10.3197/JPS.63772239426891

PEER-REVIEWED ARTICLE

Population and Sustainability: Reviewing the Relationship Between Population Growth and Environmental Change

David Samways[1]

Abstract

At a high level of abstraction, causally connecting population growth and environmental degradation is intuitively appealing. However, while it is clear that population size is a critical factor in the size and power of social systems, and hence in environmental impact, the relationship between human numbers and environmental change is complex. In particular, the long timescales involved in population growth and decline, along with the shifting role of economic development in both population growth itself and environmental impact, obfuscate the role of population size as a multiplier of impact. Moreover, the protracted nature of demographic change makes population size seem like an intractable problem, the outcome of natural processes which are not only beyond choice, but, critically, morally perilous. In this review of the role of population size in environmental impact, I argue that choices, norms, and values, as well as material factors, are interwoven and inseparable in the environmental impact of our species. Furthermore, the consideration of human welfare and wellbeing is central to arguments regarding an environmentally sustainable population.

Keywords: population; sustainability; IPAT; values; consumption; demographic transition; economic growth

1 david.samways@jpopsus.org

Introduction

It could be argued that the history of human development is the history of population growth and environmental change. Certainly, at a very high level of abstraction, this appears to be the case. In all historical periods environmental degradation has been closely associated with the growth in human numbers. Ehrlich and Holdren's (1972) I=PAT equation appears to clearly capture this relationship: environmental impact (I) is a function of the combination of population size (P) with affluence (A) and technology (T). Indeed, taking climate change as our proxy for all human environmental impacts, comparing the growth of carbon emissions to the growth in global population as shown in figures 1 and 2, it is tempting to conclude that population growth has been the principal driver of environmental impact.

Figure 1: Annual CO2 emissions 1750–2010

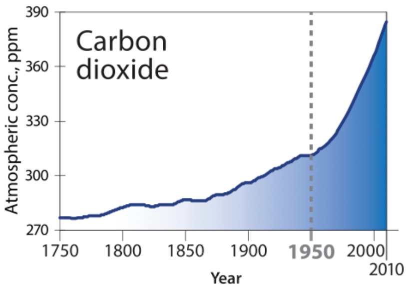
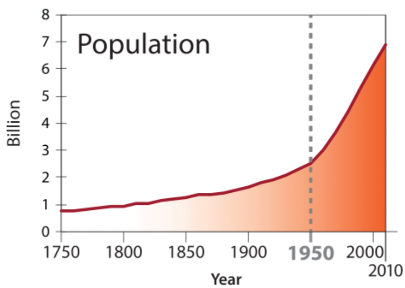


Figure 2: World population 1750–2010



(SOURCE: ADAPTED FROM STEFFEN ET AL. 2015)

However, correlation should not be confused with causation and the relationship between population growth and environmental impact – especially climate change – is more complex than it appears. Perhaps more importantly, as a means of tackling *imminent* environmental threats like climate change, focussing on population growth as a solution will not be effective (Bradshaw and Brook, 2014). Nonetheless, ethical policies to tackle population size are necessary not only to significantly mitigate our longer-term environmental impact but to improve human welfare both now and in the future.

In part, it is the fact that population growth and decline take place over long time periods that makes the problem difficult both to understand and to act upon. Indeed, the entirety of our current environmental predicament could be understood as the result of a collective failure to appreciate the unintended consequences of aggregated everyday individual behaviours beyond shorter time horizons. However, with population growth, the personal character of reproductive choices confers a 'naturalness' and sanctity to fertility decisions which becomes extended to discourses that see aggregate population dynamics as the result of entirely natural processes and therefore beyond governability. Even if population growth is recognised as potentially amenable to management it has so much momentum and is so politically sensitive that it is frequently regarded as intractable.

There is an obvious tension here between the widely accepted idea of human exceptionalism in escaping limits imposed by nature through agency (choices and actions) and the notion that aggregate human population size is beyond collectively agreed choice and governance. This tension between freedom and determinism in respect of population size is not new, but in the past the positions have been reversed. Thomas Malthus (1998 [1798]) argued that William Godwin's and the Marquis de Condorcet's utopian schemas for a society liberated from poverty would be scuppered by the natural process of the population growing to meet the food supply. In contrast, modern demographic transition[2] from high to low rates of mortality and fertility is often thought to be an autonomous process beyond policy choices (Coole, 2018), while those concerned about population growth argue that, given the context of natural boundaries, our choices make a critical difference. In fact, we will see that choices, norms, values and material factors are interwoven and inseparable in the environmental impact of our species. Furthermore, the consideration of human welfare and wellbeing is central to arguments regarding an environmentally sustainable population.

This review paper attempts to examine the relationship between human population size and environmental change. I begin by addressing the role of population growth and environmental change in the developmental history of

2 Demographic transition refers to the historically observed relationship between fertility and mortality rates and economic development in Western nations. Simply understood, by increasing welfare, economic development leads to a reduction in rates of mortality while fertility rates fall at a later date. The time lag between mortality and fertility becoming balanced produces population growth, followed by stabilisation at a higher figure.

our species. I then turn to the question of what population size can be sustained within planetary boundaries, before finally considering the political and ethical questions surrounding population degrowth. We will see that norms, values and ethical sentiments play a critical role in moving toward an environmentally sustainable population and in determining its quantitative and qualitative nature.

Population growth and environmental change

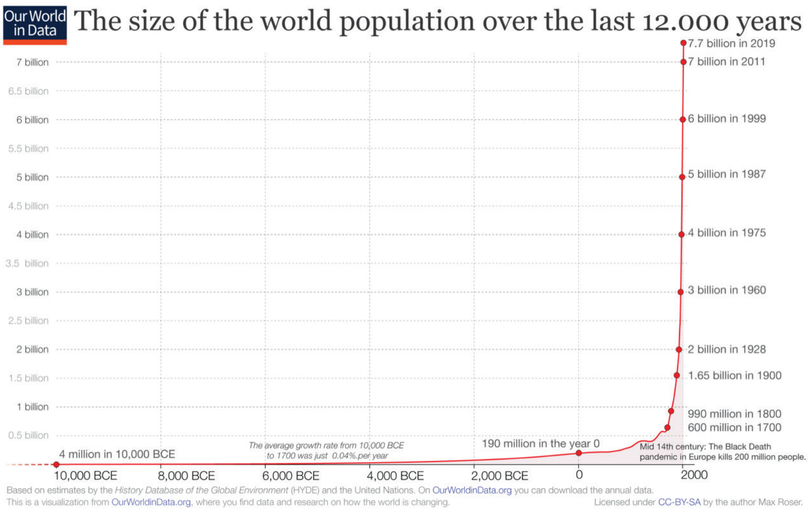
Human beings have always been a dynamic part of their environment. In the conduct of everyday life, all societies, no matter how small, intentionally and unintentionally change their environments, often producing what modern environmental discourses describe as degradation. In terms of environmental sustainability, the extensions in time and space of anthropogenic environmental changes are important and, while no fall from ecological grace can be located in the human past, turning points in the way that human beings have produced their material existence can be seen to correspond with the temporal duration and spatial extent of these changes. At the same time, these changes in the way that human beings have interacted with and manipulated their environment have also corresponded with periods of demographic transition, as the new mode of subsistence enabled numbers to grow then stabilise at a higher level (Bocquet-Appel and Bar-Yosef, 2016).[3]

In prehistory, increasing management of land by hunter gatherer societies followed by the establishment of settled agriculture enabled significant expansion of human numbers (Feeney, 2019; Gignoux, Henn and Mountain, 2011) which in turn multiplied the anthropogenic environmental change that had enabled its growth. At a local level, through the use of fire and other techniques, landscapes and ecologies were transformed by land-managing hunter-gatherers (see Kay, 1994; Krech, 1999; Anderson, 2005; Feeney, 2019) and Neolithic clearance of forest to create farmland and pasture dramatically transformed entire landscapes and ecosystems (Kaplan, Krumhardt and Zimmerman, 2009). Indeed, it has been argued that evidence from ice-cores and ocean sediments shows that, by increasing atmospheric carbon dioxide and methane concentrations, prehistoric agricultural practices, especially deforestation, may have influenced global

3 It is important to note that our knowledge of past population size and growth is provisional and made up of a patchwork of data gleaned from a variety of archaeological, historical and anthropological sources assembled to form estimates that are subject to initial assumptions and conjecture (Cohen, 1995).

climate and played a role in averting the onset of the next ice-age (Ruddiman et al., 2016). Whether entirely natural or augmented by human activity, the warming of the late Holocene contributed towards creating conditions favourable to human development and population growth.

Figure 3: Population growth over the last 12,000 years



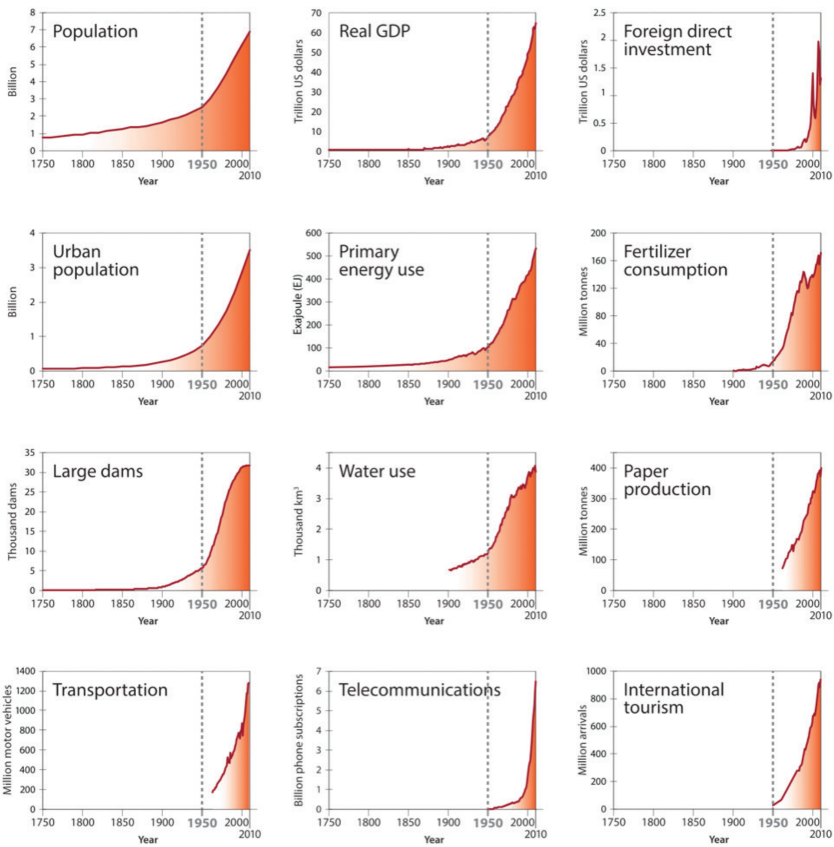
(SOURCE: WWW.OURWORLDINDATA.ORG)

From the medieval period onward, global population size began a path of apparently inexorable growth, only interrupted in the fourteenth century by the Black Death. From the relatively modest growth of the Middle Ages, the eighteenth century saw a further step-change in the rate of growth, followed by yet another after 1950. At the same time, environmental impact expanded from local environmental problems including water and air pollution mainly associated with urbanisation (see Brimblecombe, 1976, 1987), to potentially enduring impacts at the level of the Earth System.[4]

4 'The term Earth System refers to the suite of interacting physical, chemical, and biological global-scale cycles and energy fluxes that provide the life-support system for life at the surface of the planet' (Steffen, Crutzen and McNeill, 2007: 615).

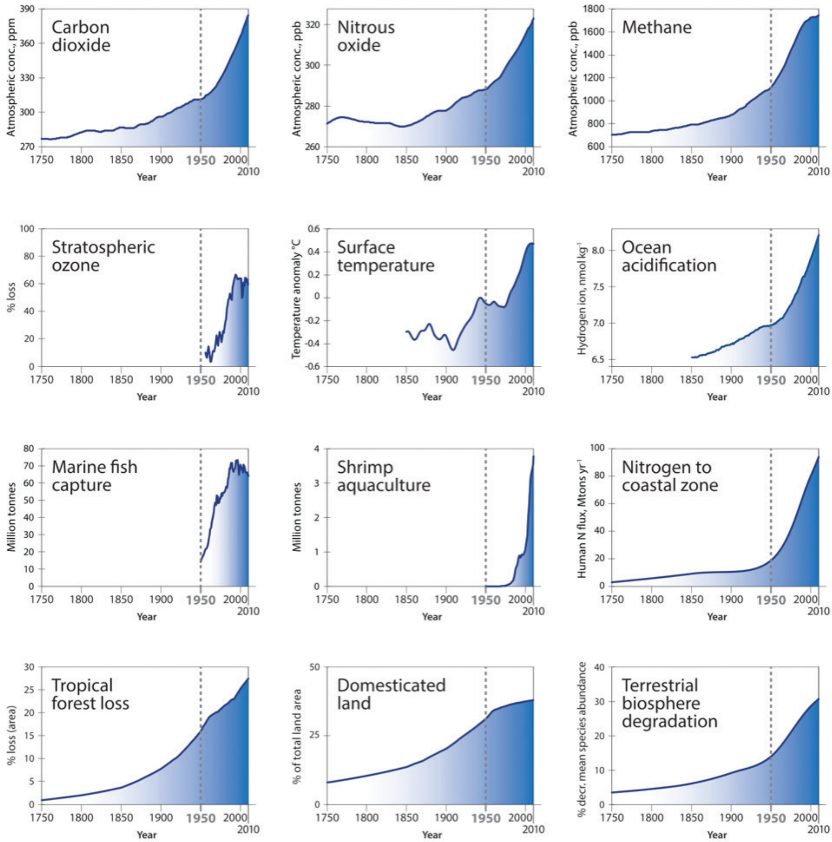
Indeed, the impact of industrial society from 1800 to 1950 was qualitatively and quantitatively so extensive and unprecedented that Will Steffen, Paul Crutzen and John McNeill (Steffen et al., 2007) proposed it as the first stage of the 'Anthropocene' – a new geological epoch succeeding the Holocene where human activity is the dominant influence on the Earth System. However, from 1950 onwards, the human enterprise expanded at such a rate that it has been termed 'The Great Acceleration' (see figures 4 and 5) (Steffen et al. 2007; Steffen et al. 2015).

Figure 4: Socio-economic trends. Reproduced by kind permission of Will Steffen



(SOURCE: STEFFEN ET AL. 2015)

Figure 5: Earth system trends. Reproduced by kind permission of Will Steffen



(SOURCE: STEFFEN ET AL. 2015)

Steffen and his colleagues (Steffen et al. 2007; Steffen et al. 2015) noted a correspondence between growth of a number of key dimensions of the world socio-economic system and changes in critical aspects of the Earth System. However, they argued that, since fossil fuels are a key factor in the generation of the Anthropocene, the growth in CO_2 concentration should serve as a barometer of its progress. While, during the first stage of the Anthropocene CO_2 concentrations exceeded the upper limit of Holocene natural variation, the Great Acceleration from 1950 produced such spectacular growth that it accounts for nearly three quarters of the total increase in all anthropogenic CO_2. Moreover, half of that total growth took place in the three decades from the mid-1970s. The same period saw similarly rapid and unprecedented growth in all other dimensions of the human enterprise, including massive expansion of the global economy and huge growth in the human population (Steffen, Crutzen and McNeill, 2007).

Understanding the relationship between modern population growth and environmental impact

With the IPAT equation in mind, the population and CO_2 curves in figures 1 and 2 might reasonably be interpreted as showing that a massive increase in affluence, resulting from economic growth, was multiplied by the huge growth in human numbers to cause the increase in CO_2 concentrations. However, a closer analysis shows a much more complex picture, with spatial and temporal unevenness playing an important role. While it is clear that a huge increase in population accompanied the growth of anthropogenic CO_2, the two have not increased proportionately. Indeed, taking 1850 as our starting point, world population increased by a little over sixfold to 2019 (1.26–7.71 billion) (Roser, Ritchie and Ortiz-Ospina, 2013) while, over the same period, anthropogenic carbon emissions have increased by a multiple of more than 180 (0.1969–36.42 billion tonnes per annum) (Ritchie and Roser, 2020). From the time of The Great Acceleration (1950) to the present, world population increased by a little over threefold (2.54–7.71 billion) (Roser, Ritchie and Ortiz-Ospina, 2013) while CO_2 emissions have increased by a factor of six (5.99–36.42 billion tonnes per annum) (Ritchie and Roser, 2020). Clearly, economic growth and affluence must have played a bigger role than population growth in the increase of CO_2 emissions, and this is supported by data which suggests a more than fourteen-fold increase in global per capita GDP between 1820 and 2018 (Roser, 2013).

However, this growth in affluence has not been evenly shared across the globe. Indeed, Steffen et al. (2015) addressed precisely this issue by breaking down the uneven environmental impact of rich world (OECD) countries compared to that of developing economies, finding that, while population growth had been greatest in non-OECD countries, economic activity and consumption were highly concentrated in the Global North. These equity issues have been flagged by

Oxfam who note that the richest ten per cent of the world's population were responsible for 52 per cent of cumulative emissions between 1990 and 2015. In contrast, the poorest half of the global population were responsible for just seven per cent (Gore, 2020). With the greatest population growth taking place in the poorest nations, many commentators have argued that focusing on population growth is irrelevant and a distraction in tackling the climate crisis and the environmental crisis more generally (see for example Monbiot 2020; Klein 2014). However, while it is clear that affluence and consumption, and their vastly unequal distribution between the Global North and South, are at the heart of discussions around environmental justice and the immediate responses to the climate crisis, it would be mistaken to draw the conclusion that population growth has not been a factor in the growth of CO_2 emissions and is therefore irrelevant to thinking about longer-term sustainability.

The temporal nature of population dynamics

One of the greatest problems of attempting to understand the relationship between population growth and environmental impact lies in the role *over time* that economic growth plays in both. The most simplistic and deterministic explanation of demographic transition contends that, by increasing welfare, economic development leads to a reduction in rates of mortality while fertility rates fall at a later date. The time lag between mortality and fertility rates coinciding towards equality produces population growth, which is then followed by stabilisation at the higher figure. However, in terms of environmental impact, the relative impact of population and affluence (consumption) during demographic transition shifts. Crudely put, during the early stages of economic development the growth rate of population is greater than the growth rate of per capita affluence and consequently population growth has a greater environmental impact. However, as economic growth and increasing per capita affluence slows population growth, the growth of per capita consumption becomes the more significant driver of environmental impact. Clearly, this does not mean that population is no longer a factor, since the absolute population of affluent individuals is much greater than that prior to economic development. Thus, this larger but stable population size acts as a multiplier of economic growth and hence of environmental impact.

Beginning around 1800, the demographic transition of the rich world had more or less been completed by the latter decades of the twentieth century; during that transition the combined population sizes of Europe and the United States quadrupled (Roser, Ritchie and Ortiz-Ospina, 2013). The same period saw the combined per capita GDPs of Western Europe and the United States[5] increase nearly sixteen-fold (Roser, 2013). Throughout the rich world's demographic transition, environmental impact continued to grow, as population size and increasing affluence multiplied the size and power of the social system. However, once population growth had declined and eventually ceased as fertility fell to replacement levels or less, the economies of the rich world continued to grow. At this point, natural population growth[6] ceased to be a source of growth in environmental impact, while increasing affluence and other factors continued to drive the expansion of impacts like CO_2 emissions.

A lack of comprehension of the relationship between economic development, demographic change and environmental impact over time frequently leads to misapprehensions about the role of population growth. A snapshot of world demographic trends at any particular point in time over the last seventy years would likely show developing regions with high rates of population growth and low per capita ecological footprints while rich countries have lower population growth rates and large per capita footprints.

In the period of the Great Acceleration, rates of population growth have been greatest in the Global South, with Asia adding the greatest number of additional people to the global population - 3.2 billion or 62 per cent of the total 5.15 billion increase between 1950 and 2019 (Roser, Ritchie and Ortiz-Ospina, 2013). While economic activity and consumption (and hence proportionate responsibility for global environmental impact) have been greatest in the Global North, during the past three or four decades Asia has undergone considerable economic development, with commensurate improvements in welfare, and at the same time considerably slowed its rate of population growth.

5 Indicative of the extent of the growth in affluence that took place across the whole of the industrialised Global North.

6 Meaning from births minus deaths rather than from immigration. It should be noted that the growth in the population sizes of both Europe and the USA have been due to a combination of natural growth and immigration which complicates a simplistic demographic transition narrative. Moreover, many developed countries are now experiencing fertility rates below replacement levels, leading to population ageing and, in the absence of immigration, population decline.

Comparing demographic, environmental (using CO_2 emissions as a proxy) and economic change in the United Kingdom and South Korea from 1960 to 2017 illustrates the role of population growth in environmental impact over time. In 1960 the UK and South Korea had annual population growth rates of 0.65 per cent and 3.02 per cent respectively (Roser, Ritchie and Ortiz-Ospina, 2013), while per capita CO_2 emissions for the UK stood at 11.15 tonnes compared to South Korea's minuscule 0.5 tonnes (Ritchie and Roser, 2020). Economically, in 1960 the UK was an extremely wealthy country with a per capita GDP of around nine times that of South Korea, which was then one of the world's poorest nations. By 2017 however, Korea had become one of the richest countries in the world with a GDP per capita equal to the UK (Roser, 2013). Moreover, South Korea's population growth rate is now considerably lower than that of the UK (Roser, Ritchie and Ortiz-Ospina 2013), but its per capita carbon footprint at 12.15 tonnes per person is greater than that of the UK in 1960 and more than double current UK domestic per capita emissions (Ritchie and Roser, 2020).

South Korea's economic development and demographic change over the last seven decades should not be taken to demonstrate autonomous, universal or 'natural' laws of demographic transition. In fact, South Korea represents a very particular case in terms of both the rapidity of economic development and fertility reduction, the latter being contributed to by a family planning programme that was so effective that total fertility had fallen to 1.78 children per woman by 1984 (Haub, 2010). Despite this, since the initiation of the programme in 1962 to the present-day South Korea's population has almost doubled (Roser, Ritchie and Ortiz-Ospina, 2013) which, along with its high per capita carbon footprint,[7] means that its environmental impact has massively increased.

While the case of South Korea is certainly not representative of all of Asia, it is nonetheless illustrative of the likely trajectory of environmental impact in the region as a result of the combination of economic development and population

7 It's important to point out that, as a manufacturing and exporting economy, South Korea's carbon emissions are not entirely due to domestic consumption. However, to some extent the same could be said of the UK in 1960 and the reduction of the UK's carbon emissions in recent years can be partially attributed to deindustrialisation and 'offshoring' of consumption emissions. Nonetheless, the Global Footprint Network (2021a) calculate South Korea's ecological footprint as 6.2 global hectares (gha) per person compared to the UK at 4.2 gha.

growth. The world's two most populous countries, China and India, despite both having declining rates of population growth, are not predicted to reach peak population size (China 1.46 and India 1.65 billion) until 2026 and 2053 respectively (Roser, Ritchie and Ortiz-Ospina, 2013). Using CO_2 emissions as a proxy, environmental impact has also grown and between 1990 and 2019 China and India, along with Iran and Indonesia, accounted for eighty per cent of the growth in carbon emissions of global emissions, with China alone being responsible for more than half this growth (Chaurasia, 2020). Moreover, from 2017 Asia's annual emissions eclipsed those of the rest of the world and China emitted more CO_2 per annum than the USA (Ritchie and Roser, 2020).

These gross figures must be treated with caution of course, since not only are the populations of these regions large, but emission figures include both those from domestic consumption and emissions embedded in goods for export. The shift of industrial manufacturing from the Global North to developing countries has also shifted emissions from the point of consumption in the rich world to the point of manufacture in countries such as China. Despite this, as incomes and welfare increase, domestic consumption emissions are growing in developing countries. China's economic growth and success in eradicating extreme poverty have been largely fuelled by coal and, as a result of rising incomes, per capita domestic consumption emissions are now approaching those of EU countries (Ritchie and Roser, 2020). While the economic development of the Global South will further slow the rate of population growth, the emergence of a middle class in countries like China and India, in combination with large and still growing populations and a reliance on coal, will significantly increase emissions (Steffen et al., 2015; Bongaarts and O'Neill, 2018).

Issues related to global economic inequality and environmental impact, as we will see, remain critical, yet continued population growth represents a serious challenge to achieving sustainability. This is confirmed by recent research (Chaurasia 2020) that showed that, although between 1990 and 2019 economic growth was the most important source of global growth in CO_2 emissions (around two thirds), population growth accounted for around a third of the increase in emissions. Significantly, it was also shown that the growth in emissions accounted for by population growth cancelled out more than three quarters of the CO_2 emission savings resulting from energy efficiency improvements, the use of lower emission fuels and renewables.

Nonetheless, although population growth has been a significant driver of carbon emissions, as Bradshaw and Brook (2014) show, demographic momentum (the forward growth of total population as the offspring of a higher fertility generation go on to have (fewer) children themselves) means that reductions in the fertility rate will take many decades to bring about a reduction in population size. Thus, as a policy instrument to tackle the imminent climate crisis, population degrowth will be ineffective and the immediate focus should be on policies and technologies designed to curb and reverse resource consumption. However, Bradshaw and Brook conclude that tackling human population size would have longer-term environmental (especially with respect to biodiversity and pressure on resources) and social benefits. Moreover, in respect of climate change, O'Neill et al. (2012) estimate that emissions could be reduced by forty per cent in the long-term with slower future population growth.

Population, welfare, sustainability.

Given the history of the relationship between population growth and environmental impact, it might be asked when the population of the Earth became unsustainable. According to the Global Footprint Network (GFN), humankind's demands did not overshoot the regenerative capacity of the Earth until after 1970 (GFN, 2021; Lin et al., 2018). The global population at that time stood at 3.7 billion (Roser, Ritchie and Ortiz-Ospina, 2013). At first glance, one might conclude that this is the point at which we trespassed beyond a maximum sustainable population, but once more this would be far too simplistic. In one sense it could be reasoned that the GFN data imply that, if humanity's resource consumption and production of wastes along with population had been instantaneously frozen at 1970 levels, this, assuming no other natural changes, could have been indefinitely supported by the Earth. However, a major problem with such an observation is that it conveys nothing of the global distribution of welfare at the time.

It is estimated that in 1970 around sixty per cent of the global population lived in poverty while 36 per cent lived in extreme poverty (Roser and Ortiz-Ospina, 2013), and the vast majority of these people lived in the Global South. The level of human welfare and its distribution is therefore a critical normative dimension of what can be considered an environmentally sustainable population size and, as we will see, features in all definitions.

It is an enduring misconception that, since the Malthusian Trap has been transcended by technical and economic development, the persistence of poverty is mostly a distributional issue and the equal sharing of wealth would give all a good life (see Raworth, 2017). Such reasoning implies that, if this was achieved at a collective global environmental footprint equal to one Earth, then such a population would be environmentally sustainable.

However, taking 1970 once again as our datum of maximum population and environmental impact, the equal distribution of global GDP would have more than eradicated poverty, but it would not have provided a high quality of life for all, with income levels of those in Western Europe falling by nearly two thirds to somewhat below those enjoyed in Eastern Europe at the time (Roser, Ritchie and Ortiz-Ospina, 2013). This 'back-of-the-envelope' calculation is provided for illustrative purposes alone; however, as we will see, others have applied similar reasoning and rigorous analysis to arrive at what might constitute an environmentally sustainable population size – a figure which is considerably less than half the present world population (Lianos and Pseiridis, 2015). Critically though, since 1970 the global population has more than doubled and planetary boundaries have been exceeded by seventy per cent (Lin et al., 2018). Today, the potentially sustainable consumption levels of 1970 must be shared between nearly eight billion people.

A good life for all within planetary boundaries

Further refutation of the idea that environmental sustainability at high welfare standards for all is simply a question of distribution was provided by research carried out by Dan O'Neill and his colleagues (2018) which attempted to understand the level of welfare that could be provided within planetary boundaries to a population of more than seven billion. O'Neill et al. showed that, in principle, an equal distribution of resources could meet the physical needs (including nutrition, sanitation, access to electricity and the elimination of extreme poverty) of seven billion within planetary boundaries. However, achieving the universal welfare standards aspired to in the UN's Sustainable Development Goals (SDGs) would require between two and six times the level of resources that are sustainable within planetary boundaries and would have 'the potential to undermine the Earth-system processes upon which development ultimately depends' (O'Neill et al., 2018: 93). Moreover, Jason Hickel (2019a) notes that, factoring in population growth, meeting the economic objectives of SDG 8 would lead to the global economy being 55 per cent larger in 2030 than it was in 2015.

To meet the sort of higher welfare standards that most people in the developed world take for granted ('life satisfaction, healthy life expectancy, secondary education, democratic quality, social support and equality' (92)), O'Neill et al. argue that 'provisioning systems' – the complex of socio-technical systems which mediate the relationship between resource use and welfare provision (see Fanning, O'Neill and Büchs, 2020) – must become two to six times more efficient. However, this is more than just a technical challenge since, while technical efficiency improvements will be significant in lowering resource consumption, social structural changes will also be necessary to prevent rebound effects, reduce inequality and enhance social support.

Building on O'Neill et al.'s data, but relying on existing policy options rather than an improvement in global 'provisioning systems', Hickel (2018) has calculated that it is possible for all to have a good life within planetary boundaries, but that a reduction in the environmental footprint of the developed world of between forty and fifty per cent will be necessary, requiring degrowth strategies and the adoption of a post-capitalist economy. This would involve a shift in values and norms and a redefining of what constitutes a good life away from resource intensive social practices and aspirations. O'Neill et al. argue that by recognising the social and environmental burdens of overconsumption and focusing on sufficiency, resource use could be significantly reduced in developed countries without affecting social wellbeing. Necessary to this shift will be the abandoning of GDP as a measure of social progress.

However, O'Neill et al. point out that, without addressing the growth in population, the task of achieving a good life for all within planetary boundaries will become increasingly difficult. Indeed, since rich countries must reduce their aggregate economic activity, Hickel suggests that:

> One approach would be to gradually reduce the size of the population (in an equitable, progressive, and non-coercive way), so that GDP per capita can be maintained even while total economic activity shrinks. But if we assume that the population grows according to existing

> projections and stabilises at 9–11 billion, this will require de-growth in both absolute and per capita terms. (Hickel, 2018: 13)

Hickel's suggestion chimes well with the observation that reducing fertility in the rich world can also have significant effects on global environmental impact since the environmental footprint of each child born into the developed world is up to thirty times greater than each born in the poor world (Maxton and Randers, 2017; Wynes and Nicholas, 2017).

While O'Neill et al. and Hickel are not primarily concerned with population size, it is obviously a critical dimension of their work and makes clear that development, human welfare and equity are directly related to the notion of an environmentally sustainable population size. Those who have examined the notion directly have also accepted the same basic assumptions and focus on the size of population compatible with both a good life and a sustainable relationship with nature to arrive at an 'optimum population'.

What is an optimum population?

In 1994 two groups of researchers, employing differing methodologies but arriving at similar conclusions, tackled the question of optimum population size. Gretchen Daily, Anne Ehrlich and Paul Ehrlich (1994) took energy consumption as a surrogate for consumption in general and argued that given a maximum energy production compatible with environmental limits and a global convergence toward what they reasoned to be per capita energy consumption compatible with a good standard of living, the optimum population size amounted to no more than two billion people. In contrast, David Pimentel and colleagues (1994) based their argument upon a calculation of the amount of sustainably managed land needed to support a single individual, concluding that three billion people might be adequately fed, but only between one and two billion could live in relative prosperity (assuming a self-sustaining and renewable energy system). In 2010 Pimentel et al. revisited the question and arrived at the conclusion that the planet could support two billion people at a European lifestyle.

More recently, Theodore Lianos and Anastasia Pseiridis (2015) examined optimum population from the perspective of sustainable Gross World Product (GWP). Exploring the notion of what might be considered optimal, they concede that optimum population is impossible to estimate with any degree of accuracy. Indeed, Daily et al. (1994) similarly point out that shifting societal goals and technology will change what might be considered an optimum, and Tucker (2019) argues that Daily et al.'s energy constraint assumptions are now technically surmountable.

Importantly, Lianos and Pseiridis consider their value assumptions in some detail, basing their notion of welfare upon Aristotelian notions of 'the best life' in which the lower and upper bounds of population size are of consequence. Such a concept extends beyond meeting basic needs to a more expansive notion of social flourishing, including more subjective ideas regarding the value of nature. However, while what constitutes a good life may be subjective, ecological footprint and conservation of natural capital provide objective criteria from which to work, and with these assumptions stated, Lianos and Pseiridis provide an economic interrogation of optimum population showing the trade-off between welfare and population size if humanity remains within the Earth's biocapacity. With sustainable welfare rather than economic development per se as a goal, they argue that the adoption of European levels of welfare as a standard for a comfortable life could sustain a population size of 3.1 billion without exceeding the planet's biocapacity.

Christopher Tucker's (2019) *Planet of 3 Billion* arrives at an optimum population size similar to that of Lianos and Pseiridis, but he does so with differing assumptions. Tucker's 'biogeographical' approach rests on three assumptions: the necessity of rewilding a large portion of the planet, a degree of technological optimism regarding resource use efficiency, and a modern industrial level of welfare equivalent to a Swiss standard of living. Importantly, his concept of sustainability draws heavily upon E.O. Wilson's Half-Earth (2016) thesis, which aims to reverse the ongoing current mass extinction by rewilding half of the planet, with Tucker making the case that the conservation and restoration of ecosystem services are essential to not only the survival but the thriving of humankind. Thus, while Tucker adopts a similar measure of welfare to Lianos and Pseiridis and is perhaps more technologically optimistic, due to his subscription to the Half-Earth thesis, he has a far more restrictive conception of natural boundaries. Yet, it is also worth noting that Tucker's assumptions regarding ecosystem services and global catastrophic or existential risk are not universally endorsed (see Kareiva and Carranza, 2018), leaving a degree of uncertainty about one of the key 'objective' limiting assumptions in his estimate of sustainable human population.

While the estimates of optimum population in the above studies have ranged between one and three billion, there appears to be a convergence around three billion people as the maximum number at anything above basic need. Moreover, (as noted by Daily et al., 1994 and by Lianos and Pseirides, 2015) even if the figures obtained in these studies underestimated the environmentally sustainable population size by a hundred per cent they would still be below current and projected population sizes. Such estimates are somewhat supported by O'Neill et al.'s conclusion that, based on current socio-technical arrangements, a high-quality lifestyle for seven billion people would require resource consumption of between two and six times the sustainable level, implying that at this level of welfare the environmentally sustainable population size is between 1.2 to 3.5 billion. However, a critical insight of O'Neill et al.'s article is that, with a concerted effort, substantial social, economic and technical changes could considerably improve the ability to provide good welfare to the existing population, but that a growing population makes this more difficult:

> Given that the United Nations 'medium variant' prediction is for global population to rise to 9.7 billion people by 2050, and 11.2 billion by 2100, the challenge will be even greater in future if efforts are not also made to stabilize global population. (92)

Assumptions, values and sustainability

We see, then, that modelling assumptions and values are central to the question of what might be an 'optimum' population size. As O'Neill et al. (2018) show, in theory it is possible that with current social and technical arrangements the basic needs of the present world population could be met within planetary boundaries. However, basic needs fall very short of what many consider to be a good life. What is considered a sustainable maximum population not only depends upon planetary boundaries, but upon our definition of the good life and of what we value. O'Neill et al.'s and Hickel's work shows that it may be theoretically and technically possible to provide a good life for seven billion within planetary boundaries but only if our social values are changed. Moreover, our values are not de facto restricted to notions of human welfare, but may be expanded to include the consideration of members of other species, of entire ecosystems and of landscapes.

From this perspective, the concept of 'sustainability' itself becomes more complex and intangible. While the value placed upon different parts of the natural world must be arrived at through debate and discussion, our knowledge of the impact of the growth in the size and power of the social system upon the Earth system itself hypothesises boundaries to a safe operating space for humanity (Rockström et al. 2009). Since the environmental conditions of the Holocene have been conducive to the development and thriving of humankind, the precautionary principle provides good reasons to assume that, in order to avoid human suffering, sustain our civilisation and preserve the environments and other species we value, we must roll back our influence to remain within the parameters of the Holocene. Environmental sustainability is therefore a complex of both natural physical boundaries and values relating to both human wellbeing and the natural world – including the 'nature' which is the outcome of thousands of years of human action.

Inequality, justice and sustainability

We have seen how sustainability and a sustainable population size are profoundly value-laden, political and ethical notions dependent on the articulation of arguments defining the good life, what we consider to be just and fair, and the sort of environment in which we wish to live. Pimentel et al. (1994: 364) saw the choice before humanity as follows:

> Does human society want 10 to 15 billion humans living in poverty and malnourishment or 1 to 2 billion living with abundant resources and a quality environment?

Unfortunately, Pimentel et al.'s choice omits a critical dimension: global inequality. Those calculating sustainable population size, whilst rebutting simple distributional arguments, usually start with the assumption of equal resource distribution, but there is little reason to be optimistic that this might be achieved in the future. It is an unpalatable fact that the degree to which wealthier people are willing to tolerate the suffering of the poor in far-off places is also a choice relevant to the environmental sustainability of a given population size. Vast inequality between the Global North and South has been an enduring feature of the modern world and, while extreme poverty has declined, this is not due to a drive towards equality and the voluntary redistribution of resources but a consequence of economic development and growth of the global economy. Cohen's (2017) observation regarding the persistence of malnutrition amongst millions as being partially the result of the food choices (consumption of meat and dairy) of those in the rich world pricing the poorest out of the global food market speaks volumes regarding the unintended consequences of everyday habits (see also Pseiridis 2012).

Without addressing the extent of global inequality, it is likely that the poor will bear the greatest cost of population growth and indeed of environmental degradation. Hickel (2018) argues that a fundamental reorientation of our approach to development is required to avoid this and, instead of concentrating on the deficiencies of poor countries, we should attend to the excesses of rich ones. While this is unquestionably true, redressing the imbalance between rich and poor whilst also attempting to live within planetary boundaries becomes increasingly less effective at improving welfare if population growth itself is left unattended to, since fewer resources must be distributed between an ever-greater number.

Yet the reticence of many in the environmental movement to acknowledge population growth as a problem is frequently based upon observations regarding the inequality between the Global North and Global South. Much of this is related to confusion surrounding the temporal disjuncture, noted above, between population growth rates and the growth of environmental impact consequent upon economic growth and increasing welfare and affluence. This confusion frequently leads to the accusation that those concerned about population growth are blaming the poor for an environmental crisis in which they have little culpability.[8] Indeed, when it is considered that the ecological footprint of the average American citizen is eight times greater than that of a citizen of Nigeria (GFN, 2021) this argument is understandable. Yet, like many other developing countries, a high rate of population growth is a significant driver of Nigeria's growing per capita ecological deficit. In contrast, since achieving a low rate of population growth, the USA's ecological deficit is almost entirely the result of the growth of affluence.

8 While it is the case that climate change and other environmental problems have been disproportionately generated by the rich world, as in previous eras, poverty and population growth can have a significant association with local environmental degradation such as deforestation (Lopez-Carr and Burgdorfer, 2013).

Moreover, 'population control' has been associated with imperialism, racism, eugenics and past coercive population policies such as those in China and India, and has somewhat understandably made the subject of population growth taboo. Even when the long-term desirability of accelerating the declining rate of population growth is acknowledged, many are uncomfortable with influencing fertility decisions because they are regarded as inseparable from personal autonomy and basic human rights. However, few actions are entirely self-regarding, and Diana Coole (2018) has noted that reproduction is an other-regarding act that has the potential to undermine the socio-ecological conditions of possibility for exercising individual basic rights. Perhaps most importantly though, ethical policies whose object is to lower fertility are in many instances emancipatory, transforming female subjectivity, enabling both men and women to take control of their own fertility and exercise choice in their family size, and frequently producing general improvements in welfare.

Moreover, it has been shown that, in conjunction with access to modern contraceptives, education, particularly of girls, is one of the most important factors in reducing fertility (Lutz, Butz and KC, 2014; Vollset et al., 2020). Not only does education develop the potential of individuals, enabling them to make informed decisions and improve their own lives, but it also improves the life chances of their offspring and of their communities. Improvements in female education are critical in breaking down patriarchal structures and roles, enabling women to participate more fully in the economy and develop occupations and careers, typically resulting in later marriage, lowering the fertility rate through increased birth-spacing and fewer pregnancies. Importantly, since the impact of climate change is likely to be greatest in developing countries with high rates of population growth, ethical family planning can not only support economic and social development, but strengthen the resilience and adaptive capacity of poor communities (Dodson et al., 2020).

Conclusion

The growth in the size of the human population is an indisputable factor in the unprecedented size and power of our social systems and their impact on the Earth system. Yet, as I have shown, the growth of population alone cannot account for the massive anthropogenic environmental impacts of modern society. As a powerful heuristic device, the I=PAT equation reminds us that environmental impact is the result of the collective outcome of three factors: the level of resource consumption, the technologies employed and the level of population. In theory, changing any one of these factors will change our environmental impact. However, in the relationship between population and sustainability, values play a critical role both in how we materially provide for our current and projected populations and in understanding what size of future population might be environmentally sustainable and how we might achieve it.

The Holocene provided environmental conditions in which humankind thrived, but the growth in power and size of our social systems has led to environmental changes that threaten the stability of these conditions. In order to remain within the parameters of the Holocene, and thus avoid human suffering, sustain our civilisation and preserve the environments and other species we value, we must curtail our influence, including the size of our population. The possible size of an environmentally sustainable population is therefore a complex of both natural physical boundaries and values relating to both human wellbeing and the natural world.

Acknowledging and tackling population growth as a driver of environmental change requires a long-term perspective: the ‘optimum’ populations mentioned in this paper, even with a concerted effort, could take hundreds of years to achieve (Lutz and KC, 2010). However, the greater the delay in tackling such problems the more insurmountable the problem becomes. Bradshaw and Brook (2014) observe that demographic momentum could have been retarded if population growth had been tackled immediately after 1945 and the present environmental and social problems would thus have been avoided. Tackling the size of the human population is therefore a long-term investment in improving welfare for all whilst staying within planetary boundaries. There is an irony in the population denial of some environmental stakeholders who, whilst critical of the short-termism of modern society, fail to embrace the role of population in achieving the long-term objective of universally good welfare within planetary boundaries.

Adopting a long-term perspective means that ethical policies aimed at bending the population growth curve must be seen as complimentary to measures tackling the more responsive drivers of the environmental crisis: consumption and technology. The necessity of such an approach is demonstrated by the fact that, so far, increases in CO_2 emissions due to population growth have been greater than the reductions achieved through technical advances (Chaurasia, 2020). As O'Neill et al. (2018) and Hickel (2018; 2019a; 2019b) have indicated, to provide everyone on the planet with the opportunity to have a good life, a radical restructuring of the global economy and provisioning systems is required. Reducing the footprint of the Global North and allowing that of the Global South to increase whilst simultaneously reducing the overall footprint of humanity to sustainable levels will require a reappraisal of what is meant by a good life across the world. Continuous growth in consumption is clearly incompatible with such ambitions, but so too is ignoring population growth.

Acknowledgements

I would like to thank Bill Anderson-Samways and the two anonymous reviewers for their helpful suggestions and comments.

References

Anderson, M.K. 2005. *Tending the Wild: Native American Knowledge and the Management of California's Natural Resources*. Berkeley, CA: University of California Press. https://doi.org/10.1525/9780520933101

Bocquet-Appel, J.P. and O. Bar-Yosef (eds). 2016. *The Neolithic Demographic Transition and Its Consequences*. Dordrecht: Springer.

Bongaarts, J. and B. O'Neill. 2018. 'Global warming policy: is population left out in the cold?' *Science* **361** (6403): 650–52. https://doi.org/10.1126/science.aat8680

Bradshaw, C. and B. Brook. 2014. 'Human population reduction is not a quick fix for environmental problems'. *Proceedings of the National Academy of Sciences* **111** (46): 16610–16615. https://doi.org/10.1073/pnas.1410465111

Brimblecombe, P. 1976. 'Attitudes and responses towards air pollution in medieval England'. *Journal of the Air Pollution Control Association* **26** (10): 941–945. https://doi.org/10.1080/00022470.1976.10470341

Brimblecombe, P. 1987. *The Big Smoke.* London: Routledge.

Chaurasia, Aalok Ranjan. 2020. 'Population effects of increase in world energy use and CO2 emissions: 1990–2019'. *The Journal of Population and Sustainability* **5** (1): 87–125. https://doi.org/10.3197/jps.2020.5.1.87

Cohen, Joel E. 1995. *How Many People Can the Earth Support?* New York: Norton.

Cohen, Joel E. 2017. 'How many people can the Earth support?' *The Journal of Population and Sustainability* **2** (1): 37–42. https://doi.org/10.3197/jps.2017.2.1.37

Coole, Diana. 2018. *Should We Control World Population?* Cambridge: Polity.

Daily, G., A.H. Ehrlich and P.R. Ehrlich. 1994. 'Optimum human population size'. *Population and Environment* **15** (6): 469–475. https://doi.org/10.1007/BF02211719

Dodson, J.C., P. Dérer, P. Cafaro and F. Götmark. 2020. 'Population growth and climate change: Addressing the overlooked threat multiplier'. *Science of The Total Environment* **748** (141346): 1–10. https://doi.org/10.1016/j.scitotenv.2020.141346

Ehrlich, P.R. and J.P. Holdren. 1972. 'One-dimensional ecology'. *Bulletin of The Atomic Scientists* May 1972: 16, 18–27. https://doi.org/10.1080/00963402.1972.11457930

Fanning, A., D. O'Neill and M. Büchs. 2020. 'Provisioning systems for a good life within planetary boundaries'. *Global Environmental Change* **64** (102135): 1–11. https://doi.org/10.1016/j.gloenvcha.2020.102135

Feeney, J. 2019. 'Hunter-gatherer land management in the human break from ecological sustainability'. *The Anthropocene Review* **6** (3): 223–242. https://doi.org/10.1177/2053019619864382

Global Footprint Network (GFN). 2021. Open data platform (ecological footprint vs biocapacity). https://data.footprintnetwork.org/#/ (accessed 2 September 2021)

Gore, T., 2020. *Confronting Carbon Inequality.* Nairobi: Oxfam https://oxfamilibrary.openrepository.com/bitstream/handle/10546/621052/mb-confronting-carbon-inequality-210920-en.pdf (accessed 12 February 2021).

Gignoux, Christopher R., Brenna M. Henn and Joanna L. Mountain. 2011. 'Rapid, global demographic expansions after the origins of agriculture'. *Proceedings of the National Academy of Sciences* **108** (15): 6044–6049. https://doi.org/10.1073/pnas.0914274108

Haub, C. 2010. Did South Korea's population policy work too well? Washington DC: Population Reference Bureau. https://www.prb.org/resources/did-south-koreas-population-policy-work-too-well/ (accessed 27 August 2021).

Hickel, J. 2018. 'Is it possible to achieve a good life for all within planetary boundaries?' *Third World Quarterly* [e-journal] 40 (1). https://doi.org/10.1080/01436597.2018.1535895

Hickel, J. 2019a. 'The contradiction of the sustainable development goals: Growth versus ecology on a finite planet'. *Sustainable Development* **27**: 873– 884. https://doi.org/10.1002/sd.1947

Hickel, J. 2019b. 'The imperative of redistribution in an age of ecological overshoot: human rights and global inequality'. *Humanity* **10** (3): 416–428 https://doi.org/10.1353/hum.2019.0025

Kaplan, Jed O., Kristen M. Krumhardt and Niklaus Zimmerman. 2009. 'The prehistoric and preindustrial deforestation of Europe'. *Quaternary Science Reviews* **28** (27–28): 3016–3034. https://doi.org/10.1016/j.quascirev.2009.09.028

Kareiva, P. and V. Carranza. 2018. 'Existential risk due to ecosystem collapse: Nature strikes back'. *Futures* **102**: 39–50. https://doi.org/10.1016/j.futures.2018.01.001

Kay, C.E. 1994. 'Aboriginal overkill: The role of Native Americans in structuring western ecosystems'. *Human Nature* **5** (4): 359–398. https://doi.org/10.1007/BF02734166

Klein, Naomi. 2014. *This Changes Everything*. London: Penguin

Krech, S. 1999. *The Ecological Indian: Myth and History*. New York: W.W. Norton.

Lianos, T.P. and A. Pseiridis. 2015. 'Sustainable welfare and optimum population size'. *Environment, Development and Sustainability* **18** (6): 1679–1699. https://doi.org/10.1007/s10668-015-9711-5

Lin, D., L. Hanscom, A. Murthy, A. Galli … and M. Wackernagel. 2018. 'Ecological footprint accounting for countries: updates and results of the National Footprint Accounts, 2012–2018'. *Resources* **7** (3): 58. https://doi.org/10.3390/resources7030058

Lopez-Carr, D. and J. Burgdorfer. 2013. 'Deforestation drivers: Population, migration, and tropical land use'. *Environment* **55** (1): 3–11. https://doi.org/10.1080/00139157.2013.748385

Lutz, W., W.P. Butz and S. KC (eds). 2014. *World Population and Human Capital in the Twenty-First Century*. Oxford: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198703167.001.0001

Lutz, W. and S. KC. 2010. 'Dimensions of global population projections: what do we know about future population trends and structures?' *Phil. Trans. R. Soc. B* **365**: 2779–2791. https://doi.org/10.1098/rstb.2010.0133

Malthus, T.R. 1998 [1798]. *An Essay on the Principle of Population.* Bellingham, WA: Electronic Scholarly Publishing Project. http://www.esp.org/books/malthus/population/malthus.pdf (accessed 26 November 2018).

Maxton, G. and J. Randers. 2016. *Reinventing Prosperity*. Vancouver: Greystone.

Monbiot, G. 2020. 'Population panic lets rich people off the hook for the climate crisis they are fuelling'. *The Guardian* 26 August https://www.theguardian.com/commentisfree/2020/aug/26/panic-overpopulation-climate-crisis-consumption-environment (accessed 19 January 2021).

O'Neill, B., B. Liddle, L. Jiang, K.R. Smith … and R. Fuchs. 2012. 'Demographic change and carbon dioxide emissions'. *The Lancet* **380**: 157–64. https://doi.org/10.1016/S0140-6736(12)60958-1

O'Neill, D.W., A.L. Fanning, W.F. Lamb and J.K. Steinberger. 2018. 'A good life for all within planetary boundaries'. *Nature Sustainability* **1**: 88–95. https://doi.org/10.1038/s41893-018-0021-4

Pimentel, D. et al. 1994. 'Natural resources and an optimum human population'. *Population and Environment* **15** (5): 347–369. https://doi.org/10.1007/BF02208317

Pimentel, D. et al. 2010. 'Will limited land, water and energy control human population numbers in the future?' *Human Ecology* **38**: 599–611. https://doi.org/10.1007/s10745-010-9346-y

Pseiridis, A. 2012 'Hunger and the externalities of dietary preferences: Demand-side considerations of the current dietary paradigm'. *SEEJE: South-Eastern Journal of Economics* **10** (1): 1–23.

Raworth, K. 2017. *Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist.* London: Random House.

Ritchie, H. and M. Roser. 2020. *CO_2 and Greenhouse Gas Emissions.* Oxford: Our World in Data. https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions (accessed 25 August 2021).

Rockström, J. et al. 2009. 'A safe operating space for humanity'. *Nature* **241**(24): 472–475. https://doi.org/10.1038/461472a

Roser, M. 2013 (updated 2018). *Economic Growth*. Oxford: Our World in Data https://ourworldindata.org/economic-growth (accessed 25 August 2021).

Roser, M. and E. Ortiz-Ospina. 2013. *Global Extreme Poverty*. Oxford: Our World in Data https://ourworldindata.org/extreme-poverty (accessed 2 September 2021).

Roser, M., H. Ritchie and E. Ortiz-Ospina. 2013 (updated 2019). *World Population Growth*. Oxford: Our World in Data https://ourworldindata.org/world-population-growth (accessed 25 August 2021).

Ruddiman, W.F. et al. 2016. 'Late Holocene climate: Natural or anthropogenic?' *Rev. Geophys.* **54**: 93–118. https://doi.org/10.1002/2015RG000503

Steffen, W., W. Broadgate, L. Deutsch, O. Gaffney and C. Ludwig. 2015. 'The trajectory of the Anthropocene: The Great Acceleration'. *The Anthropocene Review* **2** (1): 81–98. https://doi.org/10.1177/2053019614564785

Steffen, Will, Paul J. Crutzen and John R. McNeill. 2007. 'The Anthropocene: Are humans now overwhelming the great forces of nature'. *AMBIO: A Journal of the Human Environment* **36** (8): 614–621. https://doi.org/10.1579/0044-7447(2007)36[614:TAAHNO]2.0.CO;2

Tucker, C.K., 2019. *A Planet of 3 billion.* Washington, DC: Atlas Observatory Press.

Vollset, S.E., E. Goren, C.-W. Yuan, J. Cao et al. 2020. 'Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: A forecasting analysis for the Global Burden of Disease Study'. *The Lancet* **396** (10258): 1285–1306. https://doi.org/10.1016/S0140-6736(20)30677-2

Wilson, E.O. 2016. *Half-Earth: Our Planet's Fight for Life.* New York: W.W. Norton and Company.

Wynes, S. and K.A. Nicholas. 2017. 'The climate mitigation gap: education and government recommendations miss the most effective individual actions'. *Environmental Research Letters* **12** (7): 4024. https://doi.org/10.1088/1748-9326/aa7541