The human eco-predicament: Overshoot and the population conundrum

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Abstract

The human enterprise is in overshoot, depleting essential ecosystems faster than they can regenerate and polluting the ecosphere beyond nature's assimilative capacity. Overshoot is a meta-problem that is the cause of most symptoms of eco-crisis, including climate change, landscape degradation and biodiversity loss. The proximate driver of overshoot is excessive energy and material 'throughput' to serve the global economy. Both rising incomes (consumption) and population growth contribute to the growing human eco-footprint, but increasing throughput due to population growth is the larger factor at the margin. (Egregious and widening inequality is a separate socio-political problem.) Mainstream approaches to alleviating various symptoms of overshoot merely reinforce the *status quo*. This is counter-productive, as overshoot is ultimately a terminal condition. The continuity of civilisation will require a cooperative, planned contraction of both the material economy and human populations, beginning with a personal to civilisational transformation of the fundamental values, beliefs, assumptions and attitudes underpinning neoliberal/capitalist industrial society.

Keywords: overshoot; eco-footprint; carrying capacity; sustainability; population; contraction

1 Introduction: Contrasting approaches to population

My thesis in this paper is that modern techno-industrial (MTI) society is in a state of dangerous ecological overshoot—i.e., that there are too many people consuming and polluting too much on a finite planet. It is not too late, however, to take a lesson

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in sustainability from the tiny tropical island society of Tikopia. Hardly anyone has ever heard of Tikopia, but its history should be known by everyone who cares about the future of Earth. Tikopia is the remnant of an extinct volcano in the south-west Pacific Ocean with an area of less than five square kilometres, 80% of which is arable. First settled by people about 900 before the Common Era, the island has been occupied continuously for nearly 3000 years (Wikipedia, 2021). Most remarkably, for perhaps two millennia, Tikopians have practiced as many as seven forms of birth control and employed other means of harmonising their life-styles with local ecosystems. In short, *by cultural tradition*, Tikopians have managed continuously to maintain their population in the vicinity of 1200 individuals, or about 300 people per square kilometre of arable land. Even today, islanders explicitly assert that their contraceptive and other regulatory behaviours are practiced to prevent the island from becoming overpopulated (Diamond, 2005).

Contrast Tikopia with the modern global community. Planet Earth is also an island in space with a limited productive land area, but it is threatened by rampant ecological degradation (including accelerating climate change), continuous conflict over habitable territory, evidence of incipient energy and food shortages, and growing numbers of political and ecological refugees who can already be counted in the millions. Nonetheless, there are no national or global plans for population management. On the contrary, those few high-income nations whose populations have stabilised or fallen are worried about the expected negative consequences of this trend for economic growth, political influence and social stability; some world religions explicitly consider contraception to be intrinsically evil; and advocates of population policy are often vilified as being neo-Malthusian, anti-human, eco-fascist or racist (Kopnina and Washington, 2016).[1] In short, the 'population question' is still largely a taboo subject in official MTI policy—and even popular—circles. It should therefore be no surprise that in 2022, Earth's population of 7.9 billion people is still growing by more than 1% (80 million people) per year (Worldometer, 2022). Indeed, some authorities suggest that the rate is closer to 90 million per year, and that UN demographers tend to understate population growth for political reasons. According to O'Sullivan (2022), "Where *World Population Prospects 2022* [see UN, 2022] should have been a call to action, it makes an explicit call to inaction".

Against this as background, my aim in this paper is to demonstrate that the present size and continued growth of the human enterprise are anomalies, that population growth is the major contributor to dangerous degradation of the ecosphere at the margin, and that the largest potholes on the road to sustainability are the global spread of consumer life-styles and resistance to family and national population planning.

1 For a recent example that attacks and misrepresents me and my co-author, see Kaufman (2022).

1.1 The material roots of overshoot

Continuous, rapid population growth is a recent phenomenon. For most of our species' time on Earth—including most of the agricultural era—humanity's natural propensity to expand has been held in check by negative feedback; e.g., by food and other resource shortages, disease and inter-group conflict. Circumstances changed with the scientific/industrial revolution, and particularly with the increasingly widespread use of fossil fuels (FF) abetted by globalisation and trade. *Homo sapiens* had been around for perhaps 250,000 years before our population topped one billion early in the 19th century, but it took only 200 years (1/1250th as much time!) for it to balloon to nearly eight billion by early in the 21st century. While improvements in medicine, public sanitation and population health contributed, it was mainly the consumption of coal, oil and gas that made this spectacular expansion possible (half the FF ever used have been burned since 1990.) Fossil fuels are the energetic means by which humans extract, transport and transform the prodigious quantities of food and other material resources needed to support our burgeoning billions all over the world (Rees, 2020a). In short, science and fossil energy enabled *H. sapiens* to eliminate or reduce historically normal negative feedback and let positive feedback take over. For the first time in human evolutionary history, the scientific and industrial revolutions enabled our species to exhibit its full biological potential for geometric growth on a global scale (Figure 1).

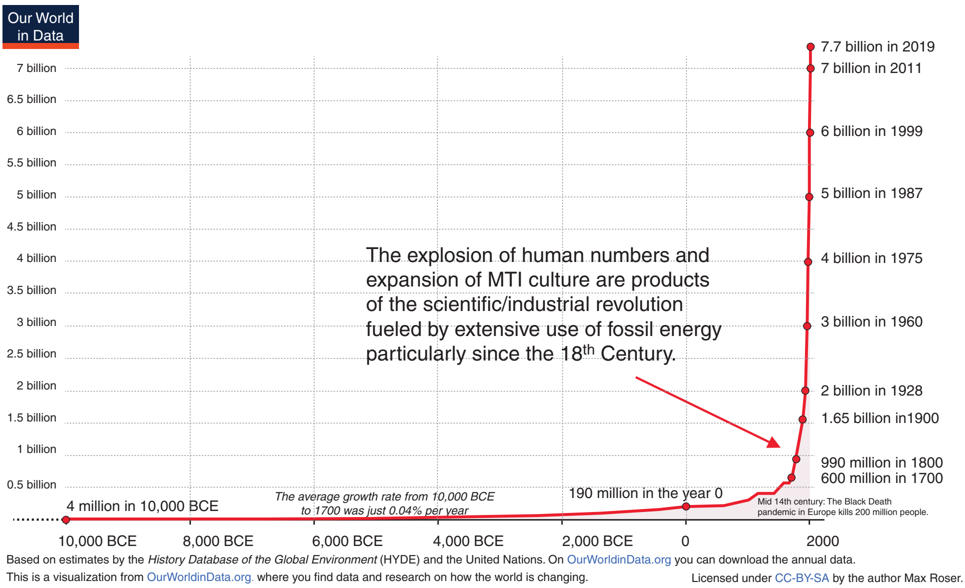
The 1300-fold increase in fossil energy use also drove economic growth. Between 1800 and 2016, Earth experienced a 100-fold increase in real global GDP; i.e., a 13-fold surge in average per capita incomes (25-fold in the richest countries) (Roser, 2019). Material consumption and pollution expanded accordingly. As William Catton wryly observed, the world was being asked to support not only more people, but ecologically larger people (Catton, 1982).

The explosion of the human enterprise is truly an unprecedented phenomenon. A mere glance at Figure 1 should be enough to convince anyone that only the most recent 10 generations of perhaps 10,000 generations of *H. sapiens* have witnessed sufficient global population and economic growth in their lifetimes to even notice such trends. Growth rates that modern techno-industrial society has come to accept as the norm actually define the single most *anomalous* period in human evolutionary history.

Unfortunately, Earth has not become any larger. Thus, the immediate consequence of unconstrained population and economic growth is that *H. sapiens* is well into a state of *ecological overshoot*. Overshoot means that the human enterprise is consuming even renewable resources faster than ecosystems can regenerate them, and is producing more waste than the ecosphere can assimilate. This is the very definition of biophysical unsustainability.

Overshoot is a meta-problem: climate change, ocean acidification, over-fishing, tropical deforestation, plunging biodiversity, soil/land degradation, falling human sperm counts, pollution of everything, etc., are co-symptoms of overshoot. *No major co-symptom can be fully addressed in isolation, but all can be solved by eliminating overshoot.* Mainstream efforts to slow climate change through the adoption of modern

Figure 1:
The growth of human numbers over the past 12,000 years



Source: Adapted from Roser et al. (2019) (CC BY-SA 4.0).

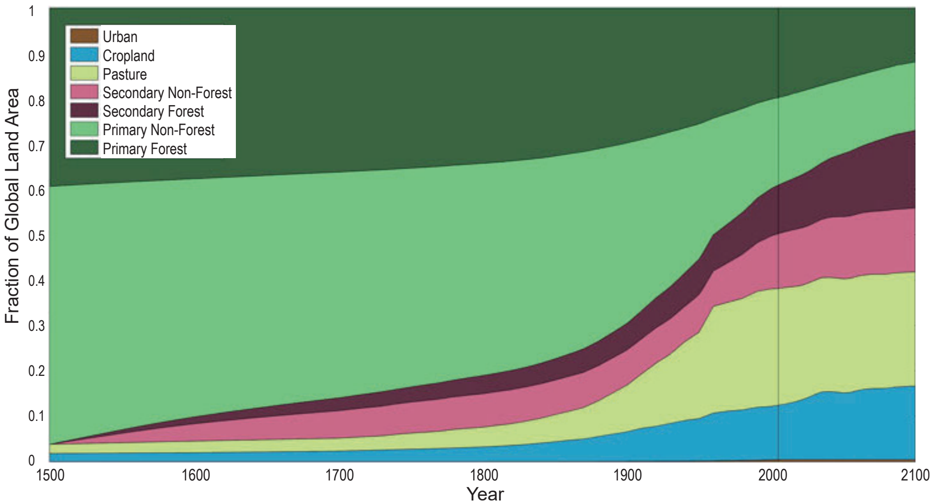
renewable energy technologies, for example, will not solve the climate problem, and can only exacerbate overshoot (Seibert and Rees, 2021).

The growing list of so-called ‘environmental problems’ is empirical evidence that we humans are literally depleting and contaminating the biophysical basis of our own existence. We are the problem. The destruction of essential natural capital erodes the functional integrity of the ecosphere and undermines life-support functions vital to human survival. The long-term costs are incalculable. Ecological economist Herman Daly has suggested that overshoot coincides with uneconomic growth; i.e., with growth that impoverishes rather than enriches (Daly, 2014). Overshoot is ultimately a terminal condition. The acceleration of climate change is merely the most popularised single symptom. (Humans tend to think in simplistic, reductionist terms.)

2 Humanity’s competitive displacement of nature

Beginning with the dawn of agriculture (perhaps the most ecologically damaging of human technologies) 10,000 years ago, humans have gradually become the major

Figure 2:
Changes in relative distribution of terrestrial ecosystems since 1500 (projection beyond 2000 assumes a low emissions scenario and global warming <2 C°) Note the rapid acceleration associated with the use of fossil fuels and increasing population in the 19th century



Source: Adapted from Hurtt et al. (2011) (CC BY-NC 2.0).

geological force changing the face of the Earth. Consider alone the human takeover of ecologically productive landscapes and the displacement (or extinction) of non-human vertebrates and other species from their habitats. In the past millennium, about 75% of Earth's land area has been affected by human activity, 50% in just the past 300 years (Figure 2). In the process, up to a third of the world's forests have been permanently converted, mostly to agriculture, which now appropriates about 30% of the land surface. Tens of millions of square kilometres of land have been lost to production or are recovering from degradation (Hurtt et al., 2006, 2011; Ritchie, 2021; Winkler et al., 2021).

The increase in human numbers *on a finite planet* necessarily 'competitively displaces' wild species. Habitats and food sources appropriated by humans are irreversibly unavailable to other life forms. Thus, the massive conversion of productive ecosystems from their natural state to serve ever more people has had a proportionate effect on the distribution of biomass among land-dwelling vertebrate species. *H. sapiens* accounts for only .01% of Earthly biomass, but the conversion of global ecosystems to support human expansion has eliminated 83% of wild animal and 50% of natural plant biomass. Scientists estimate that Palaeolithic humans represented less than 1.0% of mammalian biomass. However, with the agricultural and the more recent industrial revolutions, we now constitute 36%, and our domestic livestock another 60%, of the planet's (much expanded) mammalian biomass. All wild mammals combined now comprise only 4% of the mammalian total. Nor have birds been spared. Wild populations of many species are in freefall, and domestic poultry now represent 70% of Earth's remaining avian biomass (Bar-On et al., 2018; see also Smil, 2011; OP, 2022).

The story is being repeated at sea. Fossil-powered commercial fishing competes directly with marine birds and mammals for food-fish. Gremillet et al. (2018) report that seabirds suffered a 70% community-level population decline between 1950 and 2010 as their natural food sources were redirected to human consumption. In general, the World Wildlife Fund documents a 68% average decline of monitored birds, amphibians, mammals, fish and reptiles since 1970, which points to a dramatic loss of the health and resilience of ecosystems (WWF, 2020). There is little question that the inexorable increase in human numbers and related resource extraction are the cause. Fowler and Hobbs (2003) found that humanity's technology-aided material demands on exploited ecosystems often dwarf those of competing species by orders of magnitude—in 22 of 31 tests, human demands lie outside the 99% confidence limits of variation among those of dozens of other ecologically similar species, often at the expense of the latter. Bottom line: The growth of human populations and material consumption is driving the 'sixth extinction' (Kolbert, 2014; Shragg, 2022). Fowler and Hobbs (2003) even ask: *Is humanity sustainable*?

3 The population factor in overshoot

We can estimate the extent of overshoot using eco-footprint analysis (EFA). A population's ecological footprint (EF) is defined as: *the area of productive ecosystems required, on a continuous basis, to produce the renewable resources that the population consumes and to assimilate its carbon wastes* (Rees, 2013). In effect, a population EF is the product of average per capita consumption/carbon assimilation multiplied by total population, converted to a corresponding ecosystem area. EFA uniquely enables rough but informative comparisons of humanity's demand on the ecosphere (population EFs) with nature's supply (biocapacity).

We should note that for methodological reasons and due to data limitations, published EFA data generally *underestimate* human demand. For example, while EFA may compile a population's use of arable land, forest, carbon sinks and fishing-grounds, the method cannot reflect whether the appropriated ecosystems are being used sustainably (which they often are not). Nor does EFA account directly for the effects of most forms of pollution.

Even with these limitations, in 2017, the human EF (20.9 billion hectares) was *at least* 73% larger than available biocapacity (12.1 billion productive hectares) (GFN, 2022). The excess of demand over supply represents humanity's *ecological deficit* and provides a rough estimate of overshoot. Any eco-deficit underscores the fact that the maintenance and growth of the human enterprise is being 'financed' not only by the annual production by ecosystems, but also by the liquidation/pollution of the ecosphere. (Climate change is, in part, a pollution problem—carbon dioxide is the greatest single waste product by weight of industrial economies.)

The human EF nearly tripled from ~7.0 billion to 20.9 billion global average productive hectares (gha) between 1960 and 2017 (GFN, 2022). While both rising per capita incomes (consumption) and increasing populations contribute to material growth, we can use EFA to show that the ballooning human EF is caused primarily by swelling populations, particularly in middle-income countries (Figure 3).

We begin by considering high-income nations. Wealth-driven growth in material consumption has historically outstripped population growth in wealthy countries to produce per capita EFs averaging ~6.0 gha in 2016. This is 2.2 times the global average of ~2.7 gha in that year. On average, the wealthy demand almost four times their proportional share (1.6 gha/capita) of global biocapacity.

The total eco-footprint of high-income consumers increased by 3.2 billion gha (from 3.6 billion to 6.8 billion) between 1961 and 2016. The 2016 figure equates to 34% of the total human EF and a grossly inequitable 57% of global biocapacity. Because of their elevated consumption and outsized EFs, the addition of just 0.4 billion high-income people (5.4% of world population) added 2.4 billion gha (12%) to the 2016 total human EF. In short, the 54% increase in high-income population since 1961 accounts for ~75% of the 3.2 billion gha increase in high-income consumers' demand on nature (data from the upper-left quadrant of Figure 3)

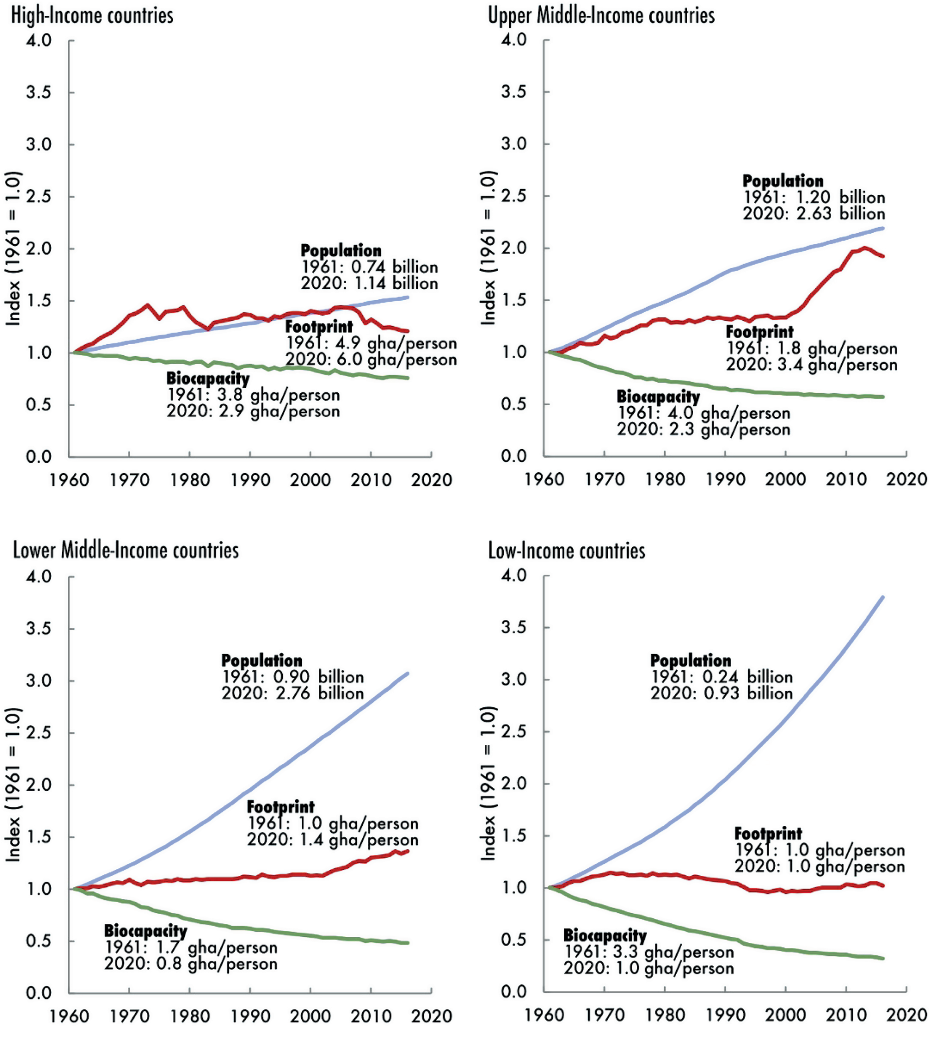
Turning to upper-middle-income countries, per capita EFs nearly doubled to 3.4 gha and the population more than doubled to 2.63 billion between 1961 and 2016, for a >four-fold increase in impact. The total EF of upper-middle-income consumers increased by 6.7 billion gha (from 2.2 to 8.9 billion). The additional 1.43 billion people accounted for 4.9 billion gha, ~73% of the increase and 55% of the upper-middle-income total. This increase alone contributed 24% to the total human EF (Figure 3, upper-right quadrant).

In the lower-middle-income countries, the average EF expanded by only 40% to 1.4 gha between 1961 and 2016, but population increased more than three-fold from 0.9 to 2.76 billion. Lower-middle-income demand on nature increased by 2.96 billion gha (from .90 to 3.86 billion gha), of which the 1.86 billion increase in population accounted for 2.6 billion (88%). This increase added 13% to the total 2016 human eco-footprint (Figure 3, lower-left quadrant).

Finally, low-income countries saw no increase in their average 1.0 gha footprints between 1961 and 2016, while their populations ballooned almost four-fold from 0.24 to 0.93 billion people. The population increase of 0.69 billion neutralised any benefits of GDP growth, but accounted for the entire ~0.69 billion gha increase in the total low-income EF to 0.93 billion gha (still only 4.6% of the global total) (Figure 3, lower-right quadrant).

Summing the above estimates shows that, between 1961 and 2016, the addition of ~4.4 billion human consumers contributed ~10.6 billion gha to the growing consumption-based human eco-footprint. The total EF in 1961 was about 7.0 billion

Figure 3:
Ecological footprint, biocapacity and population for high-income, upper middle-income, lower middle income and low income countries, 1961–2016



Source: Reproduced with permission from Wackernagel (2020).

gha, expanding to 20.2 billion gha in 2016, an increase of 13.2 billion gha (GFN, 2022). Thus, *population growth accounted for ~80% of the increase in the total human EF* above what would have accrued had populations remained constant while income/consumption and per capita EFs increased, as shown in Figure 3.

4 What it all means: Population and sustainability on a finite planet

We can draw several lessons from these data. Most important, while over-consumption and population growth have long been recognised as co-drivers of overshoot (Ehrlich and Ehrlich, 2014; Ehrlich and Holdren, 1971), population growth is currently the major contributor to total consumption growth and associated negative ecological impacts in all four income categories. Those who object to serious discussion of the relationship between population growth and the human eco-crisis must confront this reality. That said, it is crucial to recognise that EFs per capita differ greatly among income groups—increasing the population of an upper-income country by one average citizen imposes *at least* the same ecological load on Earth as a six-person increase in a typical low-income country (remember, EFs, particularly among high-end consumers are generally underestimates).

This fact serves, first, to underscore the egregious, inexcusable, yet still increasing material inequality between rich and poor people and nations in today's world. Globalisation and unfair terms of trade in world markets enable the citizens of wealthy countries to appropriate legally, by commercial means, several times their equitable share of Earth's biocapacity from other countries and the global commons. Many wealthy importing countries are running large eco-deficits. Figure 3 shows that available biocapacity per capita is declining in all income quadrants. However, remember that 1.14 billion rich consumers (15% of the human population) lay claim to 57% of global biocapacity, and that forms of eco-degradation not captured by EFA (e.g., soil depletion, overfishing, non-carbon pollution, ocean acidification, etc.) are everywhere disproportionately driven by consumers in the richest nations. Since the human enterprise is in overshoot and is rapidly eroding its own ecological foundations, *any effort to achieve sustainability within global carrying capacity must address the fundamental inequities generated by the present world economic order*.

Second, these data show that 'peak population' and subsequent population decline in high-income countries should be cause for celebration. Population growth in the richest nations generates almost an order of magnitude greater demand for biocapacity than an equivalent numerical gain in low-income countries. Even greater income disparities are revealed by studies of national 'material footprints'; i.e., the total quantity of raw materials extracted to meet a country's final consumption demands. The per capita 'material footprint' in high-income countries (26.3 tonnes/capita) is more than 13 times the 2.0 tonnes/capita generated by low-income countries (UN, 2019; Wiedmann et al., 2013). Again, it follows that the most *ecologically* significant macro-level gains from policies to reduce populations would come from accelerated population decline among high-income consumers.

But this does not mean we can ignore population growth in middle-income and poor countries. There are both socio-economic and ecological reasons for concerted non-coercive population reduction policies. First, despite the 3.9-fold increase in the total EF (consumption) in the most impoverished countries, the material well-being of the average person in these countries has remained unchanged. Ballooning populations have negated any gains from increased GDP among ordinary citizens. It follows that the most significant *social* benefits from stable populations would accrue at the micro level to the low-income families of poor countries who would enjoy larger slices of the economic pie. At the very least, a falling population would empower the poor by giving them more bargaining power in national labour markets.

Second, as was previously emphasised, humanity is already in overshoot and running a massive ecological deficit; the world community is financing aggregate population and economic growth by liquidating essential natural capital. Clearly, mere income/wealth redistribution would not correct this problem.

Nor can eco-deficit financing continue. Like a rocket, the human enterprise can accelerate only to the point that it runs out of fuel, and humanity's fuel gauge is already in the yellow zone of over-fishing, disappearing tropical forests, plunging biodiversity, receding glaciers, falling water tables, degraded soils/landscapes, incipient energy and resource shortages, etc. In particular, there are now fewer than .18 ha/capita of arable land on Earth (Ritchie and Roser, 2019; World Bank, 2022) (which compares poorly with .33 ha/capita on Tikopia, *a ratio that the island's stable population has maintained for centuries*). Population growth only further drains the global tank and shortens the time until the reckoning. Arable land/capita is declining globally, and the productivity of even our remaining .18 ha/capita is dependent on the continued use of dangerously polluting fossil fuel derivatives (pesticides and fertilisers), and on climate-wrecking fossil-powered irrigation, cultivating and harvesting equipment. What is our fall-back if we abandon FF?

In this context, consider the scale of the sustainability challenge. Let's first assume we could at least stabilise world population, Tikopia-like, in the vicinity of 2022's eight billion people. Eight billion is already ~73% too high at the global average eco-footprint of 2.75 gha (2017 data), and with rising incomes/consumption and the spread of consumer culture, everyone is striving to match the six gha ecological footprints of today's average high-income consumers. This is an impossible scenario that would fatally gut the ecosphere. Total demand would exceed 48 billion hectares on a planet with only ~12 billion productive hectares. In short, we would need the bio-capacity equivalent of three additional Earth-like planets to supply the demands of just the present population sustainably. As some wag once remarked, "good planets are hard to find". And, of course, there are no plans to hold the population constant—demographically at least, we're headed toward ~10 billion by 2050, and perhaps 11 billion by century's end.

Alternatively, the present world community might strive to live *within* global carrying capacity—to work toward achieving 'one-planet living'. This would require a reduction in the aggregate human eco-footprint of at least 42%. Assuming we would also choose to capture the benefits of greater equity (Wilkinson and Pickett, 2010), we might begin by redistributing the stock of global biocapacity equally among the human population. (For illustration's sake, we ignore the needs of non-human species.) Based on this criterion, each person alive today would be entitled to 1.5 global average hectares (12 billion ha/8 billion people)—that is, everyone would have to learn to live off the productive output and waste assimilation capacity of just 1.5 gha (~3.8 acres), and *this assumes no further population growth*.

Since the consumer lifestyles of residents in high-income countries demand, on average, the productivity of 6.0 gha/capita, the world's wealthy would have to reduce their eco-footprints by ~75%. While the lifestyle changes implied by this requirement seem impossibly extreme and would be strenuously resisted, this estimate is quite conservative for the methodological reasons previously noted. Indeed, as early as 1993, the Business Council for Sustainable Development reported that: "Industrialised world reductions in material throughput, energy use, and environmental degradation of over 90% will be required by 2040 to meet the needs of a growing world population fairly within the planet's ecological means" (BCSD, 1993, 10). Several recent estimates of necessary rich country reductions fall within the same ballpark (e.g., Bringezu, 2015; IGES, 2019). (These analyses typically fail to explore the need for population reductions.)

On the positive side, global sustainability with justice would mean that citizens of low-income countries would theoretically be able to *increase* their consumption by 50%. Their materially improved life-styles would increase their one gha EFs to the targeted 1.5 gha/capita.

This analysis makes clear that without the equity provision and significant population reductions, the world community could achieve sustainability *only* if its impoverished billions remain poor and the presently wealthy greatly reduce their material consumption.

5 The lesson of population ecology: What goes up will come down

In the real world, of course, the population is still growing and there is zero international interest in sizing the global economy to fit within carrying capacity or to share the world's bounty more equitably.

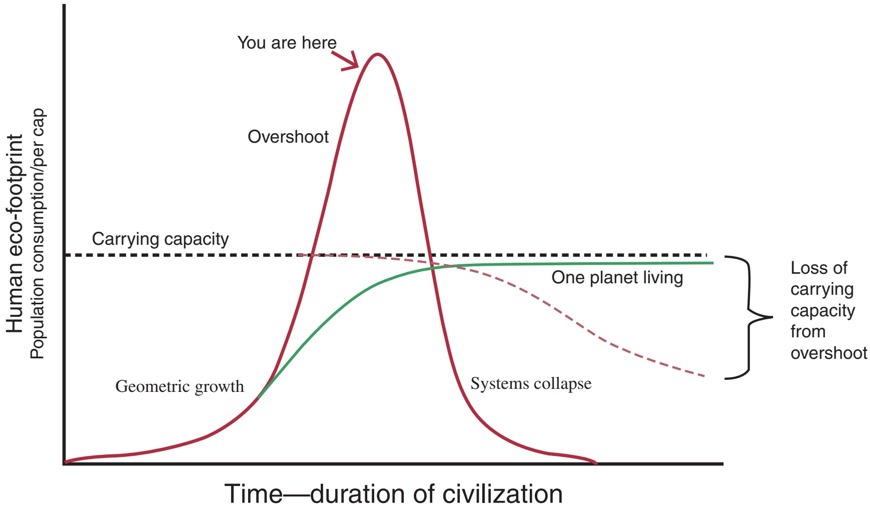
Perhaps this is to be expected. Despite our much-vaunted high intelligence, *H. sapiens* is not primarily a rational species. We tend to be foolishly short-sighted and are prone to selfishness (Pratarelli, 2008); emotions, instinct, cognitive dysfunction and acquired habits—often operating beneath consciousness—dominate personal and political behaviour (Damasio, 1994; Wexler, 2006). For example, humans share with all other organisms the inherent propensity to expand to fill all accessible habitats and to use up available resources, but with the major difference being that our technological prowess is constantly upgrading the resources that are 'accessible' and 'available'. (Even Tikopians eliminated much of their island's original fauna before being forced by their self-created circumstances to control their numbers). To complicate matters, MTI culture's natural propensity to expand (nature) is being reinforced by a neoliberal econo-cultural narrative (nurture) centred on continuous material growth propelled by technological innovation. The result is that, in many respects, humanity's expansion and depletion of Earth are analogous to a bacterium species' colonisation and depletion of nutrient broth in a Petri dish (Rees, 2020a, 2020b).

Human population dynamics are similar to those of non-human species in other ways. All living organisms, when exposed to a temporary abundance of some previously limiting resource, have the capacity to respond with a rapid population outbreak that leads to overshoot. In such cases, the inherent ability to reproduce exponentially (positive feedback) is released from the resource shortage that previously kept it in check (negative feedback). Some species in simple ecosystems exhibit regular cycles of outbreak followed by collapse, with the outbreak sometimes being called the 'plague phase' of the cycle. Whether cyclical or not, population outbreaks invariably end when resources run out or other forms of negative feedback (e.g., disease, predation) emerge and re-establish balance (Rees, 2020b).

There is no reason to think that *H. sapiens* is exempt from this phenomenon. Figure 1 shows the explosive expansion of the human population enabled by public health improvements, and particularly by the extraordinary resource abundance afforded by extensive use of fossil fuels. We are well into overshoot. As was previously emphasised, the sheer size of the human enterprise now threatens its own long-term survival as we deplete various essential biophysical resources and undermine vital life-support services (e.g., the Holocene climate). Meanwhile, poverty is again increasing; epidemic disease is becoming more common; climate change and food shortages portend famine and mass migrations; and political strife and violence, including competition for limited habitable land, is increasing. Indeed, the available evidence supports the hypothesis that modern humans may well be nearing the peak of an unprecedented and likely one-off plague-like global population outbreak affecting virtually the entire planet (Rees, 2020b). Such an outbreak invariably ends in contraction or collapse (Figure 4).

The pattern described above and in Figure 4 is consistent with the thesis of various authors that civilisations follow a common, inexorable developmental trajectory from youthful vibrancy and resilience to brittle maturity that is characterised by political corruption, material inequality, failing institutions, ecological decay and, finally, decline or collapse (e.g., Ophuls, 2012; Tainter, 1988). This thesis is also wholly compatible with the business-as-usual or 'standard run' scenario of the (in)famous *Limits to Growth* analysis (Meadows et al., 1972), in which population peaks around mid-century, then rapidly declines (see also Heinberg, 2022; Herrington, 2020; Turner, 2008). There seems to be something in human nature and patterns of socio-political organisation that drives societies toward self-destruction. As they grow and complexify, they eventually overshoot the competence of crumbling governance structures and social institutions to cope with cumulative socio-cultural disorder, resource shortages and ecological decay.

Figure 4:
The one-off human population outbreak



Source: Adapted with permission from Rees (2022).
Note: The human population, at present average levels of consumption, exceeds the carrying capacity of the ecosphere and is well into overshoot, as revealed by eco-footprint analysis and myriad other data (solid red line). However, consumption continues to grow, depleting resource stocks and undermining remaining biocapacity. A truly rational species would have maintained its population below carrying capacity (solid green line), consistent with one-planet living (as on Tikopia). This option is no longer available. As we near peak population, the global community must choose between cooperation to manage a controlled population contraction within the remaining regenerative capacity of the ecosphere (dashed red line) or enduring a violently chaotic systems collapse in which billions will suffer.

6 Conclusion: Can we break the cycle?

Knowing history, must we repeat it? Humanists and other optimists insist that *H. sapiens* has unique qualities that we have arguably yet to exercise fully in addressing overshoot, among them the capacities to reason logically from the evidence and the ability to plan ahead in ways that could dramatically alter future prospects. It helps that in times of stress we are capable of cooperation, compassion and sacrifice, and that we possess a unique appreciation of our own vulnerability and mortality. The scientific evidence tells us *that some form of contraction of the human enterprise is a biophysical necessity if we are to maintain the functional integrity of the ecosphere*. Context and history therefore present us with a choice: either we accept biophysical reality, rise to our full human potential and ‘engineer’ an orderly way down; or we challenge the evidence and do everything we can to maintain the status quo. The former option would require the world community to plan and execute a dramatic but controlled down-sizing of the human enterprise; the latter option would ultimately force nature to impose its own contraction; humanity would suffer the ugly consequences of a chaotic implosion condemning billions to suffering and death.

6.1 Where we stand

In 2022, the only 'plans' on the official table are two variations on the second option—maintaining the status quo:

> Variation 1: **Standard 'business-as-usual-as-usual'—This plan calls for the technologically-assisted maintenance of economically extractable supplies of fossil fuels (FF), supplemented by renewable energy, to enable maintenance of the economic status quo at least for several decades, based on the assumption that we can cope with any negative 'feedback' when it occurs.** This approach (*which seems to be the default position of governments*) would continue to grow the economy, exacerbate inequity, waste resources, precipitate runaway climate change, gut the ecosphere and undermine crucial life-support functions; i.e., it has a high probability of generating socio-geo-political chaos and the collapse of global civilisation.
>
> Variation 2: **'Business-as-usual-by-alternative-means'—With the ostensible goal of avoiding the worst effects of climate change (but still not acknowledging overshoot), this plan would implement an all-out renewable energy (RE) strategy quantitatively sufficient to maintain current levels of population and material growth, i.e., the status quo.** This option, the dream of RE and Green New Deal advocates (but arguably not technically feasible in a climate-friendly time frame) (Seibert and Rees, 2021), would not really halt climate change, and would otherwise generate the same negative social and ecological impacts as Scenario 1a; i.e., socio-geo-political chaos and the collapse of global society.

Both variations suggest that humanity's techno-hubris is exceeded only by collective denial and ignorance of systems behaviour.

The as-yet-unacceptable alternative—acknowledging overshoot and recognising that a major reduction of both population and economic throughput (consumption and pollution) is the only way to eliminate it—is barely beginning to take form. Victor (2019), for example, explores realistic possibilities of living without economic growth; and the degrowth movement contemplates simpler, localised lifestyles, much reduced production and consumption, and greater social equality—but not reduced populations (see R&D, 2022).

But full realisation of the controlled contraction option requires a deeper dive beginning with a personal and cultural—indeed, 'civilisational'—transformation of the fundamental values, beliefs, assumptions and attitudes that underpin neoliberal/capitalist industrial (MTI) society. Crucially, the new cultural narrative must acknowledge that the human enterprise is a fully dependent subsystem of the non-growing ecosphere that we ourselves are destroying. This, in turn, demands a shift from the prevailing obsession with material growth (quantitative increase) and technological efficiency towards true development (qualitative betterment, such as improvements in nature reserves, public facilities, health care, education, opportunities for personal development, etc.) and greater equity, but all on a much-reduced scale. The world must also formally acknowledge that (un)sustainability is a collective problem requiring collective solutions; the present individualistic competitive race to mutual destruction must give way to unprecedented international cooperation in developing an inclusive survival plan.

In short, the continuity of civilisation requires a cooperative, planned major contraction of both the material economy and human populations. The overall goal must be to establish and maintain the necessary conditions for a smaller human family (one to two billion people) to enjoy both economic and ecological security through 'one-planet living'. Rees (2020a) provides examples of policy directions consistent with this change of course. People will learn to thrive on less and live more justly in a 'steady-state' relationship with nature (see Daly, 1991), well within the remaining regenerative and assimilative capacities of the ecosphere (see Figure 4). Can there possibly be a more riveting intellectual and practical challenge?

Of course, not all problems are solvable at a global scale. To be brutally clear-eyed, the prospect that our increasingly fractious world community will happily collaborate to achieve the one-planet goal is hardly the brightest star in the constellation of possible human futures. Failure would indeed be tragic—if the world's nations cannot come together to fully engage their common fate, humanity proclaims itself to have no more practical intelligence or conscious moral agency when it comes to its own inclusive survival than does any other species in overshoot at the brink of collapse.

Thankfully there is always some good news—having long since learned 'the way', Tikopean society, at least, might well continue to thrive for another three millennia, regardless of what happens elsewhere.

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