Chapter 0
How We Got to Where We Are

Introduction

On our 4.5-billion-year old planet, life is perhaps as much as 3.7 billion years old, with photosynthesis and multi-cellularity (appearing dozens of times independently) around 3 billion years old. Oxygen levels began to rise some 650 million years ago or even earlier (coinciding with the Metazoan stage); plants, animals, and fungi emerged on land perhaps 480 million years ago; forests appeared around 370 million years ago; and modern groups such as mammals, birds, reptiles, and land plants originated about 200 million years ago. The geological record shows that there have been five global mass extinction events, the first of them about 540 million years ago. The records also suggest that 99% of the species that have ever existed (perhaps 5 billion in number) have become extinct. The last major extinction event occurred about 66 million years ago, and the number of species on Earth and the complexity of their communities and ecosystems have increased steadily since that time.[12]

Over the past 66 million years, the number of species has grown to around 8 million to 20 million (possibly more) species of eukaryotic organisms – ones with cells that have a distinct nucleus – and an unknown and much larger number of prokaryotes (Archaea and bacteria). Our lack of knowledge is enormous. Only about 1% of the species that have existed during the history of life on Earth live in the ecosystems into which humans evolved and live now. From the time that human beings evolved, our dependency on *biodiversity*, that is, the diversity of life, has remained complete. Indeed, we ourselves are a part of biodiversity.

Within the global ecosystem, the first members of humanity's evolutionary line split from the other African apes about 6 to 8 million years ago. Our closest relatives, a group that we call hominids, appear in the fossil record about 2.7 million years ago, also in Africa. One of these, *Homo erectus*, was the first to migrate out of Africa to the north, starting around 2 million years ago, where it, along with the Neanderthals, the Denisovans, and a few more local species, represented humanity until the occurrence of another significant migration out of Africa. This event occurred at least 60,000 years ago, when the hominids present in Eurasia were joined by modern *Homo sapiens*, which had originated in Africa about 200,000 years ago. By about 30,000 years ago, *Homo sapiens* had conquered and killed the other hominids that had preceded them in the Northern Hemisphere, after interbreeding with Neanderthals and Denisovans when they came into contact with them.

For tens of thousands of years after *Homo sapiens* reached Eurasia, they lived as hunter-gatherers. Over the years, they began to create artistic works and make weapons and musical instruments; but because they were frequently on the move in search of food, necessarily carrying their babies with them, there was little opportunity for them to develop what we today call civilisation. Dogs were domesticated in Eurasia at least 20,000 years ago, and crops were being cultivated by about 12,000 years ago. Domestication, therefore, took place in a period of rising temperatures following the end of the preceding cold period.

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[12] The Introduction to this chapter has been taken from notes prepared by Peter H. Raven, President Emeritus of the Missouri Botanical Gardens, for a joint meeting of the Pontifical Academy of Sciences and the Pontifical Academy of Social Sciences in Vatican City in 2017. The proceedings of the conference were subsequently published as *Biological Extinction: New Perspectives* (Cambridge: Cambridge University Press), 2019, edited by Partha Dasgupta, Peter H. Raven and Anna L. McIvor.

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The intercontinental migration of *Homo sapiens* took place during a period of glacial expansion that lasted from 110,000 to about 10,000 years ago. Human dispersal from Eurasia to Australia (about 80,000 years ago) occurred long before there was any domestication of plants and animals, a practice that never developed in that continent. Dispersal to North America (via the then existing Bering Land Bridge connecting northern Siberia and Alaska) seems to have occurred some 18,000 years ago (possibly even earlier), after the domestication of dogs, which they brought with them. No crops were carried to the New World until modern times. Both in North and South America, crop agriculture was developed independently.

Along with domestic animals, cultivated crops (the first appearance being some 12,000 years ago in the Fertile Crescent, a crescent-shaped region in the Middle East) provided a major source of storable food, one that could see humans through droughts, winters, and other unfavourable times. At that time, the entire global population of humans is estimated to have been about 1 million people, with only about 100,000 in Europe. Agriculture allowed a single person to feed more than themselves and their family, and made possible a rapid increase in population. Farmers from the Fertile Crescent swept into Europe, displacing the sparse population that had existed there earlier. In these cultivated lands, the numbers of people who could live together in a village, town or city increased greatly. The first cities were built in Southern Mesopotamia between the Tigris and Euphrates Rivers some 7,000 years ago. The economic surplus enabled most aspects of what we call civilisation to develop in that region. Individuals could learn to become toolmakers, soldiers, tradesmen and priests, and the various elements of what we consider civilisation began to develop rapidly. A very important invention was writing. Sumerian writing and Egyptian hieroglyphs, understood to be the earliest writing systems, were invented around 5,500 years ago; the earliest texts about 4,000 years ago. The Sumerians are understood today to have also invented a number system, some 4,000 to 5,000 years ago.

As our human numbers grew, our impact on the planet increased with them. By about 3,000 years ago, pastoralists, agriculturists and hunter-gatherers had transformed large areas as they gathered and grew food for their increasing numbers. The roughly 300 million people who lived at the time of the Roman Empire had grown to 500 million around the year 1500 CE, near the beginning of the Renaissance, and today has reached nearly 7.8 billion (Table 0.2).

If human history is a mere blink in the history of the biosphere, economic history is only a point in time. Drawing on material objects uncovered from archaeological sites, sketches of quantitative history reach about 5,000 years into the past; while quantitative economic history looks back at best to the start of the Common Era.[13] In this chapter, we present data on changes (or lack of changes) over time in regional living standards, and global population numbers and health status since year 1 of our Common Era (Figures 0.1–0.2). We also report findings on various successes and failures of past societies to overcome the environmental stress they faced. In current understanding, those stresses arose from population pressure, climatic changes and defective land management (soil erosion being a prominent result). The global evidence, in its aggregative form, speaks to a long stretch, until about 1500 CE, of stagnant population numbers, living standards and health status, rising slowly until the start of the Industrial Revolution (round about 1750), growing somewhat more rapidly from then, and taking a sharp and accelerated increase from around the middle of the last century until now.

0.1 Economic History Since Year 0

The economist Angus Maddison spent much of his professional life uncovering past living standards across the world. To do that, he chose gross domestic product (GDP) per capita as a measure of the

[13] Finley (1982) offered a few estimates of economic indicators in Homeric Greece (approximately 1200 BCE), but they have been found by historians to be not without problems.

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standard of living in a society. He chose that because GDP is the index in most common use today for assessing the performance of economies and for evaluating macroeconomic policy. GDP is the market value of the flow of all final goods and services produced within a country in a given year. It includes the monetary value of aggregate private consumption (consumer spending, as it is often called), gross investment (including the capital expenditures of businesses), the sum of government expenditures, and the difference between exports and imports. GDP is a measure of an economy's aggregate output. As the value of output has to reach *someone's* pocket, we will use the terms 'output' and 'income' interchangeably.[14]

Although it is routine today to study the performance of economies in terms of GDP, Maddison's work is especially interesting and important because it is on deep economic history. Peering into the past 2,000 years with a measuring rod, which is what Maddison did, takes courage, but Maddison used whatever record he could find that gave clues to wages, food consumption, clothing, housing, land rents, and so on. Table 0.1 reproduces figures constructed in ongoing work by others in what is now known as the 'Maddison Project' (Maddison, 2018; Bolt et al. 2018). The project is designed to improve upon the estimates Maddison (2001) offered in his now-classic work. The table presents output per capita in five regions of the world. The final row presents time series of global output per capita. The figures are expressed in 2011 international dollars.[15]

Table 0.1 Deep History, 1 – GDP Per Capita (2011 International Dollars)

	1 CE	1000	1500	1700	1820	1900	1950	2000	2016
Western Europe*	914	676	1,232	1,630	2,313	4,904	6,078	32,956	40,364
Western Offshoots*	636	636	636	755	2,070	8,027	14,867	44,331	51,342
Latin America*	636	636	660	843	999	1,822	3,048	8,728	13,470
Asia	725	747	904	909	939	1,099	1,201	5,286	11,102
Africa	747	676	660	668	774	1,444	1,596	2,889	4,680
World	747	723	898	978	1,132	2,446	3,277	9,456	14,574
World Bank (World)								10,346	15,080

Source: Maddison (2018), Bolt et al. (2018). Note: 'Western Offshoots' include what are today US, Canada, New Zealand and Australia.

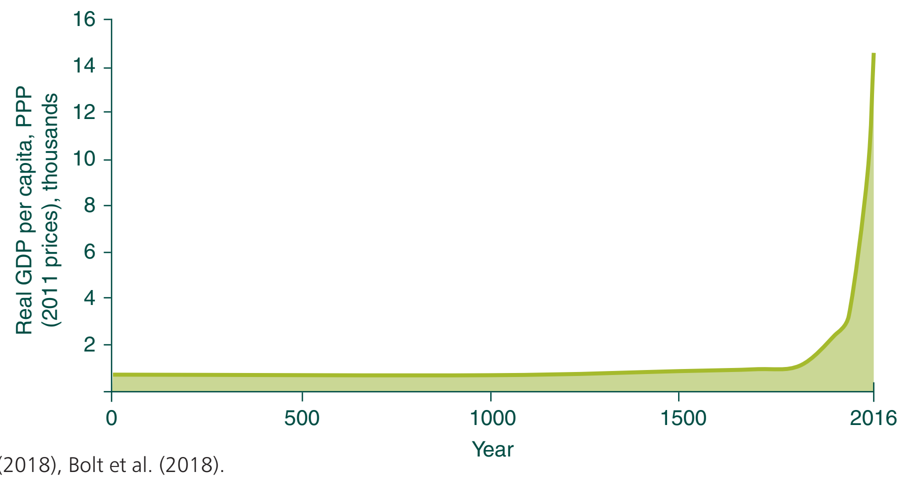
Note: The Maddison Project Database (MPD) provides long-run data on GDP per capita for comparisons of relative income levels across countries. The measure of real GDP per capita is based on multiple benchmark comparisons of prices and incomes across countries and over time. The figures between the dates 1 CE to 1950 are updated from a combination of the 2010 and 2013 MPD releases, which were in 1990 prices. To account for the change in price level, a simple GDP deflator is used to adjust all regions for 2011 prices. The differences between the rebased regions' GDP and the newly calculated GDP do not significantly change the overall trends at the regional and global level, relative to the 1990 price level estimates. The figures between 1950 to 2016 are taken from the most recent release from the Maddison Project Database, in 2011 prices, apart from the regions denoted with a star where 1913 data was also available in their updated database. For comparison, the World Bank's estimate of GDP per capita PPP (2011 prices) for 2000 and 2016 are given, which are both within 10% of the latest Maddison Project data.

[14] GDP is to be distinguished from GNP (Gross National Product). The latter is GDP plus incomes earned by residents from overseas earnings, minus incomes earned within the economy by overseas residents. For our purposes in the Review, the difference between the two indices is inconsequential. See Chapter 13 for a fuller discussion of GDP.

[15] 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 so as to bring the purchasing power in the regions on par with one another. In what follows, it should be read that 'dollars' mean 'international dollars'.

The first thing to note about the figures in Table 0.1 is that the average person in the world was very poor in terms of income right up to the beginning of the modern period (approximately 1700 CE). In Late Antiquity and the Middle Ages, average income in most regions everywhere was not much above 1.90 dollars a day (a few even below it) – the figure that was taken by the World Bank in 2015 to be the line below which spells *extreme* poverty. Regional variations became prominent in the beginning of the Early Modern period (roughly, 1500), by which time Western Europe had begun to diverge from the rest of the world. But Maddison's estimates suggest that even in 1700 the average person in Asia languished in near-extreme poverty, at around 2.5 dollars a day. As tourists we are dazzled by the art, architecture and technology of past eras. We refer to them as great civilisations and imagine that those must have been prosperous times as well. Table 0.1 says we should imagine otherwise. So long as there is a ruling class to tax poor subjects, we have the beginning of the arts, humanities and the sciences. The Taj Mahal, for example, which is today the most renowned construction of the Early-Modern era, was built in the mid-17th century on the orders of a tyrant in memory of his favourite wife, on the backs of extremely poor subjects.

Figure 0.1 GDP Per Capita from Year 0 to 2016 CE



Source: Maddison (2018), Bolt et al. (2018).

Great art, great architecture, great literature, and even great scientific and technological discoveries can coexist with general squalor and widespread deprivation of the means available for a reasonable existence. And they have coexisted for nearly all of history. Average world income in 1820 CE, which in many economic historians' reckoning was about the time of the Industrial Revolution, was only about 50% higher than in 1 CE. That means the growth rate of world income per capita over the 1,820-year period, when averaged, was indistinguishable from zero. Table 0.1 confirms that significant increases in the standard of living took place only in the 20th century, mostly in the West and what Maddison called Western Offshoots (US, Canada, Australia and New Zealand). In a matter of a little under 70 years (1950 to 2016), GDP per capita increased nearly seven times in Western Europe. It is true that in 1945 those nations were in a devastated condition, meaning that the potentials for growth were large. But as Table 0.1 tells it, we should not imagine that the poorer a nation, the greater its potential for advancement. Western Europe had institutions in place, an educated population, and a social coherence that enabled them to take advantage of their potentials. In contrast Africa, which at the end of the Second World War was a lot poorer than the West, continues to languish in poverty. Average income in Africa in 2016 was barely over 11% of that in Western Europe.

To be sure, Table 0.1 hides social improvements taking place in various places from time to time during the 1,700 years following Year 0. An interval of 1,000 years (0–1000 CE) hides fluctuations of fortunes. Temin (2013) has suggested that GDP per capita in the Roman Empire in 2nd century CE was about the same as in India in 1990. But in time the Empire fell, and incomes dropped. We also know of the Black Death and Europe's revival after it, both of which are hidden from view in the thick, 500-year spell between 1000 and 1500 CE. Fouquet and Broadberry (2015) peered closer into Europe for the period 1200 to 1870 and found that there were periods when some regions enjoyed considerable growth in GDP per capita, while others declined. But none would appear to have enjoyed *sustained* growth in incomes. Recent work by historians of Mughal India suggests that per capita income there rose considerably by year 1600. But the empire fell into disarray by the first half of the 18th century and the economy skidded. Broadberry, Custodis and Gupta (2015) have estimated that in 1600 per capita income in India was more than 60% of that in England, but by 1870 had fallen to less than 15%. Notwithstanding the caveats, the pioneering Maddison estimates of GDP per capita in deep economic history are a stark reminder that for nearly all of history the average person in the world was extremely poor.

0.2 Economic Growth and Sustainable Development

Writing at the very end of the 18th century, the Rev. Thomas Malthus postulated that population size and the standard of living had kept each other in check throughout history in what we would today call a low-level equilibrium. The world he read was composed largely of "organic economies" (Wrigley, 2004), where not only food but also most raw materials needed for manufacturing artefacts were either animal or vegetable in origin. Production was subject to diminishing returns. Given the reproductive norms of societies (although this is not quite how Malthus put it), population grew whenever living standards rose above the equilibrium level, bringing living standards down. But whenever living standards fell below the equilibrium level, more people died (wars and pestilence) and the system equilibrated. As a matter of common observation, the equilibrium living standard was low.

Both population and living standards in Malthus' theory, like any good theory, were determined by factors operating at a deeper level. So, he identified various possible causes that had perturbed economies throughout history (wars and crop failure were two proximate drivers), from which they returned to equilibrium.[16]

Table 0.2, reproduced from Maddison (2001, 2018) and UNPD (2019a), provides estimates of population size and expectancy of life at birth over the past 2,000 years.

Table 0.2 Deep History, 2 – Global Health and Numbers

Year	0 CE	1000	1820	1900	1950	2000	2020
Life expectancy at birth (years)	24	24	29	31	46	66	73
Population size, rounded figures (million)	230	270	1,000	1,600	2,500	6,100	7,800

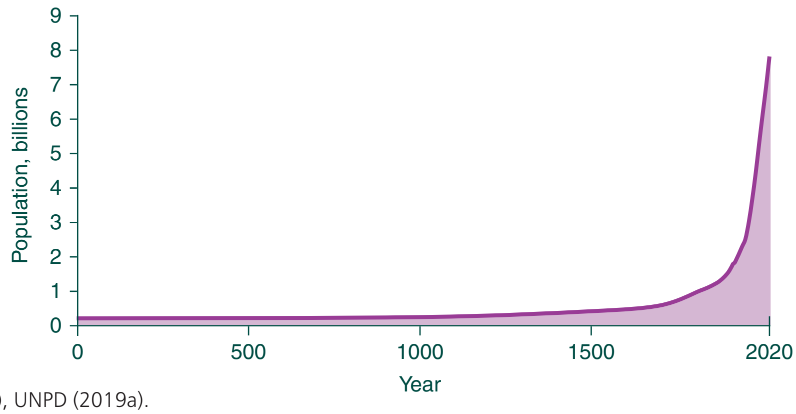
Source: Maddison (2001), Tables 1-5b and B-10, for columns 1–5; UNPD (2019a), for columns 6 and 7. See also the table of life expectancy at birth since 1800 in Riley (2005), which reports that global life expectancy at birth in 1800 was 29 years.

Note: Life expectancy at birth for 1 CE is Roman Egypt, 33–258, estimate. Data from 1950 to 2020 from UN Population Division.

[16] For a mathematical formulation of Malthus' theory, see Day (1983), who also drew attention to possible fluctuations away from equilibrium, depending on the parameters characterising organic economies.

Taken together, the two tables suggest that the global experience until 1820 CE was pretty much in line with the Malthusian theory. Global income per capita in 1820 was about 3 dollars a day, world population was about 1 billion, and a new-born was expected to live for at best 30 years.[17]

Figure 0.2 Global Population from Year 0 CE



Source: Maddison (2001), UNPD (2019a).

While Malthus' theory would appear to have fitted the *global* economy at the time he published his work, it had begun to unravel in the West earlier; many experts believe as early as the 16th century, with the seeds having been laid even earlier. Identifying the factors that led to the great divergence between the West and the rest of the world has been a major subject of research among scholars studying deep history.[18]

Landes (1998) and Pomeranz (2000) are modern classics on the 'Great Divergence' and have generated enormous debate.[19] It is not in contention that a series of societal changes took place in the West in the Early Modern period (perhaps even earlier) which unleashed the innovatory forces that account for the emergence of the modern world; the debate is over the factors behind the divergence and its timing. Experience with reading evidence that bear on socio-economic processes tells us that, as with ecological processes (Chapters 2 and 3), monocausal explanations should be discounted. A multiplicity of factors can act on one another synergistically, but they can also act on one another in a discordant or inharmonious way. The former would be read in due course as societal success, the latter as societal failure. Landes (1998) laid stress on multi-faceted cultural factors[20] and noted as well that Europe in the Early Modern era was not a monolithic state. Rivalry, competition, and differences in power and beliefs among dukes, princes, and clerical eminences enabled ideas to flourish. If a scientist was in disfavour in one state, he (it was always a 'he') could find service in a rival court.[21]

The subsequent Industrial Revolution unleashed growth in labour productivity from technological advances and the production scale economies that came with those advances, and by the beginning of

[17] See also the table of life expectancy at birth since 1800 in Riley (2005), which reports that global life expectancy at birth in 1800 was 29 years.

[18] China was the exception, it was not only a contender with the West in 1500 CE, it is believed by historians of technology to have been ahead of it. Among other inventions, paper, printing, gunpowder, and the compass had been made in China long before they reached the West. But China fell behind in the centuries that followed because, or so it has been argued by historians, of a shift toward an inward-looking national philosophy. For example, maritime trade was stopped by Imperial decree by the mid-15th century.

[19] See O'Brien (2010) for a review of the debate.

[20] Max Weber, in his work on Protestant ethic and the spirit of capitalism, had invoked a far narrower explanatory variable.

[21] Johannes Kepler was a prominent case (Boorstin,1983).

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the 20th century, Malthus' theory began to unravel elsewhere too, barring Asia (Japan excluded) (Maddison, 2001) and Africa. By then world population had risen to 1.5 billion, life expectancy at birth had advanced to Maddison's estimate of 31 years, and average income had grown to around 2,000 international dollars a year (at 2011 prices).

During the 20th century, several key dimensions of life improved greatly (and as we confirm in Chapter 4, in the second half of the century they improved spectacularly). Global income per head more than quadrupled, life expectancy of a new-born rose from 31 to 66 years (relatedly, people enjoyed ever greater protection against water- and airborne diseases, greater use of potable water and, since the end of the Second World War, antibiotics), even while world population grew by a multiple of four, to 6 billion. Even the brief period 2000–2016 was remarkable: global income per person grew by over 40%. By 2016, global income per head had reached nearly 15,000 international dollars (at 2011 prices), life expectancy at birth had risen to 73 years, and population had grown to nearly 7.8 billion. In Chapter 4, we draw attention to the 70-year span beginning in 1950. Tables 0.1 and 0.2 confirm its exceptional character. Prominent Earth scientists regard the middle of the 20th century as the period we entered the Anthropocene (Voosen, 2016).

In a famous 1930 essay 'Economic Possibilities for Our Grandchildren', John Maynard Keynes described a past that was consonant with the deep economic history of Tables 0.1 and 0.2. He concluded that humanity in his time had never remotely had it so good (Keynes, 1931). The world's living standard today is a lot higher than it was even when Keynes made his observation. The average person not only enjoys far higher income and lives longer, the proportion of the world's population in absolute income-poverty has fallen so dramatically (it is below 10% of the world's population, down from around 50% in 1970) that enthusiasts predict that within a generation the blight will have been eliminated for the foreseeable future (Jamison et al. 2013).[22]

These successes have inspired a number of intellectuals to draw the attention of the general public to the remarkable gains in the standard of living humanity has enjoyed over the past century.[23] The authors collated data on growth in scientific knowledge and the accumulation of our produced capital and human capital to argue that humanity has never had it so good. But with the exception of rising carbon concentration in the atmosphere, trends in the state of the biosphere accompanying those advances have gone unnoted by the authors. We note in Chapter 4 though, that global climate change is but one of a myriad of environmental problems we face today. And because it is amenable to technological solutions (innovating with cheap non-carbon sources of energy and, more speculatively, firing sulphur particulates into the stratosphere to reflect sunlight back into space (Pinker, 2018)), it is not representative. Global climate change attracts attention among intellectuals and the reading public not only because it is a grave problem, but perhaps also because it is possible to imagine meeting it by using the familiar economics of commodity taxation, regulation and resource pricing without having to forego growth in material living standards in rich countries. The literature on the economics of climate change (e.g. Stern, 2006; Nordhaus, 2007; Lomborg, 2013) has even encouraged the thought that, with only little investment in clean energy sources over the next few years (say 2% of world GDP), we can enjoy indefinite growth in the world's output of final goods and services (global GDP).

That is a thought that should be resisted. It will be shown that, when looking at the wider scope of the economics of the biosphere (based on an understanding of ecology and earth sciences (Chapters 1, 2, 3,

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[22] 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 COVID-19 pandemic would push an additional 88 million to 115 million into extreme poverty in 2020 (World Bank, 2020c).

[23] Micklethwait and Wooldridge (2003); Ridley (2010); Lomborg (2013); Norberg (2016); and Pinker (2018). We will discover, though, that time series of subjective measures of well-being, such as happiness and life satisfaction, tell a different story (Chapter 11).

4 and 4*), our economic possibilities are circumscribed – even if several steps removed via technological progress – by the Earth-System's workings. We are embedded in Nature; we are not external to it. No amount of technological progress can make economic growth as conventionally measured an indefinite possibility. Ours is inevitably a finite economy, as is the biosphere of which we are part. Although there has been some recent recognition among a few economists and ecologists of these issues (we highlight leading work in Chapter 1), this understanding remains far from widespread.

Nevertheless, there is the temptation to say that because natural resources can be shifted around today with relative ease, dwindling supplies in one place can be met by imports from another (see Chapter 15 for more on trade). Intellectuals have been known to say that because of 'globalisation' location does not matter. The view emphasises the prospects offered by trade and investment and says if they are not enough, technological progress can be relied upon to solve the problems arising from resource depletion and environmental degradation. Today Malthus, the 'pessimistic parson', is seen as a 'false prophet', remaining as wrong as ever (*The Economist*, 15 May 2008).[24]

0.3 Historical Success and Failures

In the past, when communities faced exceptional resource stress (droughts, pests and soil erosion are only three causes), they introduced new practices and fashioned new arrangements. If migration to better locations was a possibility, communities would be expected to have tried that, if all else failed. We should not imagine people taking impending disasters lying down if they saw them coming. Boserup (1965) collated evidence from agrarian societies to argue that resource stress generates societal responses that not only fend off disaster but can even lead to prosperity. Exceptional scarcities may raise exceptional 'problems', but as the saying goes today, they offer exceptional 'opportunities' as well. Boserup's work countered a widespread fear in the early 1960s that our capacity to produce food was being overtaken by growth in human numbers. She saw population growth as a spur to innovations. The Green Revolution that came soon after her publication matched her narrative. Population was dropped from public discourse even as Boserup came to replace Malthus.[25]

Boserup's case studies were about organic economies. Inevitably, there was sample bias in her choice of examples. Societies that had not made the cut would have disappeared or moved to blend themselves among communities that survived; they would be absent from such records as those that Boserup studied. In a study of a modern-day society, Turner and Shajaat Ali (1996) put together the contrasting concerns of Malthus and Boserup by demonstrating that in the face of rising population and a deteriorating resource base, small farmers in Bangladesh expanded production by intensifying agriculture practices and, with government help, collectively strengthening drainage systems and flood and storm defences. The farmers have not been able to thrive, they still live in poverty, but they staved off collapse (they have not abandoned their villages en masse for cities), at least for now. The metaphor that comes to mind is of a crowd walking up an escalator that is coming down at the same speed. Studies with a similar flavour for agricultural prospects in Africa have been reported in Christiaensen (2017) and Juma (2019). Historically, migration has been a coping strategy against especial ecological stress. Petraglia et al. (2020) have collated archaeological findings in south-eastern Arabia to show that

[24] The Review argues, however, that the COVID-19 pandemic can in large measure be traced to weaknesses in commodity supply chains and to biodiversity loss.

[25] Economic historians refer to our need for energy to make the same point. Human societies have over millennia improved their living standard by finding new sources of energy in the face of rising costs of established resources. The succession of human sweat, animal power, rivers and streams, wind, timber, coal, oil and gas, and most recently the nucleus of radioactive matter, is a frequently cited example of the global success in finding ways to harness energy. Barbier (2011) contains a wide-ranging demonstration of ways in which societies have historically depended on natural resources for growth and well-being.

ancient droughts during the Holocene corresponded with population movements from inland regions to the coast that were rich in resources.

If Boserup is a counterpoint to Malthus, Jared Diamond is a natural counterpoint to Boserup. Techniques for reading archaeological records have improved since the 1960s. Reviewing a series of case studies drawn from the early-to-middle second millennium CE, Diamond (2005: 6) classified the processes through which those collapsed societies he had studied had undermined themselves by damaging their ecosystems. He identified eight categories: (i) deforestation and habitat destruction; (ii) soil erosion, salinisation and fertility losses; (iii) water management problems; (iv) overhunting; (v) overfishing; (vi) effects of introduced species on native species; (vii) human population growth; and (viii) increased per capita impact of people.

Societies that are unearthed by paleo-ecologists were universes unto themselves. Those for whom transportation was costly, trade was relatively small in comparison to domestic output, and communities had to rely entirely on their own ecosystems. Communities that were under resource stress demanded more from their ecosystem than it was able to supply on a sustainable basis. Diamond's category (viii) can be read as the 'ecological footprint' (see below) of the organic economies he had studied.

In Chapters 2, 3 and 4, we find that items (i)-(vii) on Diamond's list lead to (viii). For example, Diamond reported that a number of societies that had deforested their land had been able to develop successful forest management practices and population measures, but that in contrast there were others – most notoriously in the public imagination, Easter Island – that had failed to develop successful management practices, and had collapsed as a result. He also found a common pattern in past collapses: population growth that followed access to an abundant ecosystem made people intensify the means of food production (irrigation, terracing, double-cropping) and expand into marginal land. Growing populations led to a mining of their ecosystems. That left communities vulnerable to climatic variations, as there was little room left for either mistakes or bad luck.[26]

Proceedings of the National Academy of Sciences of the United States of America (PNAS, 2012) published a Special Feature on historical collapses. Contributors reported 12 studies of past societies that had faced environmental stress. Seven were found to have suffered severe transformation, while five had overcome them through changes in their practices. Butzer (2012) reported the ways in which a number of societies in 14th-18th centuries Western Europe displayed resilience by coping with environmental stresses through innovation and agricultural intensification. Like Diamond, he concluded that collapse is rarely abrupt.

That collapse is rarely abrupt suggests that even robust socio-ecological systems become less resilient in withstanding shocks and surprises when they experience continual stress (Chapters 3 and 5). In a study of the European Neolithic societies that began some 9,000 years ago, Downey, Haas and Shennan (2016) found that the introduction of agriculture spurred population growth, but societies in many cases experienced demographic instability and, ultimately, collapse. The authors also uncovered evidence of warning signs of eventual population collapse, reflected in decreasing resilience in socio-ecological systems. Scheffer (2016) has given further support to the thesis by reporting that there had been warning signs of reduced resilience prior to the great drought in the late 1270s that destroyed the communities that had built the iconic alcove sites of Mesa Verde.

Reviewing findings on past societal collapses, Beach, Luzzadder-Beach and Dunning (2019) suggest that pioneer communities often caused soil degradation in conjunction with terrestrial species collapse

[26] The present section is an elaboration of Section 5 of Dasgupta, Mitra and Sorger (2019), which contains a formal model of the socio-ecological processes identified by Diamond in his study of the success and failure of organic economies.

because of unfamiliarity with the ecosystem they had entered. They cite the case of the Norse who first entered Iceland in about 875 CE. Vegetation covered about 65% of the island then, but the cover dropped to 25%, of which forest cover shrank to 1% of its original extent. The authors report that the decline in biodiversity was caused by deforestation and overgrazing, mainly by sheep. More than half the island's soil had experienced considerable to severe erosion.

Greenland Norse communities disappeared in the 15th century, during a period known as the Little Ice Age. Recent findings show that the communities were fishermen, and also hunted seals and walrus tusks (Kintisch, 2016). Tusks were exported to the Continent. Over time, harvesting costs increased, as severe storms over the sea occurred more frequently with a climate that had become colder. The economic downturn in the Continent during the Little Ice Age also led to a decline in the demand for tusks; the export price of tusks fell. The Norse experienced a fall in the standard of living, below tolerable levels. The prevailing population size proved to be unviable under the new climatic conditions.

As illustration of past societal successes and failures, it is useful to contrast the fate of the Norse people with the Mayas, who emerged in Meso-America round 3,000 years ago. The Classic Period of the Mayas was 250–900 CE. It saw widespread growth of infrastructure including reservoirs and agricultural fields, which together can be called 'landscape capital'.[27] This produced intensive, polyculture farming systems, water management systems, terraces, wetland fields and extensive forest garden systems.[28] Their construction boosted output while conserving soil. Some terraced systems are thought to have been adaptations to eroded or depleted landscapes from earlier periods, for some terraces were perched on slopes above depressions containing sediments derived from previous earth-slope erosion, and some others were built on bare bedrock, with soils formed behind the walls only since the Mayas built them. Evidence suggests that the wetland fields were constructed on what had previously been dryland agricultural fields, as the water table rose on account of sea level rise. This was the kind of societal adaptation to changing circumstances that had excited Boserup. But a combination of drought and warfare in what is now known as the Terminal Classic period of the 9th century CE led to an inability of the Mayas to maintain their landscape capital even as it led to soil erosion and the eventual demise of their civilisation.

Loss at war can destroy a civilisation rapidly, in contrast to ecological decline which takes place gradually until a tipping point is reached (Chapter 3). The very fact that societies had allowed their socio-ecological system to come near a tipping point tells us that they probably could not read the signs of their impending collapse until perhaps it was too late. Paleo-ecologists have an advantage. They can read the archaeological record to uncover a society's doings over an extended period of time, long before they collapsed.

0.4 Understanding Humanity's Contemporary Overshoot

Inevitably, paleo-ecologists study societies that had tight geographical boundaries. A community that failed because of population overshoot or bad resource-management practices no doubt destroyed their natural resource base, but it was their *local* resource base they destroyed; societies until modern times were incapable of affecting the Earth System as a whole. Matters are different today. The human presence is so dominant that the Earth System is no longer as modular as it was until recently. Disturbance in one location today gets transmitted to other parts in short order. Movements of people and trade in goods have created a transmission mechanism with a long and quick reach. The mechanism's medium has, however, remained the same: Nature is *mobile*. We weaken the Antarctica

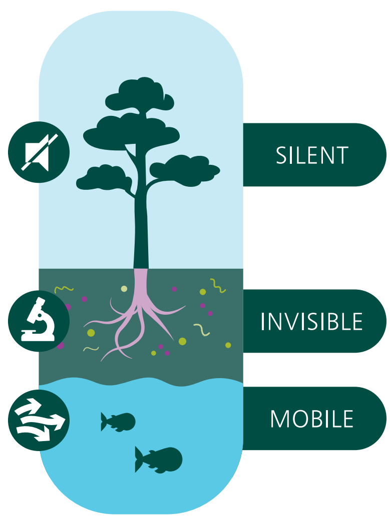
[27] This account of the Mayans is taken from Beach, Luzzadder-Beach and Dunning (2019).

[28] Beach et al. (2019) have unearthed further evidence from below contemporary forest canopies of the extensive construction of wetland fields for their food production.

ice sheet without ever going there; phosphorus discharge from farms in Minnesota contributes to a deadening of the Gulf of Mexico; emissions of soot from kitchens in the Indian sub-continent affect the circulation patterns of the monsoons; the Green Revolution's demand for water, fertilisers and pesticides pollute the rivers and ground waters of the Indo-Gangetic Plain; fish in the North Sea eat microplastic originating in markets in the Bahamas; and so on.[29]

Much of Nature and the processes governing it are also silent and invisible (Chapters 2 and 4). The three pervasive features – *mobility*, *silence* and *invisibility* – make it impossible for markets to record adequately the use we make of Nature's goods and services (Figure 0.3). That inadequacy extends naturally to the goods and services we produce. There is thus an inevitable wedge between the market prices of goods and services and their social scarcity values. This has far-reaching implications for our conception of our place in Nature. Low market prices for Nature's goods and services (we will discover that many come with a *negative* price tag) has encouraged us to regard ourselves as being external to Nature.

Figure 0.3 Nature's Properties



The *biosphere* (Nature and the biosphere are used interchangeably in the Review) is the part of Earth that is occupied by living organisms (Chapter 2). It pays to let our imagination roam and imagine the biosphere as a self-regenerative asset, a gigantic version of forests and fisheries. But there is a difference. We are a part of the biosphere; we are not external to it. What we take from our neighbourhood over a period of time and put back in is known as our *ecological footprint*. It is also known as our *impact* (Ehrlich and Holdren, 1971). We may even borrow from the economist's language and call our impact our 'demand'.

Humanity's impact does not have to equal the biosphere's regenerative rate. That is because the difference would automatically be accommodated by a change in the biosphere's stock (S). A world rich in a healthy biosphere could, on utilitarian grounds, choose to draw down the biosphere and use the

[29] 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, 2020, May 18, p.15).

goods and services it supplies so as to accumulate produced capital (roads, buildings, machines, ports) and human capital (health, education, aptitude). That is what economic development has come to mean among many people (Chapters 1 and 4). But that view and the practices the view has encouraged have meant that in recent decades our global impact on the biosphere has exceeded the biosphere's regenerative rate. That is the Anthropocene. As a result, the biosphere has been, and is increasingly being, drawn down. In our figurative way of speaking, the biosphere has shrunk. But that has meant a decline in the biosphere's regenerative rate, which in its turn has meant an increase in the gap between demand and supply.

Contemporary models of long-run economic possibilities envisage that scientific and technological progress can be relied upon to sustain an ever-increasing growth in global output of final goods and services. That requires us to imagine that, in the long run, we can break free of the biosphere when investing in further scientific and technological progress (Chapters 4 and 4*). And that is the sense in which contemporary economic thinking on sustainable development assumes humanity to be external to Nature. The Review concludes instead that the global output of goods and services is inevitably bounded.

We should therefore ask whether the biosphere could support on a sustainable basis a global population of between 9.4 and 12.7 billion, which is the error bar round the UN Population Division's population median projection of 10.9 billion for year 2100 (UNPD, 2019b) at the material standard of living we are encouraged to seek. In effect we are asked in contemporary growth and development economics and the economics of climate change to imagine that the population numbers being projected today will be able to enjoy, at the very least, the current global living standard, even while making smaller demands on the biosphere than we do currently. No study in the economics of technological change has explored whether that is possible, let alone the question of what lifestyles that would involve. As of now we should be more than circumspect that the scenario is plausible, because at least as grave a danger facing humanity as global climate change is the unprecedented rate of loss in biological diversity now taking place (Chapter 4).

Largely as a result of human activities, species are becoming extinct much more rapidly than in the past. As currently calculated, extinction rates are judged to be 100 to 1,000 times higher than their background rate over the past tens of millions of years (0.1–1 per million species per year) and are continuing to rise (Chapter 4). Continued species extinctions will damage the biosphere irreparably, involving unknown numbers of tipping points, which should tell us that potential cascades cannot be staved off by mere technological fixes (Chapter 3). Politics has intervened to prevent even the relatively small global investment that economic experts only a few years ago suggested was required to contain climate change. So we should expect the problem of biological extinctions to remain off the table, at least until citizens take the matter seriously.[30]

In any event, talking in percentage terms when pointing to reductions in our demand for the biosphere's goods and services through technological progress, as people often do, can be misleading. The Earth's life support system does not calculate percentage changes; it responds at each instant to the *absolute* demands we make of it. That will be the message of Chapters 2, 3, 4 and 4*. If, as is nearly certain, our global demand continues to increase for several decades (Chapter 16), the biosphere is likely to be damaged sufficiently to make future economic prospects a lot dimmer than we like to imagine today. What intellectuals have interpreted as economic success over the past 70 years may thus have

[30] The really hard problem in the political economy of global climate change involves using the latter's special features to frame the way we should explore the prospects for international agreements. Barrett (2003), Barrett and Stavins (2003), Barrett and Dannenberg (2012), Barrett and Dannenberg (2014a) and Barrett and Dannenberg (2014b) are incisive analytical and empirical studies on this.

been a down payment for future failure. It would look as though we are living at the best of times and the worst of times.

The Review (Chapter 4) calls the excess of impact (*I*) over the biosphere's regenerative rate (*G*), the *Impact Inequality*.[31] *I* is in turn decomposed into three factors: human population numbers, global GDP per person, and the efficiency with which we convert the biosphere's goods and services into GDP.[32] The efficiency factor reflects not only technology but also institutions. Moreover, the factors are not independent of one another. The remainder of the Review probes into the drivers of the three factors. Our inquiry points to the types of international and national policies that would help to convert the Impact Inequality into an *Impact Equality*; that is, to bring about balance between *I* and *G* at a healthy stock (*S*) of the biosphere. That, the Review argues, is what *sustainable development* should be taken to mean.

There is a risk that the Impact Inequality and the decomposition of the impact we have chosen to work with will be read as a piece of Malthusian arithmetic. In fact, there is a risk that *any* study of the overshoot in the global demand for the biosphere's goods and services that includes population as a factor is read as a Malthusian tract. But that would be to misread the Review entirely. The Review applies the tools of modern economics to study the workings of the socio-ecological world as they are currently understood. In the process, the Review tries to explain how individual and group actions over the years have led globally to the Impact Inequality. It reads the source of the Impact Inequality in the Anthropocene as analogous to each of a crowd of people trying to keep balance on a hanging bridge, with a risk of bringing it crashing down. The Review then identifies the options humanity has for reversing the sign of the Impact Inequality.

The choices are hard, they involve a lot more than a tax here and a set of regulations there. Unlike the economics of climate change, at least as it is currently presented, the economics of biodiversity we construct in this Review requires not only national and intergovernmental engagement, but engagement by communities and civil societies throughout the world. The economics we construct here is neither entirely top-down nor entirely bottom up; it is also lateral. It advocates institutions that encourage information and directives to flow in every direction. Above all, it calls for changes in our sensibilities, because the silence and invisibility of Nature make it utterly vulnerable to our activities, which neither communities nor states can wholly address. Those changes can be realised only when our sensibilities toward Nature are acquired from the earliest stages of our lives. And that is all the more reason we citizens need to attend to them.

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[31] Barrett et al. (2020) introduced the Impact Inequality so as to understand the socio-ecological processes that are shaping the Anthropocene. The Review builds on their analysis to construct the economics of biodiversity.

[32] The decomposition of *I* follows Ehrlich and Holdren (1971).