirming.

The problem is, mutual *dis*trust is also self-confirming. If everyone believes that no one else will behave in accordance with the collective undertaking, they will all act in ways that confirm their beliefs. The move from one set of beliefs to the other tips a society from order into disorder. Even though the deep cause of the societal rupture is a flip in *beliefs*, proximate causes could be extraneous events. Even a rumour that a small group of people in one small part of the country has mistreated another equally small group of people can start a riot that spreads. The benefits of cooperation can only be enjoyed if society has in place corrective mechanisms to quell and repair collective dysfunctions that may be caused by any one of a multitude of external events. Polycentric institutions create the necessary separation among jurisdictions to enable society to correct local failures to cooperate.[81]

Both MA (2005a-d) and IPBES (2019) found that CPRs have deteriorated in recent years in many parts of the poor world. Why should that have happened in those places where previously they had been managed in a sustainable manner?

Several classes of reasons suggest themselves: one stems from deteriorating external circumstances, under which both the private and communal profitability of investment in the resource base decline. Political instability is a general cause. It is, of course, a visible cause of resource degradation, as civil disturbance all too frequently expresses itself by a destruction not only of produced and human capital, but of natural capital too. But increased uncertainty in communal property rights is a frequent, often hidden cause. People could worry that the state or warlords will assume authority over the CPRs. If the security of a CPR is uncertain, the returns expected from collective action are low. The influence would run the other way too, with growing resource scarcity contributing to political instability, as rival groups battle over resources. The feedback could be positive, exacerbating the problem for a time, reducing expected returns yet further.

A second class of reasons involves the unintended consequences of even well-intentioned public policy. They can happen in curious ways. Mukhopadhyay (2008) is a historical study of the transformation of agrarian land in Goa, India, that was earlier owned and regulated by a communitarian institution called the *communidades*. When Goa became a part of India, the government introduced land reforms that gave tenants the right to purchase the land they had worked. The author does not question the underlying motivation behind land reforms, but notes one unfortunate consequence, which is the breakdown of cooperation among households in maintaining the embankments that had earlier prevented the land from flooding by tidal waters. Over the years, deterioration of the embankments has led to an increase in soil salinity.

[81] See Dasgupta (2007) for the place of trust in understanding economics, not merely the economics of biodiversity.

A third class of reasons CPRs have deteriorated in many places has to do with rapid population growth, which triggers environmental degradation if institutional practices are unable to adapt to the increased pressure on resources. In Cote d'Ivoire, for example, growth in rural population was accompanied by increased deforestation and reduced fallows in the 1990s. Biomass production declined, as did agricultural productivity (López, 1998).[82]

A fourth class of reasons appears when community rights are overturned by central fiat. In order to establish its political authority, a number of states in the Sahel, for example, imposed rules that destroyed communitarian management practices in the forests. Villages ceased to have authority to enforce sanctions on those who broke community rules. But state officials did not have the expertise to manage the commons, often they were corrupt. Thomson, Feeny, and Oakerson (1986), Somanathan (1991) and Baland and Platteau (1996), among others, have identified the ways by which the exercise of state authority can damage local institutions and turn CPRs into what are in effect open-access resources.

Management of the global commons involves an even more complicated environment for trust to emerge. Cooperation among nations over such activities as tele-communication, use of air space, and time keeping has been remarkably successful in comparison with the outcomes so far of negotiations over climate and biodiversity. In a far-reaching body of work that uncovers reasons that climate negotiations have so far failed to achieve agreed goals, Barrett (2003, 2012, 2015) has shown that the agreements made were never enforceable. What passed as commitments were thus not credible. In these works, Barrett has also explored ways in which agreements could be so framed that they would be enforceable.

16 Arbitraging Assets

We began by observing that we are all asset managers and that asset management involves *comparisons* of portfolios – across time or at a point in time. That means asset management involves making comparisons of alternative investment opportunities. That said, none of us views the world from a single perspective. We each play a private role but on occasion we also view the world as a *citizen*. This distinction lies at the heart of the *Review*. It explains why people lament our collective behaviour that leads to the Impact Inequality, even while contributing to that behaviour.

Let us then imagine for concreteness that in their role as private asset managers people desire to maximise their personal wealth and value stocks at their market prices, but that as citizens they commend, even vote for, economic programmes that protect and promote societal well-being. The latter means that as *citizen investors* people value investment opportunities in terms of accounting prices. Because markets place little value on Nature, the private investor's portfolio does not contain many investments that protect and promote Nature (that is, 'green' projects), while citizen investors favour portfolios that include green projects. Nevertheless, whether people act as private investors or commend investment projects as citizen investors, their goal is to maximise portfolio values – the big difference between the two types of investors lies in the portfolios they believe maximise wealth. In the former case, the wealth in question is *private wealth*; in the latter, the wealth in question is what we have previously called *inclusive wealth*. The difference between them lies in the prices used to value capital goods. To have a sharp distinction between the 'private' and 'public' roles we all play, let us imagine the citizen investor is concerned with the *global* portfolio of assets.[83] In either case, to say that an investor's goal is to maximise wealth is to say that her goal is to maximise the value of the portfolio from among the portfolios available to her for consideration.

[82] Diamond (2005) offers an account of past societies that collapsed as their local ecosystems collapsed. In a number of cases, the collapse was triggered by pressures of population growth that had led to unsustainable uses of land.

[83] The comparisons we make in the text can also be undertaken if the citizen investor is interested only in the nation's portfolio.

16.1 Arbitraging Assets at a Point in Time

Maximising the value of portfolios is a goal, but that does not on its own tell the investor what rule she should follow when choosing or commending a portfolio. Suppose, to take an example, a private investor has an amount of money to invest, say £X. Value maximisation would direct her to choose a portfolio that earns as large as possible a risk-adjusted return on her investment at the end of, say, a year. For simplicity, we assume she intends to spread her £X only on financial assets and a one-year government bond that offers a fixed rate of interest. The investor is interested in the real return, of course, but that is uncertain if only because she cannot forecast changes in the consumer price index. That uncertainty will make itself felt equally for all assets. So we may ignore it in the account that follows and suppose that the return on government bonds is certain.

In order to choose her portfolio, the private investor assesses the income she is likely to receive from each of the stocks that are available for purchase. Income from a stock (i.e. the dividend she would receive) is the stock's *yield*. But the price of the stock relative to the government bond could go up or down during the year.[84] We call that *capital gains*, recognising that the 'gains' could be a loss. At the end of a year the investor's wealth as capitalised in the stock would be its yield plus the value of that stock. The latter will contain the capital gains term. Therefore, *the rate return on investment in a stock is the yield on a unit of that stock plus the capital gains on it over the year*.

In contrast, the interest on £1 on the government bond would be the bond's yield. At the end of the year, the investor's wealth as capitalised in the bond would be the amount she receives when she cashes in the bond. In other words, *the rate of return on investment in the bond is the interest on the bond over the year*. Her wealth at the end of a year is her initial investment in the portfolio of her choice plus the return she earns on it. It is then obvious that value maximisation leads the private investor to choose a portfolio in which, adjusting for risk, the assets offer the same rate of return. This rule is known as the *arbitrage condition*.[85] And she holds a portfolio rather than a single asset so as to reduce uncertainty in her wealth in a year's time (as in the saying that one should not put all of one's eggs in the same basket).

No two private investors are likely to hold the same portfolio, if for no other reason than that their assessment of risks would typically differ as would their attitude to risk. But the basic idea remains: *asset management involves comparison of rates of return on investment*.

For the small private asset manager, prices would be unaffected by her portfolio choice, but for the citizen who is trying to reach an opinion on the portfolio humanity ought to hold, the prices she uses to estimate rates of return will not be independent of the portfolio she favours. She will, for example, notice that the oceans and the atmosphere have neither markets nor social institutions to mediate their use, meaning that their prices are zero. Fishing companies no doubt incur harvesting cost, but that only amounts to the cost of transporting fish from the oceans to the marketplace; the cost does not include the *rent* they ought to pay the global community for the fish they catch, nor for the wasted bycatch they throw back into the waters. Similarly, there is no global tax on carbon emissions; mostly we are free to emit as much as we like.[86] The citizen investor will know also that communities who may have been inhabiting a region rich in biodiversity have no deeds to their assets and are vulnerable to eviction by governments in aid of companies eager to mine, ranch and establish plantations. Because she recognises the

[84] Government bond serves as the numeraire in this account. There is no loss in generality in doing this.

[85] If, adjusting for risk, the expected rate of return on one asset was greater than that on another, the latter would not be included in her portfolio of choice. That is the essence of 'arbitrage', which is the practice of taking advantage of price differences between two or more asset markets.

[86] In fact, the rents are not zero in the market place; they are negative because of the plethora of subsidies governments offer people to exploit Nature (Box 9).

significance of human rights and the ecosystems where the inhabitants reside (the biodiversity in that unique region is a global public good), she will place a positive value on them – the accounting prices she estimates would be positive – but then she would proceed to apply the reasoning we have just reviewed. The reasoning in this particular example could lead her to place a non-negotiably high value to the region, which would mean to her that the region should never be converted through development. She will agitate for an international agreement to maintain the region in the global portfolio of assets, an agreement that presumably would include financial payments to governments in the region for disallowing its conversion into capital goods that are only useful for producing provisioning services.

If forecasting rates of return in the marketplace is hard, projecting rates of return on investment in assets that have no markets is harder still. Which is why our citizen investor's work is harder than that of the private investor. Measuring an ecosystem's yield when it is for free in the marketplace requires an understanding of ecology. If the capital good the citizen investor is considering is a fishery in the oceans, yield would be the additional *biomass* of fish that would be available in a year's time if a unit less was harvested today.[87] Because fisheries are expected to decline in relation to stocks of produced capital under business as usual, our citizen investor would expect the accounting price of ocean fisheries relative to government bonds to increase over time. So the rate of return – and as she is imagining the investment as a citizen, it would be the *social* rate of return – on the fishery would be its yield plus the (accounting) capital gains it would enjoy. If the asset she is considering is the atmosphere as a sink for our carbon emissions, its social rate of return would be the *reduction* in damages over the year that humanity would enjoy if emissions were reduced by a unit today.[88] Box 15 presents an estimate of the yield of the biosphere's stock of primary producers (Section 2). The exercise brings together the macro statistics of the state of the biosphere (Sections 5-7) and the application of micro reasoning to global statistics that we as investors engage in.

Box 15
Global Yield of Primary Producers

Applying remote sensing data covering several years to models that trace the yield (expressed in net biomass production per year) of various seats of biomass to such factors as sunlight, climate and terrain, the yield of the planet's primary producers was estimated at the end of the 20th century to be about 105 trillion Kg per year (Field et al. 1998). Primary producers' yield is called, understandably 'primary production'. Similar techniques have been used to estimate the global stock of biomass, which has been found to be about 550 trillion Kg (Bar-On, Phillips, and Milo, 2018). The latter figure exceeds the planetary biomass of primary producers, because it includes the biomass of bacteria, not all of which are primary producers; as well as the near-negligible biomass of animals. Viewing the biosphere from the perspective of humanity as a whole, the biosphere-wide *average* yield on the stock (105/550 a year), when units of biomass are awarded equal weights, is approximately 19% a year. That is of course not the primary producers' yield which, because of its spatial heterogeneity, should be understood to be the highest yield on a marginal unit of primary producer biomass across the biosphere. Moreover, the 19% is an underestimate because the stock is an overestimate of primary producer biomass.[89]

Jordà et al. (2019) have estimated that the long-run global yield (rent or dividend) on housing and equities has averaged around 5% a year. If we take that figure to be a proxy for

[87] Biomass in an ecosystem is the mass of living material in it, measured by weight, say, kilograms.

[88] The social cost of carbon, made familiar in the economics of climate change, is calculated by summing the damages humanity would be expected to suffer from over time if a unit more carbon was emitted today.

[89] There are further biases that point in the same direction. For details, see *Review,* Chapter 2.

the yield on produced capital *and* assume that the global economy has been managing its portfolio of assets in an efficient manner, then the capital gains on produced capital relative to natural capital would *as a minimum* have equalled the difference between the two figures (i.e. 14% a year). That is an application of the arbitrage condition. In short, under ideal circumstances we would have expected the accounting price of primary producers relative to produced capital to be *declining* by 14% a year.

Patently, the latter has not been happening in recent decades, nor is it happening today. Destruction of the world's rainforests and degradation of the soils, when taken together with global accumulation of produced capital (approximately 3% a year) points to rainforests above ground and the soils underground, which are important seats of primary producers, becoming *scarcer* relative to produced capital, not more abundant. Simple and crude as this calculation is, it demonstrates how far off we are from an efficient allocation of global assets. It points especially to the enormous imbalance we have created between produced and human capital on the one hand, and natural capital on the other.

16.2 Arbitraging Assets Across Time

In standard economic accounts, investment is interpreted as foregone consumption. That means investment in a capital good is the increase in its quantity or improvement in its quality that will be realised tomorrow if resources are diverted to it from consumption today.[90] We are talking of *net* investment, that is, investment net of depreciation. In the contrasting case of pollution, depreciation is the decline in societal well-being caused by an increase in pollution (e.g. depreciation of the atmosphere in its role as a sink for carbon emissions is the net increase in carbon concentration).[91]

Common-sense notions of investment, however, carry a sense of robust activism. When the government invests in roads, the picture drawn is of bulldozers levelling the ground and macadam being laid by workers in hard hats. But the notion of capital goods being adopted here extends beyond produced capital to include human capital and natural capital. That training people to be teachers is investing in human capital is simple enough. To leave a forest unmolested may not sound much like investment, but it *is* an investment. It enables the forest to grow; its growth is its yield. To allow a fishery to re-stock is to invest in the fishery, the growth in biomass is its yield; and so on. Investment in Nature can mean simply waiting.

We began the account of asset management by assuming that our *private* investor has £X to invest. As she has to keep funds aside for consumption purposes, her present wealth would be greater than that. So then how did she arrive at the figure X?

Suppose government bonds have a yield of 4%. To the investor that means time has an arrow, as a unit of consumption foregone today will yield 1.04 units of additional income in a year's time which she could consume. So she will not be indifferent between a unit of consumption today and a unit of consumption in a year's time, she will want more in a year's time as compensation for foregoing a unit of consumption today.

How much more? Presumably 4% more, because that is the rate on offer in government bonds. In short, she would adjust her allocation between consumption and investment to the point where the trade-off she is willing to make between an additional unit of consumption today and an additional unit of consumption in a year's time is in the ratio 1 to 1.04. From that figure, we can conclude that the percentage rate at which she is willing to swap a marginal unit today for

[90] Investment in the atmosphere when viewed as a sink for carbon compounds means a reduction in carbon emissions (a by-product of production and consumption).

[91] The oceans absorb atmospheric carbon as well, but because it becomes increasingly acidic, that depreciation should be included in estimates of the depreciation of the atmosphere as a sink.

an addition to her consumption at the end of a year is 0.04, or 4%. We say 4% is her private *consumption discount rate* over the year.

Being a reasoning person, she so chooses her mix of consumption and investment that her consumption discount rate equals the yield on government bonds. She reckons she will want to, and be able to, consume more next year and still have funds left to invest in government bonds that will make her wealthier still. And she wants to continue becoming wealthier because she plans to have children and would like her children to be wealthier than she, and so on, down the generations. In short, she wants her dynasty to enjoy sustainable development.

For the *global citizen* investor, the reasoning is altogether more complex. She is reasoning on behalf of humanity.[92] As she is trying to identify the mix of consumption and investment she can commend to the world (and remember, by 'investment' we mean investment in all three categories of capital goods), she will not regard future yields of the various capital goods to be independent of the mix she commends. Even the yield in government bonds would be influenced by her choice. But a reasoning similar in character to the one she used in her role as a private investor tells her that what she is after is the ideal point of contact between socially desirable and socio-ecologically possible futures; for that point of contact is the mix she would commend. And the mix she will commend is one in which the *social* discount rate on consumption in each period equals the *social* rates of return on capital goods.

Including the term 'social' in defining the two sets of rates is meant to signal that the citizen investor is basing them on the common good, not her personal good.[93] She will be using accounting prices to value capital goods, not market prices. Adverse environmental externalities associated with investment in produced and human capital mean that social rates on return on these two broad categories of capital goods are lower than market rates of return. Similarly, because people do not internalise the well-being of others' descendants, the social discount rate on consumption would be lower than the corresponding private rate. Taken together, as a social investor she will urge governments to design policies that coax private investors to invest more in natural capital than they do now. The call would be to tilt portfolios in favour of natural capital.

Box 16
Discounting Future Consumption

Discussions on social discount rates on consumption have been prominent in cost benefit analysis and the economics of climate change. The rates in use in policy assessment have almost always been positive in sign. Why?

Three reasons suggest themselves: (i) the citizen investor may desire to award a lower weight to a marginal unit of consumption in the future simply because it will be in the future; (ii) there is a risk that humanity will cease to exist in the future; and (iii) the citizen investor expects the average level of consumption to be higher in the future, meaning that a marginal addition to consumption in the future will have less value to a future person than it has to someone today. Reason (i) reflects myopia, (ii) reflects discounting for risk of extinction, and (iii) reflects a desire to discount to compensate for intergenerational inequity. Notice though that reason (iii) says that if the expectation is that people will be poorer in the future, then the consumption discount rate could be negative.

There is a fourth, more subtle reason the citizen investor may choose to place a lower weight to a unit of consumption of future generations relative to that of the present generation.

[92] Her reasoning will be based on more restricted considerations if she adopts the role of citizen of her country, but even that would be a lot wider than her role as a private investor.

[93] The term common good is no longer in much use among economists, who instead prefer 'social well-being' because it encompasses a wider range of ethical considerations.

It has to do with countering a bias that the productivity of capital displays toward the future. Because well-chosen investment has a positive yield, time has a direction in economic reasoning. A unit of investment gives rise to more than a unit of additional consumption in the future. The *Review* (Chapter 10) shows that unless the temporal asymmetry is countered, reasons (i)-(iii) may not be sufficient to ensure a reasonably egalitarian distribution of well-being across the generations.

The above reasoning shows that consumption discount rates reflect a combination of the citizen investor's ethical values and her reading of socio-ecological possibilities. The *Review* shows that the discount rate (the rate could vary over time) she will want to deploy on future consumption is the percentage rate at which the accounting price of consumption declines over the year in question. The citizen investor's choice of consumption discount rates has powerful implications for her portfolio selection. Here is an illustration using numbers taken from studies in the economics of climate change:

Suppose the investor expects consumption per capita to grow at the rate 1.3% over an indefinite number of years. In their work, the values chosen by Nordhaus (1994) and Stern (2006, 2015) for the required ethical parameters give rise to two very different consumption discount rates: Nordhaus: 4.3% a year; Stern: 1.4% a year.[94]

Simple computation shows that a marginal unit of consumption is awarded half the weight if it is to appear 51 years in the future for Stern and 17 years in the future for Nordhaus. Differences in their choice of consumption discount rates explain to an extent the disagreements among the authors on the urgency over global climate change. Nordhaus' 4.3% a year may not seem very different from Stern's 1.4% a year, but is in fact a lot higher when it is put to work on the economics of the long run. Just how much higher can be seen from the fact that the present-value of a small loss in consumption 100 years from now if discounted at 4.3% a year is 17 times smaller than the present-value of that same consumption loss if the discount rate used is 1.4% a year. The moral is banal: if the time horizon is long, even small differences in consumption discount rates can mean large differences in the message cost-benefit analysis gives us.

Drupp et al. (2018) reported findings of a survey in which economists were asked to say what rates they thought would be appropriate for discounting investment projects. While 30% of respondents recommended Stern's 1.4% or lower, only 9% recommended Nordhaus' 4.5% or higher, with 61% forming the middle ground between the two. The authors also reported that there is much less disagreement among economists than we are led to believe from the literature on discounting. 90% of economists find a discount rate between 1-3% acceptable for long-run public projects.

17 Inclusive Wealth and Social Well-Being

We have now studied the way our citizen investor would reason so as to arrive, in only broad terms no doubt, at the mix of consumption and various forms of investment she would commend. The reasoning moved from considerations of consumption-investment mixes at the micro level (for that is what portfolio analysis amounts to) toward a picture of the macroeconomy moving through time (the mix of consumption and investments in the aggregate).

But there is an enquiry that runs the other way, from the evaluation of the macroeconomy to rules that should govern decisions at the microeconomic level (i.e. at the level of households and firms). Our citizen investor would no doubt be astonished if the two routes did not lead

[94] The figures are taken from Dasgupta (2008), who also offers their justification.

her eventually to commend the same policies. In this section we confirm that. For simplicity, we continue to imagine the citizen investor to be interested in evaluating the global economy.

There are two types of economic evaluation that we all conduct as citizens. One is *policy analysis*, the other is *sustainability assessment*. To see what they involve, consider the list of six questions we all ask frequently:

(1) How is the economy doing?

(2) How has it been doing in recent years?

(3) What would be our projection of the economy in the future if policies and institutions evolve in the way we expect them to evolve?

(4) How is the economy likely to perform under alternative policies?

(5) Which policies should we support?

(6) What would be an ideal set of policies?

The questions prompt the citizen investor to make *two* types of comparisons:

Questions (1)-(3) require that she assesses whether an economy is on a path of *sustainable development*; that is, she evaluates a change that has been or is likely to be experienced by an economy *as it moves through* time. That is *sustainability assessment*. An example of the kind of question she asks is: "Are the prospects of improvements in people's lives and the lives of their descendants better now than they were a decade ago?"

Questions (4)-(6) on the other hand prompt the citizen investor to engage in *policy analysis*. There she evaluates the economic change that would be brought about by a proposed shift in policy *at a point in time*. An example of the kind of question she asks in policy analysis is: "Is the wetland preservation project being proposed likely to improve people's lives and the lives of their descendants?"

Question (3) is the projection of the socio-ecological world around which both sustainability assessment and policy analysis are conducted.

It transpires that sustainability assessment and policy analysis, though seemingly different, amount to the *same* exercise.[95] It transpires also that the measure our citizen investor should use to conduct the exercise is an inclusive measure of wealth, that is, adjusted for demographic changes, the sum of the accounting values of produced capital, human capital and natural capital. So we call the measure *inclusive wealth* (Figure 20).

Adjustments for demographic changes over time could be taken to mean inclusive wealth *per capita*, rather than inclusive wealth itself. Figure 9, which presented the Managi-Kumar (2018) estimates of movements in the three components of global inclusive wealth per capita in the period 1992 to 2014, signalled just that.

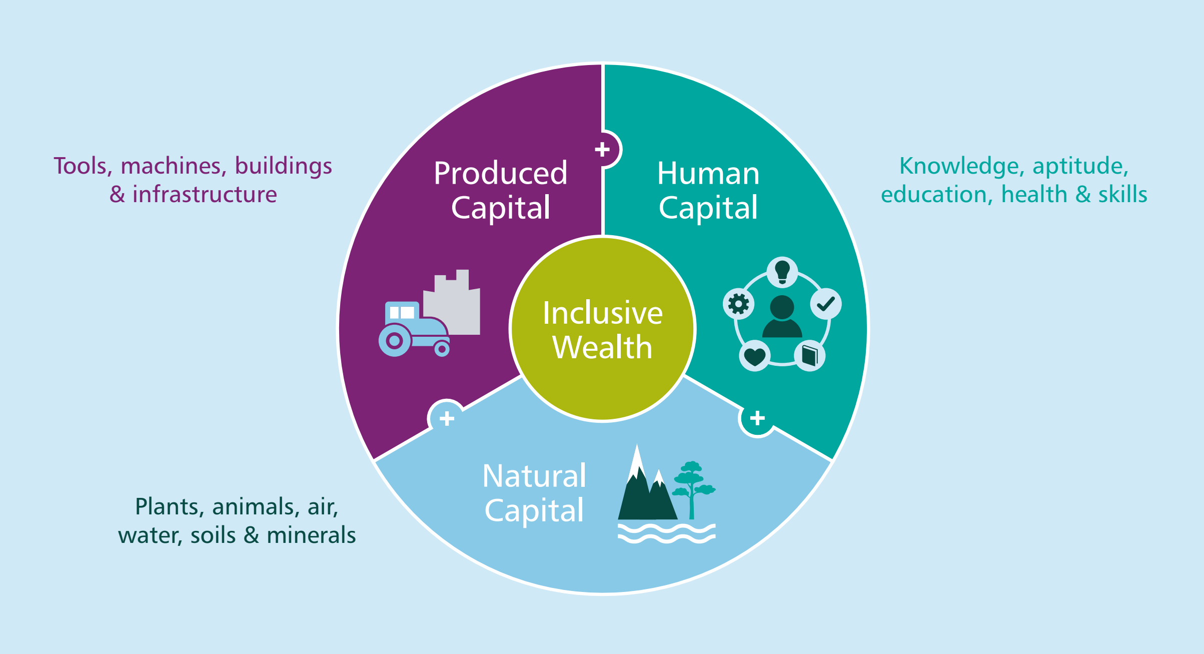
Inclusive wealth is the measure of an economy's productive capacity. If the inclusive wealth per capita we bequeath to our descendants is greater than the inclusive wealth per capita we ourselves inherited, we would be leaving behind a larger productive base for each of our descendants. Being an aggregate figure, inclusive wealth does not reflect its distribution across people. An enormous literature on distributive justice can be brought to bear to sharpen

[95] The *Review* (Chapter 13) contains the formal arguments that show their equivalence.

sustainability assessment and policy analysis. In doing that though, the citizen investor would be reading the distribution of inclusive wealth, not the distribution of GDP.[96]

Presenting economic accounts in terms of balance sheets (for that is what wealth accounts amount to) rather than incomes and expenditures tells us that we will have to revise received economic wisdom in many areas. Box 17 presents an argument based on environmental externalities that shows how misleading the argument for free trade can be.

Figure 20 Three Classes of Capital Goods



Box 17
Trade, Consumption, and Wealth Transfers

The presence of adverse environmental externalities tells us to question our enthusiasm for free trade.[97] To illustrate why, imagine that timber concessions have been awarded in an upstream forest of a low income country by its government so as to raise export revenue. As forests stabilise both soil and water flow and are the habitat for birds and insects, deforestation erodes soil, increases water run-off, and reduces pollination and pest-control downstream. If the law recognises the rights of those who suffer damage from deforestation, the timber company would be required to compensate downstream farmers.

But compensation is unlikely when the cause of damage is many miles away, the victims are scattered groups of farmers, and the damage cannot be restricted to farmers who have not bargained with the company. Problems are compounded because damages are not uniform across farms – their geography matters. Moreover, downstream farmers may not even realise that the decline in their farms' productivity is traceable to logging upstream. The timber

[96] That social well-being and what we have defined here as inclusive wealth are equivalent for the purposes of sustainability assessment and policy analysis was shown in a general setting by Dasgupta and Mäler (2000) and Arrow, Dasgupta, and Mäler (2003a-b). Dasgupta (2004) is a book-length treatment of the equivalence. Arrow et al. (2012, 2013) applied the theorem by estimating movements in inclusive wealth in five countries (Brazil, China, India, USA, and Venezuela) over the period 1995 to 2000. Managi and Kumar (2018) is the third of a series of publications that began with UNU-IHDP/UNEP (2012, 2014) in which the idea has been to estimate movements over time in the inclusive wealth of more than 120 countries, akin to estimates the World Bank provides annually of movements in the GDP of nations.

[97] The analysis here is based on Dasgupta (1990) and Chichilnisky (1994).

company's operating cost would in those circumstances be less than the social cost of deforestation (the latter, at least as a first approximation, would be the firm's logging costs and the damage suffered by all who are adversely affected). So, the export would contain an implicit subsidy (the externality), paid for by people downstream. And we have not included forest inhabitants, who now live under even more straightened circumstances. The subsidy is hidden from public scrutiny, but it amounts to a transfer of wealth from the exporting to the importing country. Ironically, some of the poorest people in the exporting country would be subsidising the incomes of the average importer in what could well be a rich country. That cannot be right.

Aside from the economic waste associated with externalities, the example has a noteworthy feature that is rarely noted in celebrations of free trade. As low income countries depend greatly on the export of primary products (coffee, tea, sugar, timber, fibres, palm oil, minerals), there is a *hidden* transfer of wealth from them to importing countries. If the importing country is rich (which has tended to be the case), then this wealth transfer only exacerbates such a disparity. The transfer of wealth remains hidden from the national accounts of both countries because national accounts do not record externalities.

The example also has a general message. Modern consumption patterns, relying as they do on imported primary goods from distant parts of the world, are prone to being under-priced. And they are under-priced at source for reasons similar to the present example. That the final products are under-priced provides people with an incentive to consume not only too much, but also consume the ecologically wrong sorts of goods. Moreover, research and development expenditure is directed toward producing new products and new technologies that are profligate in the use of primary products. That puts further pressure on the biosphere.

Why should our citizen investor want economic accounts to include inclusive wealth? The reason is, movements in inclusive wealth track *well-being* across the generations exactly. If a change increases well-being across the generations, it records a rise in inclusive wealth. Conversely, if a change has an adverse effect on well-being across the generations, it records a decline in inclusive wealth. Inclusive wealth and well-being across the generations are not the same object, but they move in the exactly the same way.[98]

How can a measure that is designed to reflect an economy's productive capacity also reflect well-being across the generations? The answer is that in estimating inclusive wealth, *accounting prices* are used to value capital goods. If we were now to return to the definition of accounting prices (Section 5), we would recognise that they provide the link between wealth and well-being. Though it may seem materialistic to speak of wealth, in talking about *inclusive* wealth rather than wealth without the qualification, we do not create any dissonance between our ethical concerns and our concerns about the means to use for enabling lives to flourish. Which is why it should cause no surprise that appraising investment projects amounts to examining whether the projects contribute to inclusive wealth.

Economists have long advocated that the criterion for project appraisal should be the net present value (NPV) of the flow of social benefits. The idea is to measure the flow of benefits, net of costs, in terms of the accounting values of the flow of goods and services. The procedure then involves summing the flow of net benefits, discounted at social discount rates. But summing a project's benefits over time amounts to the change in inclusive wealth that would be brought about by the project. It is entirely satisfying that a criterion long in use in social cost-benefit analysis matches the requirement that policy analysis should be conducted in terms of the effect of policies on inclusive wealth. Notice though, there is no connection between GDP

[98] The equivalence is stated formally and proved in the *Review* (Chapter 13).

and the NPV of investment projects. To advocate the use of GDP to measure economic progress while advancing NPV as the criterion for project appraisal is bad economics. We have no explanation for why the two have managed to survive simultaneously.

We have now come full circle to where we began, for our citizen investor now recognises that maximising the value of portfolios amounts to wealth maximisation, but as *citizen* she interprets wealth to be inclusive wealth. Accounting wages and salaries in this reckoning are the social returns on human capital; continued protection afforded by mangrove forests against storms is the return on keeping shrimp farmers at bay; planting and tending trees helps to raise biodiversity and at the same time reduces carbon in the atmosphere; creating Protected Areas on land and the seas prevents loss of biodiversity; and so on.

The citizen investor now understands that she has been misled all these years in being told that GDP growth amounts to economic progress, that her concerns over biodiversity loss run against what she is told is *sound economic reasoning*. She realises that the change from one period to the next in inclusive wealth amounts to *inclusive investment*, that is, the accounting value of net changes over the period in the quantities or qualities of all three classes of capital goods.

She now puts pen to paper to confirm that inclusive wealth increases from one period to the next if (and *only if*) consumption in that period is less than *net* domestic product (NDP), that is, GDP minus the accounting value of depreciation of all capital goods. She realises that it is possible for GDP to increase over a period of time even as inclusive wealth increases. But she also realises that because the Impact Inequality globally is so large today, the possibility of global GDP growth generated by activities that cause depreciation of natural assets for an indefinite period into the future, even while inclusive global wealth increases, is highly unlikely. She realises that only formal economic models that include natural capital can, once they have been estimated from data, provide an answer.

She may also feel that for equity reasons, raising material standards of living in low income countries and regions ought to take precedence. And because she is persuaded that individual preferences are socially embedded, she is sanguine that citizens of wealthy countries would not be sacrificing anything of substance in changing their patterns of consumption to be less damaging.

Our citizen investor realises as well that economics, when practised correctly, reflects her ethics and provides her with a grammar for expressing her concerns – opposite to what she has been told over the years. Once she has understood all that, she will complain to her government that it is relying on a misleading index of economic success and is correspondingly mismanaging the economy's assets. She will ask her economic and finance ministry to explain, for example, why its economists do not include the accounting value of natural capital in the investment projects they appraise or in the public policies they advocate. She will ask her government to explain to her why it is not doing more to repair a global financial system that permitted the world's 50 largest banks last year to provide more than US$2.6 trillion in loans and other credit to sectors that have an adverse impact on biodiversity (forestry and agriculture).[99]

She will then bring her complaints to the attention of her community. Her hope is that if citizens act together, not only will her government listen, but the world will listen too. She will insist that eternal vigilance may be the price we have to pay for freedom, but that that freedom will prove to be meaningless if we are unable to prevent Nature from utter exhaustion.

[99] See Portfolio Earth (2020).

Part II
The Road Ahead

18 Options for Change

At their core, the problems we face today are no different from those our ancestors faced: how to find a balance between what we take from the biosphere and what we leave behind for our descendants. Whereas though our distant ancestors were incapable of affecting the Earth System as a whole, we are not only able to do that, we are doing it. Humanity now faces a choice: we can continue down a path where our demands on Nature far exceed its capacity to meet them on a sustainable basis; or we can take a different path, one where our engagements with Nature are not only sustainable but also enhance our collective well-being and that of our descendants.

The *Review* constructs a unified framework for the economics of biodiversity (*Review*, Chapters 0-13), which we have presented in a brief form in Part I here. The framework has enabled us to show that the reasons we are on our current path can be traced to institutional failure writ large – it is not merely a case of market failure – and the failure of contemporary conceptions of economic possibilities to acknowledge that we are embedded within Nature, we are not external to it.[100]

The *Review* has also applied the framework to explore institutions that can help us to better engage with the natural world (Chapters 14-20). Because biodiversity varies geographically, success will look different from one region, ecosystem or country to the next. Part I showed why. Different environmental problems also require action that is sensitive to local socio-ecological conditions. There are countries that are so badly governed that the prime recommendation of concerned citizens there would be to let their communities manage their local ecosystems without state interference. There are countries where well-meaning governance has weakened the place of local knowledge in people's lives. Then there are countries where with every good intention the state has embraced policies that may have worked elsewhere but are unsuitable there. And, of course, societies differ also in their conception of what enables lives to flourish.

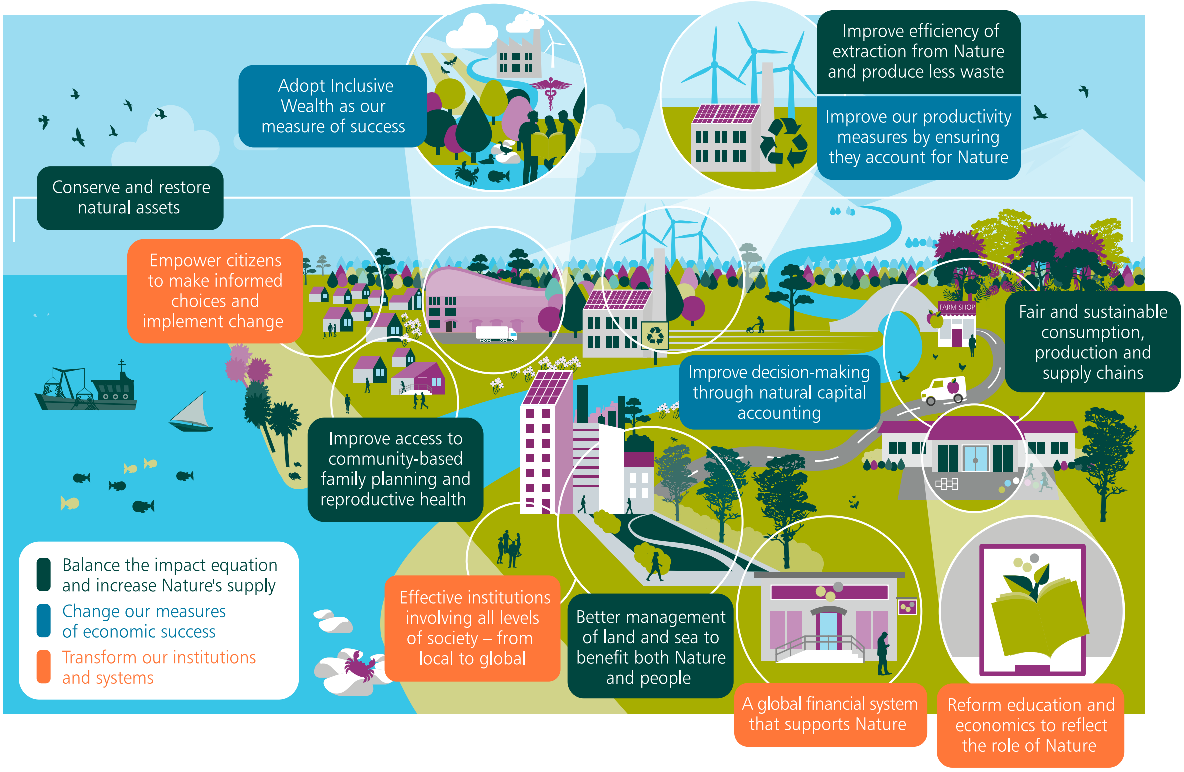
The Review has addressed the currently near-universal conception of economic progress and shown it to be wildly misleading. The Review has also constructed the necessary grammar if economics is to help shape our values and serve them, not direct them. That is why we do not even attempt to produce a blueprint of policies appropriate in different locations. What follows instead guides the reader through options humanity has for achieving the necessary change.

The options for change are geared towards three broad, interconnected transitions, requiring humanity to (i) ensure that our demands on Nature do not exceed its supply, and that we increase Nature's supply relative to its current level; (ii) change our measures of economic success to help guide us on a more sustainable path; and (iii) transform our institutions and systems – in particular our finance and education systems – to enable these changes and sustain them for future generations (Figure 21). The changes needed in our institutions and our

[100] The failure writ large includes especially our failure to *create* appropriate institutions. We are genetically and culturally a small-group animal that in an evolutionary eyeblink has gone from tens of hundreds to groups of millions to billions. We have developed technologies in a few generations that enable us to alter the biosphere dramatically, potentially exterminate ourselves, but we have not developed the supra-national institutions that are increasingly necessary if we are to achieve a sustainable pattern of activities. We are most grateful to Paul Ehrlich for framing this problem for us.

customary behaviour will involve hard choices. In what follows we present some of the ideas that, hopefully, will prove to be useful and on which others will build.[101]

Figure 21 Summary of Options for Change



The success stories from around the world brought together below not only show what is possible, they also encourage the thought that the same ingenuity – some would say the innate capability – that has led us to make demands on the biosphere so large, so damaging and so quickly relative to the history of the biosphere, can also be redeployed to bring about transformative change, perhaps even in just as short a time. Although time is not on our side, it is not too late for us, both individually and collectively, to make the conscious decision to change paths. Our descendants deserve nothing less.

19 Nature's Supply and Our Demands

In the wake of the Second World War, what became known as the Marshall Plan was launched to rebuild Western Europe. While most historians agree that the recovery experienced in Europe cannot be attributed to the Marshall Plan alone, there can be no doubt that it sped that astonishing recovery: industrial production in recipient countries leapt by 55% in just four years; by the effective end of the Marshall Plan in 1951, national per capita incomes in Britain, France and West Germany were more than 10% above pre-war levels; and the resumption of growth was sustained over the decades that followed (Eichengreen and De Long, 1991; Eichengreen, 2010). If we are to enhance the biosphere's health and reduce our demands, large-scale changes will be required, underpinned by levels of ambition, coordination and political will akin to (or even greater than) those of the Marshall Plan.[102] We elaborate on why below.

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[101] What follows has been adapted from Chapter 21 of the *Review*.

[102] Such a plea has been made by others, including in Al Gore's *Earth in Balance*, first published in 1992, and more recently in a speech by HRH The Prince of Wales to mark the start of Climate Week NYC, 2020.

19.1 Conservation and Restoration of Ecosystems

In Part I we identified reasons it is less costly to conserve Nature than it is to restore it, other things equal. It was noted that markets alone are inadequate for protecting ecosystems from overuse. Uncertainty in our knowledge of ecosystem tipping points, the irreversibility of ecosystem processes, and imperfections in verifying one another's activities, when taken together, mean that quantity restrictions (e.g. on extraction or pollution) may be a better instrument than taxation. In the context of conservation, it follows that quantity restrictions, informed by science and supported by legislation, will help to correct the externalities pervasive in our engagements with Nature.

Protected Areas have an essential role in conserving and restoring our natural capital, but it has been estimated that only 20% of Protected Areas are being managed well.[103] Improvements can be made by ensuring that Protected Areas (i) are extended and integrated into the surrounding land and sea; (ii) involve indigenous people and local communities; and (iii) receive sufficient resources for their effective management (*Review*, Chapter 18). The *Review* points to successes from around the world to demonstrate what is possible and what works. Examples include the co-management of the Gwaii Haanas National Park Reserve and Haida Heritage Site in Canada, the community-led management of Cabo Pulmo National Park in Mexico, and the increase in the global designation of Marine Protected Areas, from 3.2 million km^2 in 2000 to 26.9 million km^2 today (Duarte et al. 2018; Duarte et al. 2020a, 2020b).

More investment in Protected Areas is needed. The funds required are small. It has been estimated that to protect 30% of the world's land and ocean and managing the areas effectively by 2030 would require an average investment of US$140 billion annually, equivalent to only 0.16% of global GDP and less than one-third of the global government subsidies currently supporting activities that destroy Nature (Waldron et al. 2020). The benefits, even when confined to financial benefits, of such levels of protection are estimated to exceed the costs significantly (Waldron et al. 2020). But there are wider benefits, including lowering the risks of societal catastrophes in relation to human health – not least the risks of the emergence and spread of infectious diseases. Dobson et al. (2020) have estimated that the associated costs over a 10-year period of efforts to monitor and prevent disease spillover (which is driven by wildlife trade and by loss and fragmentation of tropical forests) would represent just 2% of the estimated costs of COVID-19.

There is the fear though that biodiversity conservation afforded by marine and terrestrial protected areas would be neutralised by disruptions caused by climate change. And that should remind us that Nature's regulating and maintenance services are complementary to one another. Neither climate change nor biodiversity loss can be tempered on its own and the efforts designed to temper them should recognise that.

While avoiding degradation of Nature should be the priority, restoration – habitat management, rewilding, allowing natural regeneration and creating sustainably productive lands and seas – also plays an essential role in improving the health of the biosphere (*Review,* Chapter 19). Restoration can also help us to address the imbalance between our demands for the biosphere's provisioning services on the one hand and for its regulating, maintenance and cultural services on the other.

Much of global biodiversity and many of our ecosystems lie outside Protected Areas. Modern agriculture has driven a great deal of environmental decline. Even though monoculture systems have raised food production, they have diminished biodiversity. Restoration can shift monocultures and degraded lands and seas to a landscape that provides multiple ecosystem services, balancing provisioning services with regulating services. Shifting cultivation and crop

[103] See UNEP-WCMC, IUCN and NGS (2018).

rotations (they increase soil fertility and reduce pests) have been standard practice in sustainable land management. Today that should be supplemented by the offer of greater incentives to farmers to adopt practices that support biodiversity and ecosystem services. Agri-environment schemes and Payments for Ecosystems Services (PES) are obvious candidates for further development. As noted in Part I, the effectiveness of PES schemes has proved to be mixed in low income countries. But even where such schemes hold great potential, their success depends on their design and scale of funding.

Better planning for the use of land and marine ecosystems, in the form of legally binding instruments, can help to provide a framework for balancing the competing demands we make of our ecosystems. By requiring that more space be given over to Nature, the planning process can also help to maintain, and even increase, stocks of natural capital. Lessons can be drawn from successes, from sustainable infrastructure development in the Bahamas, to coastal zone management in Belize (*Review*, Chapter 19).

Ecological solutions (often referred to as Nature-based solutions) have the potential to provide multiple benefits. Restoring ecosystems by ecological means can not only address biodiversity loss and climate change, they also deliver wider economic benefits. They have frequently been found to be more cost-effective than engineered solutions and have far fewer unexpected consequences. They also create employment. As part of fiscal stimulus packages and public expenditure, investment in natural capital has high social value and the potential for quick returns. Recent research suggests that ecological investments such as afforestation, parkland expansion, and restoration of rural ecosystems should have high priority as part of COVID-19 recovery stimuli (UNEP, 2020). Hepburn et al. (2020) have pointed to three reasons for investing in such activities. First, training requirements are minimal for many 'green' projects, implying that they can be implemented quickly. Second, the work meets social distancing norms. Third, many countries have blueprints of projects in existing mandates, for example, in programmes designed to meet international agreements on climate change.

A deeper case can be made for why we should expect a positive link between employment and 'green investment'. If natural capital were valued at accounting prices, we would expect green investment to increase substantially, possibly compensating for declines in produced or human capital accumulation (Section 2). Moving toward a Nature-based economic development will lead to greater returns to human capital. That in turn would lead to a greater demand for investment in human capital and for employment.

19.2 A Sustainable Ecological Footprint

If we are to avoid exceeding the limits to what Nature can provide on a sustainable basis, consumption and production patterns will need to be fundamentally restructured. By quantifying the resources required for meeting basic human needs, and comparing the estimates to planetary boundaries (Annex 2) for over 150 countries, a recent study found that while nutrition, sanitation and the elimination of extreme poverty could be met for all people without transgressing planetary boundaries, the universal achievement of contemporary lifestyles in high income countries would require resources several times the sustainable level (O'Neill et al. 2018). The authors' figures are very much in line with the crude estimates we reported in Section 7 of our ecological footprint.

19.2.1 Changing Consumption and Production Patterns

Estimates of our current and predicted future use of provisioning services including food, fibre, biofuels, timber, water and fishery and aquaculture output tell a clear story of escalating demands, and corresponding declines in regulating and maintenance services (*Review*, Chapter 16).

Several approaches can help us to meet rising demands for provisioning services while safeguarding regulating and maintenance services. In addition to changing the balance of crops intended for human food and animal feed, closing gaps in agricultural yield could go some way without expanding agricultural land further (Foley et al. 2011). Establishing clear boundaries for conservation and agriculture (known as 'land-use zoning'); making payments to avoid habitat conversion and reducing food waste; strategically deploying technology, infrastructure or knowledge; and introducing standards and certification schemes are examples of schemes that can help (Phalan et al. 2016). As well as strategies for avoiding habitat conversion, sustainable production systems can effectively deliver multiple ecosystem services. Regenerative agriculture, organic agriculture, agroforestry and low-trophic level aquaculture are capable of enhancing regulating services (such as pollination and air quality regulation) even while providing food.

Our ecological footprint is not only made up of the material we take from the biosphere, but also the transformed material we deposit into it as waste (*Review*, Chapter 4 and 4*). Enforcing standards for re-use, recycling and sharing also has an important role to play, and is likely to have a positive economic impact, including the creation of jobs.

Technological innovations can contribute enormously to reducing our footprint. Genetically modified crops can increase yields even while reducing the contribution food production makes to climate change and to biodiversity loss (Zilberman, Holland, and Trilnick, 2018). Vertical farming and meat analogues can increase yields, while reducing the contribution food production makes to climate change and biodiversity loss. In addition, there are ways to reduce environmentally damaging inputs, through such methods as precision agriculture and integrated pest management. Technological innovations can also help to reduce bycatch in fisheries. Each has potential, but they will only emerge if incentives are provided for developing and then establishing them on a large scale. Historically the private sector has relied on the state to provide the investments in research and development (R&D) that raise the productivity of its own investment in R&D. That there are synergies to be exploited between the two has been much discussed among historians of science. The state has an enormous role here for helping to finance and coordinate the investment that will prove to be necessary to help shift to a sustainable future.

We cannot however rely on technology and human ingenuity alone, we need also to change our production and consumption patterns. The human economy is bounded, so it would be entirely counterproductive to seek economic growth that damages Nature for providing the necessary finance for investment in R&D. If 'business' continues as before, consumption in high income countries and in the emerging high-middle and low-middle income countries is projected to remain the main factor driving the world's ecological footprint. An important factor in our ecological footprint is our diet. Diets rich in animal products have much higher footprints than those based on plant products. If pastureland and land used for livestock feed are combined, animal agriculture uses nearly 80% of global agricultural land. Moreover, greenhouse gas emissions from plant-based food are 10 to 50 times less than those from animal products (Poore and Nemecek, 2018). Regions differ substantially in their relative footprints. Estimates suggest that if diets shifted away from animal products, it would be possible to feed the world's present population with as little as 50% of current agricultural land. Estimates also suggest that it would not be possible to supply the world with environmentally intensive diets even if the Earth's entire land surface was converted to agriculture (Alexander et al. 2016).

19.2.2 Supply Chains and Trade

The expansion in global trade over the decades has run parallel with GDP. That has increased our ecological footprint greatly; it has also given rise to transfers of wealth from primary producers to importing countries (Box 17). It is therefore useful to study the effect of trade on the biosphere by tracking entire supply chains.[104]

A shift to sustainable patterns of consumption and production will require us to embed environmental considerations along entire supply chains. Transparency and the sharing of information across supply chains is needed, and such information should be verifiable and support the enforcement of standards (*Review*, Chapter 8). Novel technologies can help. Improvements in geospatial data and implementation of 'blockchains' along entire supply chains can help to raise transparency, for they display the impact of commodity production on local ecosystems and individual species. Geospatial data combined with machine learning have been used to estimate a global figure for the potential threat posed by extractive activities to natural World Heritage Sites (WWF and Swiss Re Institute, 2020). They have also been used to monitor Nature-related risks in sovereign debt investments (WWF and Investec, 2019). Certification schemes can make a difference, but existing schemes differ in their effectiveness. WWF, for example, compared various voluntary certification schemes in 2013 and concluded that their socio-ecological performance varied substantially between schemes.[105]

Changes in broader trade practices and policies can support a shift to sustainability (*Review*, Chapter 15). While there are limits to what market-correcting measures, such as taxes, are able to achieve for reducing our ecological footprint, they can make a difference if they are applied widely and designed well. Border Adjustment Taxes are an important example, but face both technical and political problems. Sustainability provisions in regional trade agreements also have potential, and there are encouraging signs that the number of regional trade agreements featuring environmental provisions has increased over time. Similarly, financial commitments to environmental objectives as part of aid expenditure directed at supporting trade have also increased; today they account for approximately one-third of total aid (UNEP and WTO, 2018).

19.2.3 Pricing

The accounting price of an asset or service is the sum of its market price and the tax that ought to be imposed on it.[106] The gap between accounting prices and market prices is therefore a measure of inefficiency in the allocation of goods and services: the gap reflects waste in our use of resources. But unlike food waste (Box 7), the gap is not visible. The *Review* discusses various ways available for estimating accounting prices. Open access resources such as ground water and ocean fisheries are free, so their accounting prices are the taxes that ought to be imposed on their use (*Review*, Chapter 7).

When reliable estimates of accounting prices are available, taxes can be a useful instrument for reducing environmentally damaging behaviour. At present, no OECD or G20 country collects more than 1% of its GDP in environmental taxes beyond those related to energy or motor vehicles (OECD, 2019). There is scope, therefore, to raise further revenue through environmental taxation. Such taxes need to be designed carefully, to avoid potential shifts to other activities that damage Nature (leakage), to avoid the risk of crossing tipping points (if behaviour is insufficiently influenced by the tax), and to ensure the environmental harm being taxed is measured to a reasonable degree of accuracy.

There is also an urgent need to tackle perverse subsidies, which in total are equivalent to some 5-7% of global GDP (Box 9), implying that the accounting value of Nature must be greater still. All prevailing subsidies have a historical rationale – distributional justice, national food sufficiency, political pressure from powerful lobbies and so on – which is why they prove

[104] Green et al. (2019), for example, have traced the habitat loss caused by consumption of soy to the product's final destination.

[105] Perhaps not surprisingly, in countries with weak governance there has been rapid growth of ineffective certification schemes (WWF, 2013).

[106] In a case where the ideal policy would be to subsidise the good, the accounting price would be the market price less the subsidy.

difficult to dislodge. But the resources that would become available to governments if they were removed could be used to finance programmes that benefit not only populations at large, but in particular the most vulnerable in society. Correcting inefficient economic distortions to resolve institutional failures can serve the common good.

19.2.4 Future Population

Expanding human numbers have been a significant factor in the growth of our global footprint. Global population is expected to continue to rise over this century (UNPD, 2019). In Part I, we explained how individual fertility choices are influenced by the choices made by others. We explored ways in which a society can become embedded in a self-sustaining mode of behaviour characterised by high fertility and stagnant living standards, even when there are potentially self-sustaining modes of behaviour that are characterised by low fertility and rising living standards.

As well as improving women's access to finance, information and education, greater access to community-based modern family planning and reproductive health programmes is a means for women to have greater control over their lives, shift behaviours, and improve the chance of having healthy babies.

The benefits of modern family planning and reproductive health programmes are high (Box 8). But there has been significant under-investment in family planning to date. OECD estimates suggest that less than 1% of Official Development Assistance (ODA) from the EU to Africa is directed towards family planning. It has even been suggested that a dollar spent on family planning and reproductive health is more beneficial than a dollar spent on agricultural research, rotavirus vaccination, preschool education, trade facilitation, even mosquito nets (Kohler and Behrman, 2018). As a route to accelerating the demographic transitions, investment in community-based family planning and reproductive health programmes should now be regarded as essential.

20 Measuring Economic Progress

Standard economic measures such as GDP can mislead. If the goal is to protect and promote well-being across the generations (i.e. social well-being), governments should measure inclusive wealth (a measure of societal means). Inclusive wealth is the sum of the accounting values of produced capital, human capital, and natural capital. The measure corresponds directly to well-being across the generations (*Review,* Section 17): if a change enhances social well-being, it raises inclusive wealth; if the change diminishes social well-being, it reduces inclusive wealth. Social well-being and inclusive wealth are not the same object, but they move in tandem. There lies the value of inclusive wealth in economic accounts.

Natural capital accounting is a necessary step towards the creation of inclusive wealth accounts. It enables us to understand and appreciate the place of Nature's services in our economies, including the services that are usually overlooked; it enables us to track the movement of natural capital over time (a prerequisite for sustainability assessment); and it offers us a way to estimate the impact of policies on natural capital (a prerequisite for policy analysis).

Frameworks for natural capital accounting and assessment are being developed, in many cases through the UN's System of Environmental and Economic Accounts. Countries are beginning to incorporate natural capital and ecosystem services into national economic metrics of success. China's Gross Ecosystem Product, and New Zealand's Living Standards Framework are examples (*Review,* Chapters 12 and 13).

These are early days for natural capital accounts. Increased investment in physical accounts and in ecosystem valuation would improve them. International cooperation in the construction of national accounts and the sharing of data would improve decision-making around the world. Harmonisation of national accounts should be coupled with technical assistance. Incorporating natural capital accounts in macroeconomic surveillance undertaken by international financial institutions – for example, the International Monetary Fund's Article IV surveillance activities (IMF, 2020) – would also send a strong signal, inspiring governments' reform agendas to reflect the scale and urgency of the problems societies face.

Whether we account for Nature in economic measures is key for how we interpret productivity.[107] Contemporary models of economic growth and development tend only to consider produced and human capital as primary factors of production, not explicitly natural capital (*Review*, Chapter 13). Typically, Total Factor Productivity estimates are biased upward and should be treated with scepticism. Improving and using measures of productivity that account for the use of, and impact on, Nature are crucial if we are to understand what improved productivity means. There are several initiatives, such as the OECD's *greening productivity measurement* workstream (OECD, 2017a), that have made a start.

21 Transforming Our Institutions and Systems

Our global collective failure to achieve sustainability has its roots in our institutions. Many of the institutions we have built have proved to be wholly unfit to curb our excesses; worse, they have helped to enlarge the gap between what we are led to believe is possible and Nature's bounded capacity to respond to our demands. Effective institutions are the foundations on which to rebuild our engagement with Nature and manage our assets. Beyond ensuring our institutions are fit for purpose, including in relation to managing public goods, changes in two other systems are particularly important: the global financial system and our education system.

In Section 17 we presented a general finding: neither top-down nor bottom-up institutional structures work well. What the inhabitant of an ecosystem knows and can observe differs from what an agent from the national government knows and can observe. Moreover, institutions that work well are neither entirely rigid nor entirely flexible, they are both 'polycentric' and 'layered', meaning that knowledge and perspectives at all levels from different organisations, communities and individuals are pooled and spread.

It is a commonplace assertion that we live in a highly interconnected world today. That has been applauded over the years because the fruits of labour at one place have been transmitted to other places in short order. Ideas and practices in one location are transmitted rapidly to other locations through movements of people and goods. But adverse disturbances are also transmitted rapidly. That has become cruelly evident in the rapid spread of COVID-19.

What makes for effective institutions has particular salience for the management of global public goods. Beyond exclusive economic zones the oceans are a public good. They are also an open-access common property of all nations.[108] As they are a global public good (in the 1970s they were called a Common Heritage of Mankind), the accounting rents from the issue of fishing rights and charges levied on the use of the oceans for cruises and the transportation of goods could be collected and shared among nations. A lively discussion took place in the 1970s of the amount of global rents that could be collected in the form of a tax on ocean resources (e.g. manganese nodules on the sea bed), the idea being that the tax could be used as development aid. The proposed Global Ocean Treaty, currently under negotiation among UN members, presents an opportunity to fill gaps in governance within existing supra-national arrangements to address biodiversity monitoring and conservation.

Some ecosystems have the features of a global public good but are not a global common because they are located within national boundaries. Tropical rainforests are an example.

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[107] The technical term for productivity of aggregate capital is Total Factor Productivity (Chapter 13).

[108] By creating exclusive economic zones of up to 200 miles, the UN Convention of the Law of the Sea sought to eliminate the incentives nations have to deplete ocean resources, but technological and geographical advantages mean that adverse incentives remain.

Management of river basins that cover many countries are a regional example. It is right to ask whether the fate of our economies, livelihoods and well-being should rest on national sovereignty. A fairer approach would be to pay those countries for the protection of the ecosystems on whose services we all rely. The 15th Conference of the Parties to the Convention on Biological Diversity will agree on global goals post-2020. Nature is also an important theme for the 26th Conference of the Parties of the UN Convention on Climate Change. These conferences provide powerful opportunities to set a new direction for the coming decade.

22 The Global Financial System

Finance plays a crucial role. A significant portion of the responsibility for helping us to shift course will fall on the global financial system. Governments, central banks, international financial institutions (such as Multilateral Development Banks) and private financial institutions all have a role to play in making the shift.

The problem is to encourage private financial institutions to take note of accounting prices, *if only implicitly*. The qualification is required because market prices of natural capital are far from their accounting prices. So indirect means are required. One such means is for governments and international financial institutions to invest in Nature, which may involve directing investment *away* from projects that degrade Nature and their unsustainable use. Projects that are complementary to public investment would then be attractive to private financial institutions. The financial system would be made to move its lending and credit activities also if consumers signal their distaste for investments that are rapacious in the use of Nature's goods and services. Citizens can insist that firms disclose conditions along their supply chains (product labelling is a partial method for doing that). Consumers could also boycott such products as those that do not meet standards. Reputation matters to firms, and that can be exploited by citizens.

To leave Nature alone so that it is able to thrive is to invest in it. Governments have tools at their disposal to make that happen, even if through indirect means. They range from taxes, subsidies, regulations and prohibitions to Nature-specific mechanisms, such as payments for ecosystem services (Box 13) and biodiversity offsetting schemes. While the relative share of biodiversity funding within the overall budget for Official Development Assistance has increased in recent years, existing flows are insufficient to meet conservation needs in developing countries. Increasing those financial flows could take the form of debt forgiveness, direct grants or technical assistance. The creation of binding targets on public investments in natural capital to ensure that globally agreed objectives are met would go an important step further.

The *risks* associated with biodiversity loss – reductions in the productivity and resilience of ecosystems along supply chains – have significant macroeconomic and financial implications. Far more global support is needed for initiatives directed at enhancing the understanding and awareness among financial institutions of Nature-related financial risks, learning and building on the advances on climate-related financial risks. Central banks and financial supervisors can support this by assessing the systemic extent of Nature-related financial risks. A set of global standards is required. They should be underpinned by data that are both credible and useful for decision-making. Businesses and financial institutions could then be obliged to integrate Nature-related considerations with their other objectives. The idea ultimately is to have them assess and disclose their use of natural capital. The Task Force on Nature-related Financial Disclosures, established in 2020, is a step in that direction.

There is growing evidence that individual investors want investment providers to consider sustainability and Nature in their investment decisions (UNEP and PRI, 2019). Integrating the protection of biodiversity with the fiduciary duties of institutional investors and asset managers would be a way to ensure their investment policies account for natural capital. One barrier to this is myopia. Impacts of Nature's diminution can be felt over long time-horizons. Fisheries practices in the oceans will leave an imprint that will be felt by generations of future people.

Destruction of tropical rainforests is to all intents and purposes irreversible. The time horizon within which financial actors plan and act is, unhappily, not more than a few years. Financial regulators and supervisors can play a key role in the necessary shift by changing their own assessment horizons and using their regulatory powers.

Many of the risks to life and property associated with ecological degradation are *positively correlated* among those who are affected. If the loss of mangrove forests makes someone more vulnerable to cyclones, it makes their neighbours more vulnerable also. Which is why there is need for global, regional and national insurance funds. Although there are examples of regional insurance schemes for environmental disasters (e.g. the African Risk Capacity and the Caribbean Catastrophe Risk Insurance Facility), there is currently no global insurance scheme. In principle, a global risk pool – with contributions from all countries – could help protect vulnerable countries against such shocks following extreme events. Emergency relief is not uncommon even at the global level, but its volume is always uncertain. And it that comes *after* a disaster strikes a community. Insurance, in contrast, is a security against disaster. Investing in Nature is a reliable form of insurance.

23 Empowered Citizenship

Ultimately though, it is we citizens who can bring about such changes. As citizens, we need to demand and shape the change we seek. We can do this, for example, by insisting that financiers invest our money sustainably, that firms disclose environmental conditions along their supply chains (product labelling is a partial method for doing that), even boycotting products that do not meet standards. Reputation matters, and that can be exploited by citizens. If we are not acting now, it is because we have grown distant from Nature. Such detachment is in part a symptom of societal change, including growing urbanisation, the profusion of technology, and reduced access to green spaces. Detachment from Nature has meant a loss in our physical and emotional state.

In their admirable survey of a growing literature on the role played by our direct experiences of biodiversity with personal well-being, Capaldi et al. (2015) distinguish two aspects of those experiences: *contact* with Nature and *connectedness* with Nature. The former could even involve interaction with the natural world via indoor plants or from virtual representations of Nature such as photographs or paintings of natural landscapes. The latter refers to a person's sense of connectedness with the natural world, it reflects the extent to which she internalises the experiences she has with Nature. If contact with the natural world is a means to furthering personal well-being, connectedness with Nature is an aspect of well-being itself.

Access to green spaces (they are local public goods) can also reduce socio-economic inequalities in health. Interventions to increase people's contact and connectedness with Nature would not only improve our health and well-being, there is a growing body of evidence to suggest that those interventions would also motivate us to make informed choices and demand change (*Review*, Chapter 11).

There are glimmers of hope. Examples of Nature renewal in urban environments are one (Box 13). That our desires and wants are to a significant extent socially embedded is also a cause for hope that economising on the use of Nature's provisioning services among the many throughout the world who enjoy high material standards of living would prove to be personally less costly than they fear, provided of course the economy is shared. Contemporary conceptions of the human person cuts against the grains of our sociability; we are encouraged to imagine that the thriftiness we may feel should be practised by all will fall on us unilaterally. That probably explains why most of us do not act with our neighbours to practise it.

So, there are grounds for hope. The grounds no doubt have involved small initiatives so far, but the economics of biodiversity is not the preserve of the large. The conception we would all wish to adopt is grand, but it is ultimately we citizens who will determine whether we are able live in peace with Nature.

24 Education

Our increasing detachment from Nature would seem to accompany the increasing detachment of Nature from economic reasoning. Many view Nature almost entirely through an anthropocentric lens, even while our physical interaction with and emotional attachment to Nature declines. It would seem then that if we are to appreciate our place in Nature, we have to educate ourselves.[109] We would only then begin to appreciate the infinitely beautiful tapestry of Nature's processes and forms.

Every child in every country is owed the teaching of natural history, to be introduced to the awe and wonder of the natural world, to appreciate how it contributes to our lives. Establishing the natural world within educational policy would contribute to countering the shifting baseline, whereby we progressively redefine ourselves as inhabitants of an emptying world and believe that what we see is how it is and how it will continue to be. This shifting baseline has been termed the 'extinction of experience' (Pyle, 2003).

Achieving tangible effects, however, is not straightforward. The development and design of environmental education programmes can be directed to overcome the problems. Bawa et al. (2020) have used agricultural colleges in India as examples to propose that their curricula should now include 'biodiversity science'. In their wide-ranging survey of documenting direct impacts of environmental education, Ardoin, Bowers, and Gaillard (2020) have suggested that focusing on local issues or locally relevant dimensions of broader issues, such as collaborating with scientists, resource managers and community organisations, are of enormous help. The *Review*'s emphasis on the role of communities and civil societies in the economics of biodiversity is consonant with that line of thinking. [110]

But even that would not be enough. Connecting with Nature needs to be woven throughout our lives. The connection has been found to decline from childhood to an overall low in the mid-teens, followed by a steady rise that reaches a plateau lasting the rest of one's life (Hughes et al. 2019). It is a cruel irony that we surround children with pictures and toys of animals and plants, only to focus subsequently on more conceptual knowledge, marginalising environmental education relative to the wider curriculum. Even if we had studied Nature in primary school, we may not have encountered the subject subsequently.[111] In US universities it was common practice to require first-year students to complete a course on a broad-brush history of civilisation. There is every reason universities should require new students to attend a course on basic ecology. Field studies that would accompany such a course would be a way to connect students with Nature, in particular those that may have grown up in an urban environment. Understanding even the simplest of the biosphere's processes may well be the first step toward developing a love of Nature.

There is a further reason for connecting people with Nature at an early age. The three pervasive features of Nature – mobility, silence and invisibility – mean that the consequences of actions which desecrate Nature are often untraceable to those who are responsible. Neither the rule of law nor the dictates of social norms are sufficient to make us account for Nature in our daily practices. Institutional rules, no matter how well designed, would be insufficient for eliminating

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[109] We are grateful to Mary Colwell for preparing a note for us on the place of education in the economics of biodiversity. This section is adapted from her piece.

[110] In a study of institutions of higher education in India, Bawa et al. (2020) have advocated that agricultural colleges should now include biodiversity science in their curricula.

[111] There are signs of change. The charity iAfrica is experimenting with a digital education programme on Nature conservation in schools in sub-Saharan Africa. In the UK, a GCSE in Natural History is expected to be introduced in England in 2022

environmental externalities. We will have to rely also on *self-enforcement*, that is, be our own judge and jury. And that cannot happen without creating an environment in which, from an early age, we are able to connect with Nature.

25 Nature's Intrinsic Worth: Sacredness

The *Review* has developed the economics of biodiversity by viewing Nature in anthropocentric terms. That is an altogether narrow viewpoint, but it has a justification. If, as we have shown in Part I, Nature should be protected and promoted even when valued solely for its uses to us, we would have even stronger reasons to protect and promote it if we were to acknowledge that it has intrinsic value.[112]

Many people, perhaps in all societies, locate the sacred in Nature. And the sacred is not negotiable, unless we are able to rationalise by imagining it to be incorruptible. The Ganges is sacred to Hindus – she is known as Ma Ganga. And yet it is one of the most polluted rivers in the world, being the sink into which industrial chemicals, household waste, agricultural runoff, and cremation remains are fed. Many say there is no dissonance between the river's sacredness and its role as a carrier of human waste because being celestial, Ma Ganga is incorruptible. It is common practice everywhere to rationalise when we are faced with contending needs and wants.

We are able to avoid rationalising incompatible demands only when protecting the sacred is not too costly. It is only then that we regard the sacred to be non-negotiable. In Benin, legislation has enshrined the sanctity of sacred groves into law. Many social practices of communities there rely on materials and resources drawn directly from forests: leaves, animals, water and stones. Those areas are considered sacred because they have traditionally been seen to be inhabited by deities or spirits. The sites also serve as spaces for rituals. Hunting is prohibited there, as is setting fires to the groves. Traditionally, custody of sacred forests was entrusted to members of a certain lineage. Logging and gathering plants for food and medicine were regulated by local communities (Houngbo, 2019). Benin has nearly 3,000 sacred groves – covering an area of over 18,000 hectares, which accounts for 0.16% of the national territory. The groves themselves are mostly small – only around 10% are larger than 5 hectares (Soury, 2007). Forests are, however, disappearing in Benin: in 1990 they covered 50% of land, but today the figure is less than 40%.

Many today would regard an awareness of the sacred to encompass a sense of awe and wonder, of a way to become aware of the transcendent. That is how we all try to locate ourselves from time to time within the landscape around us, imagining what lies beyond. That sense is not confined to what cosmopolitans might call 'traditional cultures'. Some of the most sublime songs of the poet Rabindranath Tagore have roots in the Vedanta, but they are detached from the rituals that had been given expression in Vedic times. They invoke the transcendent, but they are not tied to religion.

That sense of spirituality is often experienced today not only in isolation but also communally, such as among ramblers, birdwatchers, mountain hikers, cyclists, surfers and divers (Grove-White, 1992). The historian Simon Schama (1995) has argued that it is a mistake to think that Western cultures have abandoned the spiritual aspects of the natural world, or that they have abandoned the myths that were created around Nature. He showed that the transcendent has been expressed repeatedly in art and architecture. Nature's transcendence gives it a value that is independent of us.

Although the sense of transcendence that Nature invokes may still exist everywhere, it has taken a severe beating in modern times. Contending needs and wants have displaced our feeling that

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[112] We have benefited greatly from discussions on the intrinsic value of Nature with Simon Beard of the Centre for the Study of Existential Risk at Cambridge, including on ways to conceptualise the moral value of Nature, with a view to showing us *how* to think about these difficult matters, not what to think. The *Review* (Chapter 11) contains a sketch of his ideas.

by protecting the landscape we protect ourselves. The ability of richer societies to desecrate the landscape elsewhere has helped to accommodate those conflicting feelings, and the discipline of economics has increasingly aided that accommodation. Economic justification in high income countries is all too often a euphemism for commercial justification; and in low income countries the term 'economic development' is routinely used to justify blatantly unworthy investments.

That need not have been. Correct economic reasoning is entangled with our values. Biodiversity does not only have instrumental value, it also has intrinsic worth – perhaps even moral worth. Each of these senses is enriched when we recognise that we are embedded in Nature. To detach Nature from economic reasoning is to imply that we consider ourselves to be external to Nature. The fault is not in economics; it lies in the way we have chosen to practise it.

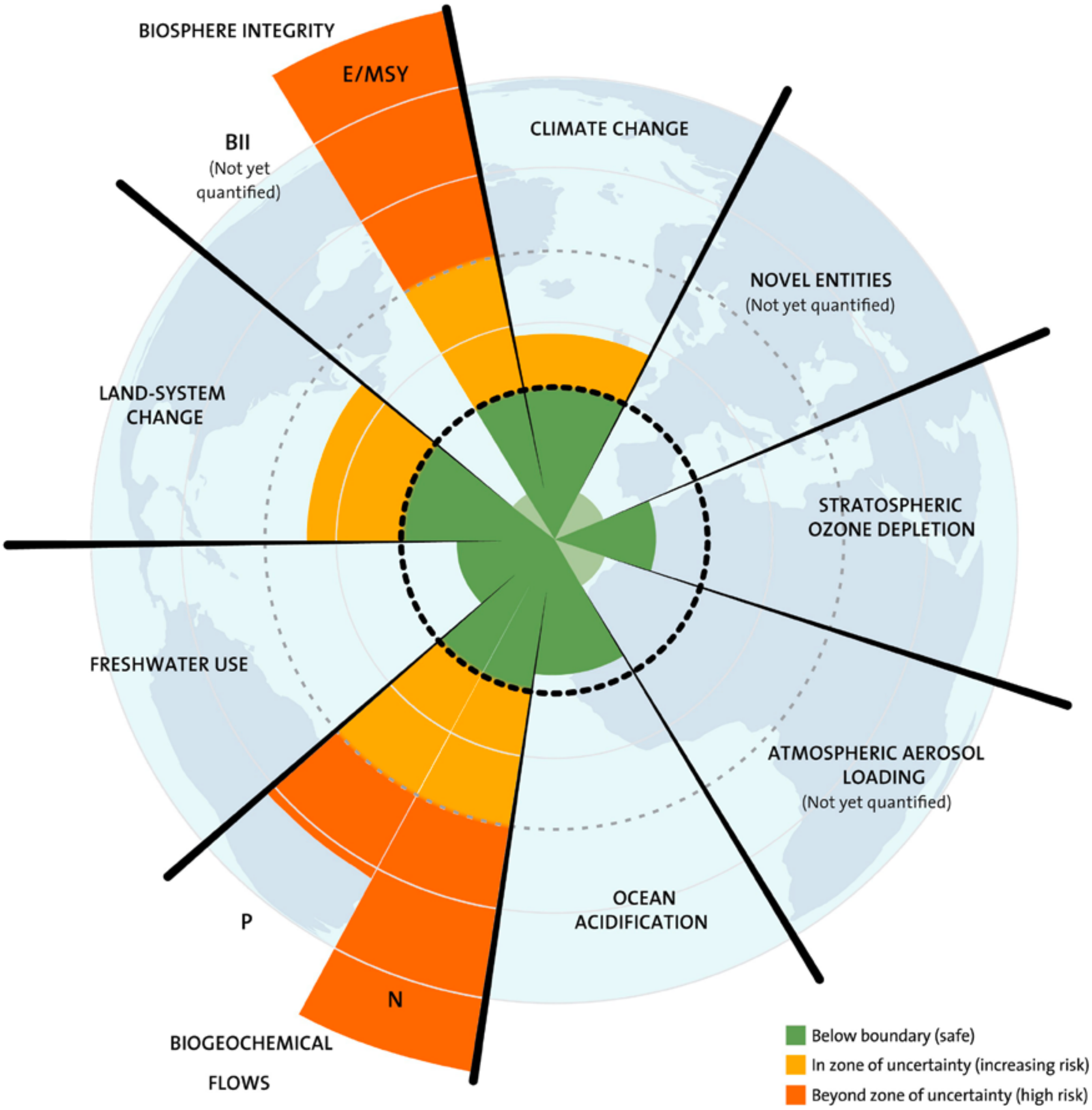
Annex 1 Safe Operating Distance From Planetary Boundaries

Further evidence of the biosphere's degradation is adduced from a study of Earth System processes. The idea has been to identify processes of the biosphere that are critical for maintaining the stable state we experienced in the past 11,000 years or so (the Holocene). Rockstrom et al. (2009) identified *nine* biophysical processes that are critical for Earth System functioning. The authors' proposal was to set quantitative boundaries for each, beyond which the Earth's Holocene state would be put at further risk, making the move to the Anthropocene firmer. The authors named the markers that may be used to check whether the processes are undergoing rapid change, *planetary boundaries*. A planetary boundary is not equivalent to a global threshold or tipping point. In any case, not all nine key processes are known to possess single definable thresholds, and for those where a threshold is known to exist, there are uncertainties about where they might lie. Boundaries are placed upstream of these thresholds at the safe end of the zone of uncertainty.

Although not all the nine processes have single identifiable markers, crossing the boundaries increases the risk of large-scale, potentially irreversible, environmental changes. Four of the nine processes have taken the planet into regions the authors regard as outside safe operating space, meaning that there are now increasing risk of a significant change from the biosphere's conditions in the Holocene. Biosphere integrity (for which one may read 'biodiversity') and nitrogen and phosphorus cycles have exceeded their boundaries farthest. But land-use change and climate change are also outside their safe operating space (Figure 22).

Unravelling the notion of biosphere integrity has proved problematic. As Figure 22 shows, Rockstrom et al. (2009) had identified it with the extinction rate of species per million per year (E/MSY). One problem with the use of this metric is that extinction rates are estimated most often for vertebrate species (only amounting to $<2\%$ of described species). Mace et al. (2014) have argued moreover that extinction rates do not reflect the genetic library of life, nor the functional diversity of ecosystems, nor the conditions and coverage of Earth's biomes. The authors' observations speak to the markers of biodiversity we explored in Chapters 2 and 3. We see below that those markers reflect ominous features of the Anthropocene. A new boundary based on the Biodiversity Intactness Index (BII) is under development, but has yet to be quantified (Steffen et al. 2015).

Figure 22 Critical Earth System Processes and Their Boundaries



Source: J. Lokrantz/Azote based on Steffen, W. et al. (2015) 'Planetary boundaries: Guiding human development on a changing planet', Science, 347(6223:1–10). Note: P = phosphorus; N = nitrogen; BII = Biodiversity Intactness Index and E/MSY = extinctions per million species per year.

A further respect in which the idea of planetary boundary has been extended is to study sub-global boundaries. This is important because, as was noted in Chapter 2, crossing a boundary at a regional level (e.g. destruction of the Amazon rainforest) can have implications for the whole Earth System. Regional level boundaries have now been developed for biosphere integrity, biogeochemical flows, land-use systems and freshwater use.

The idea of planetary boundaries has powerful heuristic appeal and has excited the public's imagination of the processes that govern the Earth System. It may have proved to be a problematic concept, but it is a most useful classification of the Earth System's biogeochemical processes.

Annex 2 Why Common Pool Resources?

Why did communities not permit themselves to divide their local ecosystem and turn them into private properties? One reason would have been the need to pool risks. Woodlands, for example, are spatially heterogeneous ecosystems. Microclimate matters, as does variation in soil quality. In some years one group of plants bears fruit in one part of a woodland, in other years some other group of plants, in some other part, are fecund. Relative to average output, fluctuations could be presumed to be larger in arid regions, mountain regions and unirrigated areas. If a woodland was to be divided into private parcels, each household would face greater risks than it would under communal ownership and mutual-regulation. The reduction in individual household risks may be small, but as average incomes are very low in Indian villages, household benefits from communal ownership and mutual enforcement of agreements could be expected to be large. Communal ownership helps to pool risks.

An immediate corollary is that income inequality is smaller in those locations where CPRs are more prominent. Aggregate incomes is a different matter, though, and it is the arid and mountain regions and unirrigated landscapes that are the poorest. However, the dependence on CPRs even within dry regions declines with increasing incomes across households. Theory predicts it and case studies confirm it (Jodha, 1986, 2001; Cavendish, 2000).

Where users are symmetrically placed, distributions would be expected to be symmetric – a subtle matter to devise if the resource is heterogeneous. Rotation of access to the best site is an example of how that can be achieved. It is often practised in coastal fisheries, fuel reserves in forest land, and fodder sites in the grasslands and mountain slopes (Netting, 1981; Baland and Platteau, 1996). Rotation enables users to get a fair share.

It would be possible in principle for the community to parcel out the resource as private property and let households establish a mutual insurance scheme. But that move would jeopardise cooperation in other activities. For at least two reasons. First, cooperation appears to be habit forming, which means dispensing with cooperation in any one activity could lead to a weakening of cooperation in other activities. Secondly, cooperation is more robust when sanctions for opportunism in any one venture include exclusions not only from that venture, but also from other collective ventures. Abandoning cooperation in one field of activity thus reduces the robustness of cooperation in other fields of activity. This fact is an implication of the theory of games. It explains why economic relationships are so frequently tied to one another (Dasgupta, 2007).

Local ecosystems are frequently CPRs also because animals, birds and insects are mobile. Mobility integrates an ecosystem's components. A coastal ecosystem can hardly be split into bits: fish swim. In Section 2 it was also noted that the productivity of ecosystems is greater than the sum of the productivities of their spatial parts. Ecosystems therefore have an element of indivisibility to them. But even if it was decreed that no portion could be converted for another use, parcelling ecosystems into private bits would be inefficient because of the externalities that would be created by mobile components. Communal ownership internalises those externalities. Admittedly, private monopoly would avoid the externalities, but it would grant far too much power to one person in the community.

Agricultural land, especially in densely populated areas, is a different matter. Both labour and capital are critical inputs in production. Investment can increase land's productivity enormously. Agricultural land as CPRs would be subject to serious management problems, including those due to the temptations to free ride on investment costs. The lack of incentives to invest and innovate would lead to stagnation, even decay. The experience with collective farms in what was previously the Soviet Union testifies to that. Those regions of sub-Saharan Africa where land is, or was until recently, held by the kinship were exceptions, but only because land was plentiful in the past and because poor soil quality meant that land had to be kept fallow for extended periods. Of course, it may be that agricultural productivity remained low there *because* land was held by the kinship, not by individuals. As elsewhere in the social sciences, causation typically works in both directions.

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