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Session 1. Pathways of the health transition in a changing world

Global health trends: Evidence for and against sustainable progress

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Overview

The Earth Summit in Johannesburg has again highlighted the importance, potential and difficulties associated with attaining "sustainable development" (SD), in a process that involves national governments, international agencies, citizens groups and business. Inherent in SD, but sometimes overlooked, is that the "development" referred to concerns the improvement of living standards of the poor, especially in developing countries. A key indicator of progress for poor populations is their position along the spectrum of "health transition" (HT). While populations in many countries have moved from regimes of high to low mortality and fertility, progress has stalled, and even gone into reverse in a number of countries, mainly in sub-Saharan Africa, but also in North Korea and Russia. The optimism that once viewed progress towards the HT as almost unstoppable must be re-examined.

This paper attempts to assess the degree to which reversal of these recent setbacks might be threatened by a failure to significantly advance SD. As well, we ask to what extent, if any, might the HT be threatened for *other* populations, for whom health parameters are still advancing.

An awkward and widening gap exists between the priorities and prerequisites advocated by supporters of economic globalisation and the imperative to advance SD. Supporters of economic globalisation argue that it is the best – if not the only – means to generate the wealth needed to facilitate SD. We argue that this view warrants critical examination. A major flaw of this worldview is its assumption that the global "human carrying capacity" (HCC) – the human population supportable on the Earth – is, for practical purposes, sufficiently elastic, plastic to both technology and expanding wealth, to support the bigger, richer and healthier population that achievement of the global HT implies. We argue, to the contrary, that the processes of globalisation and conventional wealth creation are eroding these life-supports, incrementally risking the sustainability not only of future but even existing global health gains.

We propose that a useful way to think of HCC is as an interacting function of five forms of capital. Capital, once understood as only financial and built (i.e. the infrastructure created by humanity), is increasingly conceptualised as having human, social and natural[1] forms. Like financial capital, these

[1] Natural capital refers to environmental assets, both living and inert, including many ecosystem services, non-renewable goods such as fossil fuels, and global environmental systems that involve an interaction between living and non-living elements, including the climate system and the stratospheric ozone layer (Costanza et al, 1997; McMichael et al, in press). Natural capital, once entirely of a public good nature, have increasingly been privatized, as technology and human systems have developed. Examples of the latter include deep sea oil supplies, near-shore fish stocks, and, increasingly, forest ecosystems.

forms of capital accumulate slowly over time, and can be both added to and withdrawn from. And, like financial capital, social, human and natural capital can be destroyed, sometimes very quickly.[2]

Population size is intimately related to the "environmental withdrawal" made by humanity on stocks of natural capital, and also on the interactions between humans at local, regional and global scales. Co-operation and useful knowledge (social and human capital) increase carrying capacity, but conflict and mistakes reduce it. Moreover, conflict may have evolved as a means to try to preserve or enhance carrying capacity for competing sub-populations, triggered by the perception or reality of encroaching limits to local and regional carrying capacity.

All forms of capital change with time, and so too does HCC. HCC is not a figure "set" by destiny, but a dynamic property of these five forms of capital. Nor is HCC the maximum possible population theoretically attainable were all these stocks of capital at their peak. Instead, HCC is more likely to be a significant fraction of this maximum. This is because it is prudent – and indeed evolutionarily necessary – for populations to retain a degree of "reserve HCC" as insurance against temporary declines in one or more of the kinds of capital enumerated above.[3] As well, especially in high-income populations, large parts of HCC are used to generate valued surpluses such as affluence, good health, and military forces. Often, especially in developed countries, these surpluses are used to secure and to enhance the living standards of large numbers of people, rather than providing a subsistence living standard for as large a population as possible. A corollary of this is that the maximum population that the Earth can support is not a simple function of the world's theoretical capacity to produce food, fibre and other consumables, but is substantially lower.

We use several indicators to explore these issues. Average global life expectancy is a vital measure of global population health, and has continued to increase globally. From an anthropocentric position, total human population size is also a measure of human success. However, neither increase is a sensitive indicator of the *sustainability* of human wellbeing and health, though some commentators have tried to make this case by extrapolating the trend of the last few centuries (Simon, 1981). On the other hand, Dasgupta (2000) cautions that an assessment of economic progress over a much longer

[2] Like financial capital, the decline of these other forms of capital is often non-linear. For example, social harmony may gradually deteriorate before crossing a threshold into war. Human capital can also disappear quickly, as occurred in Cambodia during the Pol Pot era (Gollogly, 2002).

[3] At the very least, temporary declines in primary production are inevitable, due to fluctuations in climatic and other natural factors. Even though non-human species occasionally experience massive population fluctuations, there is evidence that at least some animal species have evolved ways to reduce resource exploitation beyond a threshold. For example, kangaroos are able to suspend foetal development in times of severe environmental stress. Ecological systems also contain feedback systems that check excessive environmental depletion by any one species (Sinclair, 1977), though these are vulnerable to disturbance, especially by loss of "keystone" species, especially of top predators (Terborgh et al., 2001).

period is more sobering, and warns against enthusiasm that the recent progress will inevitably continue.

We introduce a new measure, called global years of life expectancy (GYLE), and contrast this with an index global environmental change (IGEC). Data of sufficient quality are available for each measure (over the last 250 years) to highlight an obvious paradox – while GYLE has shown a dramatic increase, the IGEC has shown a steep fall. We suggest that the two trends are closely related and that the paradox is understandable upon examination.

Forecasting a reversal to human health because of environmental change requires an assessment of the maximum human tolerable impact upon the Earth's systems. This is, naturally, difficult and controversial, but is preferable to delaying until such time when there can be no doubt that a crisis has occurred. While acknowledging the difficulty of this task, we argue, enough *is* known make sensible recommendations.

There are many fundamental questions about how population health relates to SD. To what extent have recent gains in health and longevity depended on the depletion of natural capital? Might the lagged impacts of this process, in future, halt or reverse these health gains? Put starkly, there are three possible explanations for our current situation, which combines rising longevity with declines in environmental-ecological infrastructure:

1. Modern human societies, via technological, economic and political achievements, have attained near-immunity to adverse external environmental circumstances. At its most extreme, this can be called the "Cornucopian" position.
2. Adverse health effects *are* already occurring, but remain largely invisible, especially to affluent populations. (With no global population living in an unstressed environment, we do not know if the health gains would have been greater without environmental change.)3. A lag period exists between the decline in environmental conditions and the resultant health impacts. This lag reflects both complexity of process and the protective buffering afforded by human culture. This buffering is a function of wealth, in which the shocks of environmental degradation are substantially absorbed by populations with fewer means.
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The first explanation is not tenable, as a long-term proposition. The experience of many great societies and civilisations over the past 5-6 millennia shows their vulnerability to the loss of ecological supports (Tainter, 1998). A combination of the latter explanations therefore seems more plausible.

Meanwhile, we should also ask whether globalisation is harming or improving important elements of social and human capital. If, globally, social and human capital are falling, could this also impair or reverse health gains? The population health sciences have an important contribution to make to this epoch-defining discourse.

Introduction

Future levels of population health depend on the priorities, technologies and policy choices of global society. Predicting the future of such a complex system is extremely difficult. Despite some setbacks, the past two centuries have seen dramatic increases in average life expectancy (Riley, 2001), maximum life expectancy (Oeppen and Vaupel 2002) and human population size (see figure 1).

We propose a new indicator to combine the two, tentatively called "global years of human life expectancy"(population*average life expectancy at birth) (GYLE). The current magnitude of this indicator is therefore about 6.2*66 = 410 billion.[4] This combined measure provides more information than either component on its own.[5]

Figure 1 (GYLE) about here

Trends in life expectancy not only indicate future cross-sectional population size, but also both reflect and anticipate changes in average lifetime cumulative consumption, as well as risk-taking and other health-related behaviours (people with longer life expectancies have more to lose). Those with utilitarian, anthropocentric views may argue that a desirable target is one that maximises, at a sustainable level, both global average life expectancy and human population size – which, together, determine cumulative consumption and waste generation levels. The attainment of sustainability may therefore necessitate a trade-off between these two variables, limiting the expansion of both.

[4] GYLE is not the most accurate indicator of person years of LE. The current global average LE applies only for the youngest cohort of the population, and the LE of earlier cohorts is lower. A desirable refinement to GYLE would be to multiply life expectancy at birth by the estimated births in the same population, resulting in an incident life years measure. This would be slightly lower than GYLE at each year, but would follow a similar trend. Adjusting GYLE for disability is also desirable and would create a more sensitive measure.

[5] One can imagine Hobbesian worlds with larger populations but shorter life expectancies (say 10 billion * 35 years) or utopian worlds with smaller populations but higher life expectancies. The latter are not considered in this paper because such scenarios are inconceivable in this century without catastrophic (irruptive) population collapse.

The recent increase in GYLE (Figure 1) attests to human ingenuity and to past and current environmental abundance, but provides no evidence for or against sustainability. This is because it cannot be used to predict threshold events that may substantially alter the slope and even direction of trend. Optimists may point out that, at any time in history, pessimists have made this proposition. We argue, however, that compelling evidence exists to support a fresh examination of this question.

Optimists might be thought, perhaps unfairly, to be commentators who make linear extrapolations of the past to predict further progress. In contrast, there is a persuasive body of evidence and theory pointing to a non-trivial risk of a major correction to the upward path of human progress, unless major shifts occur in the operation of society. Because we think these shifts in behaviour, technology, social organisation and economic practice are possible, we regard ourselves as optimistic adaptationists.

The debate over sustainability can be traced for over two centuries, since Thomas Malthus reacted to the optimism of Godwin and Condorcet (1795) in his *Essay on the Principle of Population* (Malthus, 1798; Boserup, 1978). Today, some commentators consider the Malthusian debate so stale as to warrant only a footnote.[6] Though this topic may still seem quaint to some economists, and even to some workers in the population and health sciences,[7] the broad topic of global sustainability is fast becoming *the* central issue for the scientific community at large (McMichael, 2002a; Raven, 2002).

This sustainability debate may also be considered a variant of a wider economic and social debate (Rostow, 1998), between those who argue that progress, including of human wellbeing, democracy, and human rights, is an almost inevitable consequence of technological and economic development (Hartwell, 1961; Nardinelli, 1990) and those who point out the high price paid by some for this progress (Szreter, 1997; Mann, 2002). Similarly, Hirschman (1982) identifies an oscillating cycle of opinion between schools who argued that capitalism would "polish and soften … barbaric ways" and those who thought it would lead to social implosion.

Optimists argue that the long sweep of history has been more or less one of perpetual success for dominant populations, especially Europeans and their offshoots. People usually regarded by this school as pessimists (Ehrlich, 1968; Ehrlich and Holdren, 1988; Brown et al., 1999; Strong, 2000) ask not only if the progress is worth the human and ecological price, but question the possibility of its continuation unless there are radical shifts in global social and technological organisation (Raskin et

[6] Even in his own lifetime Malthus was bitterly attacked. Yet Malthusian theory was regarded by both Darwin and Wallace as of key importance in formulating the theory of evolution. Thus, some elements of Malthusian theory remain central to modern science (Desmond and Moore, 1991; Short, 1998).

[7] Kelley (2001, p 26) notes, perhaps wryly, that though many economists and demographers have in recent decades flirted with "revisionist" – anti-Malthusian – thinking about the risk of rapid population growth, such ideas barely gained a toehold among the biological and ecological community.

al., 2002). Those who advocate reform point out that humanity has changed course many times in the past and can do so again.

The paradox of improving health in a declining global environment

Over many centuries, the changing patterns of health, disease and survival within populations reflect the interplay of human biology with changes in culture and environmental conditions. Human history has been marked by several profound transitions in food production methods, social structures, urbanisation, reproductive behaviour, and demographic profile. These radical shifts in human ecology have caused commensurate shifts in prevailing diseases and in life expectancy.

Humans, in past millennia, have generally lived within the limits of Earth's carrying capacity. While this has been true in aggregate, regional excesses from time to time have been associated with the collapse of particular societies (McMichael, 2001). The recurring outline of the human story is this: (i) the environment sets limits on the size of the population that can be supported, given its demands and prevailing technologies, (ii) human societies find ways of extending that limit, (iii) sustainable societies then accept a tradeoff between population size and environmental impact.

Today, that story-line has acquired a global relevance, for three reasons. First, social and economic changes are increasing in speed and scale, as the processes of globalisation and urbanisation accelerate. Second, we have begun to induce unprecedently large-scale environmental changes, including to the world's atmosphere, climate, elemental cycles, various service-producing ecosystems, and stocks of biodiversity, freshwater, and food (Daily, 1997; Butler, 2000a, McMichael, 2002b; Soskolne and Broemling, 2002) (see figure 2).[8] Third, in response, the international discourse on "sustainable development" is gathering momentum. Importantly, this debate increasingly invokes the consequences for human health of unsustainable global change (McMichael, 2002b; McMichael and Kjellstrom, 2002).

Figure 2 (Index Global Environmental Change 1750-2000) about here

The three main, well-known, determinants of human impact on the environment are the size of the population, the level of material wealth and consumption, and the environmental sophistication of the technology (Ehrlich and Holdren, 1971). Wackernagel and Rees (1995) argue that, without radical,

[8] The World Wildlife Fund for Nature has published a detailed report describing the trends over the past three decades in indices of the state, or health, of major categories of ecological systems, including freshwater ecosystems, marine ecosystems and forest ecosystems (Loh, 2000). The overall global estimation was that the "Living Planet Index" has declined by about 30% since 1970. The report estimates that the aggregate consumption pressure of humankind is currently growing at around 5% per year. Since the current annual rate of world population growth is 1.4%, the other two-thirds of that estimated growth in consumption pressure is due to increasing per-person levels of consumption based on today's technologies.

currently implausible, reductions in the environmental impact of technology, at least three planet Earths would be required to provide the living standard of North Americans for today's global population of six billion. This implies that the projected increase in both population and living standards cannot long continue, or that there are major flaws in these researchers' arguments. Even the profound reductions in environmental impact foreseen by some techno-optimists (von Weizsäcker et al., 1997; Hawken et al., 1999) are unlikely to resolve this dilemma. It is more likely that the global population will pass a bottleneck, beyond which smaller numbers may make the attainment of high living standards for all more likely.

Like Ester Boserup (1981) we do not doubt that the environment's human carrying capacity for many regions can and has been increased, particularly by labour, knowledge and capital.[9] However, unlike some of Boserup's most enthusiastic interpreters (Simon, 1981), we perceive limits to this process. Such limits, for example, may underlie the recent downturn in the per capita grain harvest[10] (see figure 3).

Figure 3, about here (global grain harvest 1966-2002)

In order to elucidate these relationships, we need to explore several of the wider, ecological, dimensions of the relationship between human societies and their living environments.

Human carrying capacity and five kinds of capital

We propose a novel framework for considering the environment's human carrying capacity as an interaction between five different forms of capital: human, social, natural, built and financial. In turn, these forms of capital are partially interchangeable. For example, financial capital can be used to provide education, thus increasing human capital. Cycles of both positive and negative feedback may develop. An example of the former is that a well-educated population may attract more financial capital, in turn attracting other well-educated people.

Some forms of natural capital can be improved, repaired or substituted. Fertiliser can be applied to restore soil fertility and hills can be terraced to reduce erosion. Clean water can be piped to urban

[9] The transition from hunter-gathering to agricultural settlements greatly increased human carrying capacity, as did the harnessing of fossil fuel energy, the synthesis of nitrogen and the Green Revolution (Meyer, 1996; Trewavas, 2002).

[10] Ecological factors include declining soil fertility, heat stress from climate change, falling irrigation per capita, unseasonable floods and droughts, and a flatter part of the curve that describes yield increases, as theoretical limits approach.

areas, but other "ecosystem services" (Daily, 1997), such as pollination and the carbon sink[11] are, currently, too expensive to substitute.[12]

Social capital, or social cohesiveness (Putnam, 1995), is an important modifier of carrying capacity. Members of co-operative, organised societies can work on common projects to increase carrying capacity, such as the Grand Canal in China (Elvin, 1973) or the preservation of local common resources, such as fisheries, ponds and water sources (Dasgupta, 1996). Of course, no society is entirely egalitarian, fair, and democratic. Nevertheless, humans exist as members of groups, at different scales – and these groups are, more or less, cohesive, bound by customs and laws of mutual reciprocity, family and ethnic ties, a common language and common mediums of exchange (Nowak and Sigmund, 2000; Wedekind and Milinski, 2000; Grafen, 2002).

While degrees of conflict and discord exist between and within these groups, it is reasonable to conclude that their reproductive success reflects their cohesion, as well as access to resources (Dasgupta, 2000; Diamond, 2002). We do not suggest that the most cohesive groups are necessarily the most successful (indeed such groups may fail because they are too resistant to new ideas), but, certainly, groups marked by deep division and infighting are less likely to succeed.

In the 19th century, the appropriation of the remnants of the English commons and other changes increased overall carrying capacity.[13] These advances were also facilitated by the increased human and financial capital derived from previous productivity improvements (Buck, 1985). However, for some members of the population, especially peasants who lost access to the supplementary protein, crops and fuel once provided by the commons, living standards probably declined, increasing overall inequality, and reducing social cohesion. In turn, these hardships helped to drive urbanisation, as many rural workers turned to the factories, mills and slums to survive. Szreter (1997) argues that the life expectancy of these workers initially deteriorated, before recovering (in no small means because of the agitation of reformers). Science and technology played crucial roles in this transformation. However, ultimately, Britain also remained a great power because it did not allow its social capital to

[11] Most of the carbon released to the atmosphere by the burning of fossil fuels returns to the carbon sink in the land and oceans. Ecosystems are essential for this process.

[12] Recognising the greater economy of nature, the city of New York invested in preserving the Catskill Mountains ecosystem, to ensure an ongoing supply of clean water for the city. This has proven far cheaper than the alternative of building an artificial water purification system (Chichlinisky and Head, 1998; Daily and Ellison, 2002).

[13] Larger fields afforded economies of scale, such as horse-drawn rotary harvesters. Better fertilisers, especially guano, were imported from all over the world (Trewavas, 2002).

deteriorate to the point of civil war.[14] Gray (1999) argues that the experiment of unrestrained capitalism practised in early 19th century Britain was revised to maintain this cohesion.

The trajectory of human carrying capacity and progress has not been inevitably upwards. Human carrying capacity can, and at times has been reduced on substantial scales, at least temporarily. Causes include war, epidemics, loss of knowledge, and social disintegration or disorganisation. For example, the European Black Death of the 14th century led to massive population loss and, consequently, a far smaller total harvest.[15] The *total* European population supportable in 1380 was smaller than in 1320 because of the reduced farm labour supply. (However, the per capita harvest may have increased following the Black Death, because decreased population pressure allowed the retirement of less fertile tracts of land.) Van Bath (1963) and Ziegler (1982) argue that this traumatic event also prefigured the end of serfdom and higher real wages in Western Europe, because of the increased bargaining position of now-scarce farm workers. We suggest that the increased availability of per capita carrying capacity also assisted the ensuing increase in living standards.

Damage or loss of natural capital can also reduce carrying capacity. For example, Flannery (1994) describes the rapid extinction of the New Zealand moa, a large flightless bird that was a major food source for the first Maori settlers. Life appears to have become much harder for the Maori following the moa's extinction, with cannibalism apparently satisfying some of the demand for protein it previously supplied. Importantly, the Maori were not able to easily substitute this protein with other animal species.[16] The gradual collapse of the Mesopotamian civilisation is likely to have been contributed to by the progressive salination of its soil, which caused a shift from wheat to the more salt-tolerant barley. After a while, the barley yield also started to decline (Jacobsen and Adams, 1958).

<u>The case of Rwanda – reduced carrying capacity because of multiple per capita capital depreciation?</u>

The Rwandan genocide resulted in the rapid loss of over one tenth of its population. Clearly, causation was multi-factorial. However, three identifiable elements were: (i) the loss of financial capital secondary to the fall in the price of Rwanda's main export, coffee (Chossudovsky, 1997); (ii) the fall in social capital evidenced by the resurgence of frank inter-tribal hatred and murder, and (iii)

[14] The marked inequality of the early Industrial Revolution led to movements for social reform, such as the Chartists. Though the Chartists' demand for suffrage was rebuffed, other reforms, including the sanitary revolution, were subsequently introduced (Szreter, 1997).

[15] The carrying capacity of large parts of the New World was substantially reduced following European contact. Only recently have scholars discovered that the Amazon basin once supported much larger populations. The Amazonian carrying capacity was reduced not only because the diseases that almost eliminated its human population reduced its labour force, but also, presumably, much of the knowledge that was formerly commonplace was lost (Mann, 2002).

[16] It is curious that pigs were apparently not used for this purpose (Tony: I am exploring this question).

the per capita fall in natural capital, as the supply of unutilised farming land was exhausted in the face of continuing population growth (Bonneux, 1994; King and Elliot, 1996; Butler, 2000b).

As well, the low average level of education in Rwanda contributed to a comparatively low human capital. This, combined with a paucity of financial investment,[17] limited the capacity for Rwandan society to successfully develop strategies to compensate for its poverty[18] and its simmering ethnic tension.

While it is fruitless to search for a single root cause, it is plausible that the decline in per capita natural capital was an important contributor to the decline in Rwandan social capital. Many conflicts are triggered by the desire of more powerful populations to retain sufficient access to resources to at least maintain their position. Where resources are abundant, conflict is less likely. Brittain (2001) reviewing a recent book about the Rwandan genocide (Mamdami, 2001*) points out that its author believes that those Hutu who wielded the machetes saw themselves as victims who feared losing out in the struggle for power, and that Hutu leaders therefore encouraged a victim mentality by painting the Tutsis as settlers who would take Hutu rights and property.

The substantial decline in the Rwandan population that occurred because of the genocide resulted in a large increase in the per capita availability of natural capital. The Rwandan carrying capacity has also since increased because of a greater flow of foreign aid, further development of its gorilla-viewing ecotourism industry (Bohannon, 2002), and, possibly, the material spoils brought back to Rwanda by its soldiers active in the Congo. As well, most of the recovery in the Rwandan population still constitutes very young people – who in future will demand land and/or jobs. Rwanda, which has a history of repeated repression and mass population movements (Schwab, 2001: 80) is likely to have to endure further tragedy.[19]

Changes in human ecology as determinants of survival and disease patterns

Many theories have been developed to explain the changes in health profiles of populations. Our preferred model is based on human ecology, defined as a society's culture, habitat and relationship with the wider environment (McMichael, 2001). A central example, throughout the past 10,000 years since human societies first began farming, has been the nutritional impact of staple-based, often

[17] In turn inhibited by fear of instability and the low human capital.
[18] Such as export industries and tourism.
[19] We are not arguing that there are no external factors that have impacted upon Rwandan carrying capacity, including decades of colonial exploitation and international trade policies that discriminate against Third World countries (Watkins, 2001). Nor are we trying to use Malthusian theory as a way to justify the Rwandan genocide, as was done during the Irish famine of the 1840s (#). We simply argue that, given Rwanda's history

monotonous, agrarian diets. Prior to the "second agricultural revolution" in Europe in the nineteenth century, most agrarian societies experienced widespread malnutrition and recurring famines (Rotberg and Rabb, 1985). After some respite, many rural populations, especially in the Third World, continued to experience periodic food shortages as their populations increased, until another increase in food supply was facilitated, this time by the "Green Revolution" starting in the 1960s.

The geographic spread of humans to areas that, because of being either sparsely populated or totally uninhabited, beckoned as potentially rich additional sources of carrying capacity (Flannery 1994), has often compounded this nutritional deficiency problem.[20] For example, the extension of agrarian societies into highlands and arid regions has exposed many populations to micronutrient deficiency, such as various iodine deficiency disorders (Hetzel, 1989). Because of the overall increase in environmental carrying capacity conferred by increased land utilisation, improved agricultural yields and trade, farming populations – notwithstanding their nutritional deficits and occasional die-offs – have generally outnumbered and in many cases displaced smaller hunter-gatherer populations. Even if the average life expectancy for most historical agrarian populations was lower than for contemporary hunter-gatherers, this was more than compensated, including in strategic terms, by the larger total of person years supported at any given time by an area used for agricultural and farming.

Cultural and technical advances over the past two centuries have markedly reduced mortality and increased life expectancy in populations dependent on agriculture. Meanwhile, the quality and duration of life for many hunter-gatherers deteriorated as they came into increasing contact with the larger, more powerful and – often – disease-adapted and disease-carrying peoples who frequently displaced them from their most fertile territories (McNeill, 1976, Sahlins, 1972, Mann, 2002). These recent improvements applied particularly in early life, as humans learned to survive many of the infectious, crowding diseases, which themselves had developed partly as a result of the higher population densities, of both humans and animals, made possible by agriculture and domestication. In turn, increased life expectancy was typically followed by a reduction in birth rates. This composite process, the demographic and health transition, continues to transform life expectancies and patterns of disease in developing countries.

The world has undergone great political, ideological and technological shifts over the past several decades. The process of global interconnection, that started several centuries ago, has accelerated. This process has reduced many forms of diversity – including biological, cultural, linguistic and ideological. It is also a world in which the scale of commerce, trade and environmental intervention is

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and the current global political realities, carrying capacity has to be considered as a contributory causal factor for the genocide.

expanding. In accordance with the ascendancy of neo-liberalism and the free market ethos, it is a world in which - at least for the moment -corporate values appear to be prevailing over community values and in which short-term profitability takes precedence over long-term sustainability. This has far-reaching consequences for population health (McMichael and Beaglehole, 2000). Nevertheless, there is a widespread belief that the energy, creativity and efficiency of free and open markets can generate sufficient new wealth to alleviate poverty and solve social problems on a global scale, no matter what obstacles lie ahead.

This foregoing discussion has sought to make clear that human population health is a manifestation of the prevailing lifeway of a society and the compatibility of that with the environment's human carrying capacity. The remainder of this article will examine how these increasingly large-scale changes in global economic structures and processes, and the oft-related global environmental changes, have begun to affect patterns of health and disease. This bears directly on the sustainability of our ways of living, as indexed by long-term maintenance of good health and survival in successive future generations.

Human-induced environmental change and health

Human communities have, for long, depleted natural resources and degraded local ecosystems. Today, this process is beginning to be played out on a much larger scale – and some of the longer-term consequences for the health of human populations could be commensurately more serious. Today's unprecedentedly large human impact on the environment reflects the great, ongoing, increases in population size and in energy-intensive, high-throughput consumerism. Human-induced changes are becoming evident in the composition of the lower and middle atmospheres, in the world-wide depletion of other natural systems (e.g., soil fertility, aquifers, ocean fisheries, and biodiversity in general), and in the disturbances to great natural cycles (especially carbon, water, nitrogen and sulphur) (Vitousek et al., 1997). These large-scale physical, biological and ecological systems are the source of 'life-support' upon which the sustained health of populations – human and other – depends (Daily, 1997).

The risks to health posed by these global environmental changes are, in many ways, different from the better-known, locally acting, environmental hazards from direct-acting toxic pollutants (McMichael, 1993). Global change processes are, for example, likely to alter the geography of infectious diseases (especially vector-borne diseases such as malaria and dengue fever, sensitive to changes in climatic conditions and land-use patterns), the productivity of food-producing systems on land and at sea, the availability of freshwater, and, through biodiversity loss, to destabilise and weaken the ecosystems

[20] The initial movement into previously uninhabited areas is likely to have been driven by the hope, and often

that underpin these and other life-support processes. The depletion of stratospheric ozone poses several direct health risks, including increases in skin cancer incidence and the occurrence of eye disorders, and it may also depress immune function (de Gruijl, 2000). Climate change-related changes in weather extremes, natural disasters and sea-level rise are also likely to have many direct and indirect health consequences, especially affecting poor populations. The recently-identified global dissemination of various "persistent organic pollutants" (POPs) (Simonich and Hites, 1995) poses another set of environmental health problems, which may contribute to biodiversity losses in general and to changes in human biological functioning (fertility, reproduction, and immune function).

The spectrum and extent of health impacts from global environmental change will vary with geography and social circumstances. Poor and isolated populations will, usually, be the most vulnerable. Environmental changes and stresses may often coincide, compounding the impact on local human populations. For example, the combined impacts of climate change, freshwater shortages, and land degradation may have its greatest adverse impact on agricultural productivity in subtropical and semi-arid regions where food insecurity is already prevalent (Fischer et al., 2001).

The scientific assessment of actual or potential health impacts faces some unusual difficulties in this complex topic area. There are various types and levels of uncertainties. Many of the systems under study, both ecological and social, are complex, non-linear and dynamic (Lewin, 1994). An interdisciplinary research effort is needed to accommodate an unusual mix of complexity, uncertainty and predictive modelling.

Crucial to discussion of this topic is that these global-change processes have major implications for the long-term sustainability of human population health by weakening, perhaps irreversibly, the natural life-supporting infrastructure. The widespread, dramatic, gains in health and longevity over the past century have been closely related to the processes of urbanisation, social modernisation, industrialisation and increasing material wealth, as well as to technological advances in preventive medicine, medical care, sanitation and hygiene. Those gains have therefore been associated, to some (uncertain) extent, with the depletion and degradation of our external environment, including, most recently, larger-scale environmental changes. However, theory, personal experience, and an increasing body of empirical data (Scheffer et al., 2001, Rauch, 2002; Soskolne and Broemling, 2002), suggest the existence of critical thresholds beyond which lie great danger to society and population health.

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the reality, that living standards would be better than in the vacated area.

A presage of this may be when further use of environmental resources leads to no further improvement in health, as is broadly evident from the plateauing of national average life expectancy in relation to per capita GNP at higher income levels. The particular question arises: given, now, the advent of global environmental change, can we maintain parallel increasing trends in consumption, environmental damage and life expectancy?

Indicators of population health and sustainability

An increasingly large proportion of the global population are concerned about sustainability; many such persons are scientifically well-informed (Union of Concerned Scientists 1997). Optimists (as conventionally defined in our opening statement) should ask: is it rational to ignore the concerns of so many people, especially those expressed by so many of the global scientific elite?

A decline in global life expectancy may reflect unsustainability, but is unlikely to have any practical value as an indicator because it will not provide any advance notice. Using global life expectancy is problematic in all cases as an indicator of anthropocentric success or sustainability because if a population crash occurs it is conceivable – though unlikely – that the survivors could have a high average life expectancy. For example, a global nuclear war could leave an affluent population of 0.5 billion with an average life expectancy of 70 years. In fact, in hypothetical cases where people who are poor and who have short life expectancies die in disproportionate numbers, average global life expectancy *of the survivors* may increase after the dieoff effect passes. In the example above, GYLE falls to only 35 billion, far less than its current value.

A declining *rate* of increase in average global life expectancy may be a very valuable indicator of approaching unsustainability, but this measure has two problems. These are: (i) potential confounding by the difficulty in gaining extra years of life beyond a threshold, as biological limits approach (Horiuchi, 2000), and (ii) excessive uncertainty in the data, making any deceleration indistinguishable from background noise. The first problem may be overstated, at least for the near future, since recent examinations of maximum life expectancy have found no evidence for such a deceleration (Tuljapurkar et al., 2000; Oeppen and Vaupel, 2002).

We can also be confident that, the *rate* of increase of global life expectancy has recently decreased because of the scale of regional decline in life expectancy, especially in sub-Saharan Africa (SSA), Eastern Europe and North Korea.

Sceptics may argue that these regional declines in life expectancy are temporary phenomena, unlikely to be of sustained significance for either the average global life expectancy, nor to be related in any way to carrying capacity limits in that region. As discussed, above regional average life expectancy

has declined many times previously – such as during the Chinese famine of 1959-1962 (Smil, 1999). While the *proximal* causes of such declines were pathogens such as Yersinia pestis, the smallpox virus and frank starvation, it is impossible to disentangle carrying capacity elements from their deeper causation. For example, plague was spread by invading Mongol populations, seeking to improve their own living standards through conquest and plunder. The smallpox and other epidemics that depopulated large parts of the Americas also arose from contact with disease-bearing invaders, seeking, primarily, new resources. The high mortality of the Black Death may also have had nutritional and environmental causes. The cause of the recent Chinese famine lay largely in human error. The result of this error was, however, indisputably, a regional reduction in human carrying capacity, even if temporary.

A declining rate of increase in GYLE may signify: (i) a slowing rate of population growth, and/or (ii) a slowing rate of increase in average life expectancy. The first explanation is certainly true, since the rate of global population increase peaked in the early 1960s. More contentious is the suggestion that a reason for the global fertility transition has been a growing appreciation that global human carrying capacity limits are approaching. We think this is plausible for several reasons. Easterlin (1971; 1975; 1976) argues that there are powerful economic reasons that interact with human fertility choices. Abernethy (1979) reviews evidence among tribal people in New Guinea and the Arctic, as well as Europeans, to support the argument that many cultural and religious practices (such as marriage age and customs regarding widows) serve to adjust human fertility in response to carrying capacity.

For the most part, humans want their offspring to have at least similar opportunities to themselves. Causes for the demographic transition are usually attributed to factors such as reduced infant mortality, education, greater female status and increased wealth. Further, greater aspirations, including for lifestyles that are observed only third hand, such as through the media, may play a role (Martine, 1996). None of these specific factors contradict an economic motivation.

More directly, a substantial factor in the decline of the global human population growth rate is the state-sponsored family-planning campaigns practised especially in China and, to a lesser extent, in India. While a detailed discussion of the theory called the “low-level equilibrium trap” (Butler, submitted) is beyond the scope of this paper, the view that excessively rapid population growth was likely to slow economic development was clearly, though not immediately, accepted in these countries, especially China (Borrie, 1974).

An alternative explanation for the decline in the rate of global population growth is that humans have succumbed to excessively successful propaganda spread by neo-Malthusianists. This is implausible. We argue instead that the declining rate of population growth is a rational human response to

approaching limits of regional and global carrying capacity. Counter examples, such as high population growth rates in certain oil-rich states support this argument, because these states have high per capita human carrying capacity, at least for the present. Population growth rates in the US also remain comparatively high (Jencks, 2001) again, in part, because of the confidence that comes both from current access to a high per capita human carrying capacity and from the belief that this will continue – which, given US military superpower status – appears plausible and rational.

Economic factors for a declining rate of population growth cannot be separated from factors related to human carrying capacity. Though conventional economic measures make little explicit attempt to measure environmental goods and bads, nevertheless a rough correlation exists between key economic measures (such as per capita gross national product) and carrying capacity. Thus, in general, wealthy countries have access - including via advantageous trading conditions - to comparatively higher carrying capacity than do poor countries.

The next several sections examine how different aspects of human culture modify the environment's human carrying capacity.

Trade and human carrying capacity

As globalisation proceeds, it is increasingly appropriate to consider *global* human carrying capacity, that is the human carrying capacity of the world as a single unit.[21] Effectively, almost every individual in the world population can be thought of as utilising a share of global human carrying capacity. Much of this share is still produced locally, but, as globalisation has proceeded, an increasing proportion of the elements that constitute human carrying capacity are traded, exchanged or otherwise transferred (e.g., by conquest or appropriation) between different populations.

We use Sen's concept to argue that the flow of human carrying capacity is largely a function of a population's *entitlement* (Sen, 1981). Entitlement provides a means to project *effective* demand. Most commonly, the currency of entitlement is an agreed means of exchange, such as a currency, but entitlement is also conferred through reciprocal obligations and treaties, and by direct appropriation, such as war, intimidation and the threat of force or other sanctions. Thus, powerful populations have greater entitlement, usually reflecting their many forms of access.

There are myriad examples of transferred human carrying capacity elements. These include traded and otherwise transferred goods, such as oil and coal, building and clothing materials and foods such as deep-sea fish, grain, coffee and fruit. Human services are also an important component of human

carrying capacity. These may be veiled from the consumer, such as the unseen, often foreign labour forces who sew shirts and assemble computers, but they may also be visible, such as "guest workers" who perform low-paid domestic, construction and factory work. Skilled workers, such as economists, teachers, surgeons and politicians also contribute to human carrying capacity, as do entrepreneurs, entertainers, artists and other service-providers, who enhance living standards.

Migration and human carrying capacity

These flows of goods and services are largely determined by factors of supply, demand and regulation. For example, the temporary or permanent migration of lowly-paid guest workers is influenced by the existence and enforcement of laws that govern minimum wages. Where minimum wages are comparatively high (on a global scale) barriers to permanent and temporary immigration are also likely to be high. If minimum wages and other conditions are comparatively low, *but still higher than in supplier populations*, then the barriers to migration are more likely to be porous. Such cheap labour primarily increases the material living standards of the employer populations.

Importantly, the motivation of many guest workers is not just to increase their own opportunity or living standard. Many also remit a proportion of their wages to the families that they have left behind. This money (financial capital) increases the entitlement, and hence the total human carrying capacity of the population to which it flows.[22]

The flow of human capital between differently entitled populations is not confined to low-skilled workers. Many professionals, often trained in comparatively poor countries, migrate to comparatively wealthy countries (Pang et al., 2002). Strong "pull" and "push" factors operate. Host countries generally welcome skilled migrants, especially as, in most cases, their population growth trajectories are now so flat. At the same time, many professionals have strong incentives to leave, not only because they can earn more money (especially in terms of foreign exchange rather than purchasing power parity adjusted income) (Butler et al., 2001), but for reasons to do with educational and intellectual stimulation – and, often, to seek greater political freedom.

The relocation of skilled populations changes the distribution of human capital. In most cases, poor populations appear to be disadvantaged by these transfers – the human capital paid for by investment in the poor country is transferred to the wealthier country, who benefit without having to pay for the education and infrastructure needed to produce the skilled individual. As mentioned above, some individuals contribute to a two-way flow of human and financial capital. In some cases, such as India,

[21] The number of hunter-gatherers who still live entirely separate economic lives is now very small. As well, the resources used by such populations remain vulnerable to larger, more powerful groups.

this flow may be substantial in each direction. However, for other populations, the effect to date remains strongly negative. In these cases, while the benefits of the brain drain to the individual and even to his or her family in the original country may be substantial, the overall human capital of the poor country is likely to have been reduced.

For example, Hassan (2001) argues that in the late 1960s and early 1970s the science departments in many African universities were among the finest in the developing world. He estimates that 30,000 Ph.D. holders of African descent, many with science degrees, live and work outside their home countries, and that this figure far exceeds the total number of African-born scientists with PhDs working in Africa. Conway and Sechler (2000) also link the luring of African scientists to wealthier countries with that continent's perennial food scarcity. A collaboration of over thirty leading conservation scientists (Pimm et al, 2001) agreed unanimously that an important element in the struggle to protect natural capital in developing countries is the establishment of a cohort of conservation professionals in each biodiversity-rich country. This will not only improve the human capital in such countries, but help to protect the ecosystem services, including eco-tourist and income-attracting national parks, of increasing importance in countries such as Costa Rica (Chichlinisky and Head, 1998) and even Rwanda. Thus, human and natural capital can positively interact to preserve and even increase carrying capacity.

Natural capital and human carrying capacity

Natural capital can be divided into renewable (many natural and ecosystem services, eg wind, climate and flood control by forests; fish nurseries in mangrove forests and coral reefs) and non-renewable forms (oil, mineral deposits, guano). As well, a broad definition of natural capital includes the stratospheric ozone layer and more subtly, the Earth's buffer systems, especially to preserve global homeostasis, including a comparatively stable global climate system. These include the global "carbon sink" which comprises the capacity of the ocean, atmosphere and ecosystems to absorb the additional amounts of carbon dioxide and other greenhouse gases which humans have released, in increasing quantities, in recent centuries.

Slowly and belatedly, humans are beginning to understand that a fraction of global HCC depends on the resilience of the natural systems that underpin the measured economy. Constanza et al (1997) have estimated that the value of these services, normally uncosted, approximates that which is measured. Of course, humans have always produced wastes, be it flakes of stone tools, shards of pottery, or discarded bones. Until recently, the problem was trivial, because the human environmental footprint

[22] Whether it increases the per capita HCC of such populations will be discussed in detail later. Put simply, this depends on whether the factors of HCC for that population are increasing at a higher rate than the population.

was so small. In the last millennium this problem has become increasingly evident, particularly as populations have experienced thresholds of crisis and local or regional awareness. Examples include of both water and air pollution, such as during the 1952 London smog.[23] In these localised cases, it was clear to the affected populations that health and wellbeing were being damaged, and led to legislative attempts to improve the local environment.

It is increasingly clear that the scale of human waste is now global, and that this may have profound effects on many systems which underpin human wellbeing, and human carrying capacity. The best-known examples are of emissions of carbon dioxide and other greenhouse gases which contribute to global warming. These are released, disproportionately, by high-income populations, but are then distributed globally, including to the atmosphere, the oceans and the biosphere. There is increasing consensus that these emissions will cause climatic change, and that the harmful effects of this are likely to exceed the benefits. The harmful effects will disproportionately affect poorer populations, particularly via their increased vulnerability to extreme weather events, sea level change, and altered distribution of agricultural productivity.

Other examples of damaged and depleted global resources include the depletion of easily recoverable stocks of non-renewable "fossil" fuels, the partial loss of the stratospheric ozone layer (Slaper et al., 1996), and the destruction of large tracts of tropical forests, especially in South East Asia (Jepson et al., 2001). Many other ecosystems are changing, such as coral reefs, soil systems, and the heterogeneity of global food crops.

Population, consumption levels, and technology choices: relative impacts

The ongoing climate change debate illustrates well the relativities between the environmental impacts of increases in population and in consumption levels. There is a strong positive correlation between GDP/capita and national carbon dioxide emissions up to a GDP of US$10,000, above which the correlation becomes progressively less strong (Dietz and Rosa, 1997). Historically, during the 20th century, as population increased by just under four-fold the annual fossil fuel emissions of CO_2 increased twelve-fold. (Holdren, 1991, Carbon Dioxide Information Analysis Centre, 1997). In 1995, the 20% of world population living in high-emission countries accounted for 63% of CO_2 emissions, while the lowest-emitting 20% of world population contributed just 2% (Engleman, 1998). Bongaarts (1992) has calculated that projected world population growth between 1985-2100 would contribute around 35% of growth in CO_2 emissions, whereas economic growth would account for the remaining 65%.

[23] And the lesser known Meuse Valley fog, in Belgium in 1932 (Nemery et al., 2001).

Overall, then, the larger potential threat is not from the increase in human numbers *per se* but from moderately environmentally disruptive humans becoming highly disruptive - in other words, from a "development" process that would generalise the patterns of production and consumption typical of today's rich countries (Butler, 1997). Current practices in rich countries are clearly *not* generalisable to a human population likely to exceed 10 billion and demanding a higher average standard of living. It has been estimated that citizens of high-income countries today each require approximately 4-9 hectares of Earth's surface to provide the materials for their lifestyle and to absorb their wastes - while India's population gets by on one hectare per person (Willey, 2000). There is not enough Earth to allow more than one hectare of "ecological footprint" per average-person when the world population reaches around 9 billion during the coming century - and yet that future world population will presumably wish to live more like Californians than Calcuttans.

Serious investment in the development and deployment of less disruptive technologies, and a hugely greater commitment to international equity, will be required if a smooth and timely transition to an ecologically sustainable world is to be achieved. Rich countries remain the main source of new knowledge and new technologies; hence, the responsibility for finding paths to sustainability rests mainly with them. Minimising the probabilities of long-term harm to health will be a major consideration. Indeed, this is now becoming the most important health-related aspect of the "population debate".

Much recent research indicates that health depends less on the consumption opportunities provided by income than on personal and social capacities to protect and enhance health. These capacities reflect, at the individual level, determinants such as schooling and, at the social level, determinants such as food cultures (whence the protection against vascular mortality in Mediterranean populations), drinking cultures (whence the catastrophic mortality that has befallen Russia during its economic and political transition (Leon et al., 1997; McMichael et al submitted) and elements of the built environment such as sewers, water supplies, transport systems and safe roads. Given that life expectancy differences between today's high-income countries are only very weakly related to income, it makes little sense to see increasing national income as an important path to sustainable improvements in health.

Inequality and global social capital

Increasingly, the human population is supported by a single interlinked fabric of natural, social and ecosystem services. Depletion of a form of capital in any local or regional can, at least theoretically, be compensated for by transfer from other regions replete in that form of capital. In practice, this ideal is not realised, leading instead to increasing inequality of many forms, including international entitlement, opportunity, and the density of knowledge and opportunity (see Figure 4). It makes

increasing sense to theorise that a form of social capital is developing on a global scale, in a world that increasingly shares similar aspirations, media images and a sense of connection or exclusion. This theory makes plausible the suggestion, made by many commentators, that the terrible events of September 11, 2001 may be a consequence of global inequality (Lash, 2001; Butler, 2001).

Figure 4 (global income distribution) about here

More generally, this may imply that the inequality that has increased the living standards for a minority of the global population at a far faster rate then the majority may harbour the cause for a future reduction in carrying capacity. The possible possession of nuclear and other weapons of mass destruction by populations who consider themselves excluded from the mainstream of progress means that sustainable social progress is not yet secure. As the population continues to increase, in a world system which remains closed, it is probable that per capita carrying capacity will continue to diminish, and that critical environmental buffers will continue to erode. Reduction of global inequality appears a prudent and important step to reduce the risk of increasingly severe conflict. Yet, at the same time, it is probable that any such reduction in inequality will be accompanied by a surge in global consumption, putting more stress on the global ecosystems and other natural services.

This reduction in global material and political inequality will need to be complemented by a building of stronger, more cohesive, societies, enriched by social and human capital. Society arises from the interaction of its constituent influences, including human capital, culture, religion, shared beliefs, history, education, governance, and the distribution of wealth, income and opportunity. It is impossible to measure social capital simply by summing or otherwise mathematically manipulating its identified constituents.

Not only are emergent phenomena “greater than the sum of their parts”, but they are also, often, very hard, if not impossible to describe or predict from first principles. We argue, however, that social systems have identifiable levels of resilience. Societies characterised by high resilience are better able to tolerate disruption than societies with little resilience. High social capital is a desirable quality in that it facilitates high and improving life expectancy, through mechanisms such as good governance and social organisation, including the effective delivery of public health services. Societies with high social capital are also likely to have comparatively low inequality, and comparatively low rates of crime, conflict and mental ill health.

The sustained achievement of a high rate of social capital may well appear to be artificial and utopian, because even idyllic societies have borders, beyond which other populations exist, many with reduced resources and environmental human carrying capacities that are already under substantial pressure, or in frank decline. Indeed, the causation of much conflict can be analysed in terms of human carrying

capacity. As was mentioned in the case of Rwanda, wars aim to either increase, or at least to preserve human carrying capacity or to increase consumption levels for the victors. Often they aim to do both.[24]

Declines in regional life expectancy in Sub-Saharan Africa support the case that that region's human carrying capacity is under considerable strain. The causes are multifactorial, by no means as simple as a failure to (say) grow enough food.[25] Contributing causes are poor social organisation, poor governance, and a paucity of highly skilled persons, because of factors including low education levels, HIV/AIDS affecting many with secondary education (Piot, 2000) and the brain drain. This leads to low levels of social and human capital. As well, there is a scarcity of financial capital, because of under-investment, capital flight because of corruption, trade subsidies that discriminate against agricultural exports and an over-supply of tropical cash crops on the world market (such as coffee).

Natural capital has also been in short supply on a per capita basis in much of Sub Saharan Africa, evidenced especially by the Sahelian drought and the periodic – possibly intensifying - cycle of floods and droughts in much of southern Africa. The death toll in the Congo war in the last few years is though to exceed 3 million, i.e. more than Rwanda and more than any other recent global conflict (UNICEF and WHO, 2001).

The fall in life expectancy in the former Soviet Union appears to reflect a loss of social capital, as people, especially men, lost both hope and access to strategies that previously curtailed overt alcoholism. Violence also increased (Leon et al., 1997). Demine (2000) argues that the decline appears to have preceded the collapse of the Soviet Union in rural regions as resources were increasingly diverted to military purposes at the expense of social capital. A decline in public health measures – itself a manifestation of organisation, government and social capital (eg diptheria vaccinations) probably also contributed at the margin. Overall governance possibly deteriorated, as did income and wealth distribution. This is best analysed as a fall in social capital.

As well, the population in parts of the former Soviet Union has also fallen, probably reflecting a decline in confidence, a relative unattractiveness to migrants, and a reduction, at least temporarily, in regional human carrying capacity. Despite widespread ecological damage[26] it is likely that the natural

[24] Of course, other factors also play a role, such as national pride, resentment, religious zeal and so on. But these causes, such as the Crusades, can usually be analysed as also having economic causes, such as bounty and plunder. Some of WWII's roots clearly lie in HCC factors, including the German desire for "lebensraum" and the tenacity with which the Germans fought for the oil resources of the Caucasus at Stalingrad. Similarly, the Pacific War was in part caused by Japanese desire to secure oil and other resources in South East Asia.
[25] Whether or not the causes of the drought are primarily human-caused.
[26] Ecosystem services of the Aral and Caspian Seas deteriorated while that of the Black Sea has recently recovered (Kideys, 2002), radioactive contamination around Chernobyl and alleged widespread but patchy nuclear and other toxic waste contamination.

capital of the former Soviet Union could support a far larger population, and an even larger regional years of life expectancy (RYLE). Human, social and probably financial capital need boosting in this region if this downward trend in RYLE is to be reversed.

Could the case of Sub-Saharan Africa, herald a wider pattern? The regional life expectancy of Sub-Saharan Africa has fallen far more than total population. The region is almost certainly compromised by the combination of under- and mal-nutrition, especially of micronutrients (iron and iodine) and also of energy malnutrition (Grantham-McGregor, 2002). Impoverished populations, thus physiologically impaired, also suffer many structural disadvantages that combine to impede learning, such as poor infrastructure and breakdown in social cohesion. Negative feedback loops can develop, spiralling into chaos, including civil and regional war. Many countries in SSA are affected to some degree, including the Congo, Rwanda, Sudan, Burundi, Malawi, South Africa, Nigeria, Ghana, Angola and Zimbabwe.

Sceptics will point to alternative explanations for regional falls in LE, such as infectious disease, poor governance, ethnic conflict, poor harvests, extreme weather events, poverty and, in the former Soviet Union, alcoholism. However, these proximate causes may well reflect an underlying deficit of natural, social, financial and human capital available to the population.

Optimists will point out that all previous HCC limits – at least for European populations - have been overcome, particularly by substitution and expansion. There are numerous examples, such as coal for wood, oil for whale oil, petroleum for horses and migration to the New World for lack of fertile land. We argue that a new transition is approaching, where again, considerable substitution is needed, such as alternative progress measures for the Gross Domestic Product (Cobb et al, 1995) such as decarbonisation for power and such as better organisation for transport. This "technological transition" is well underway, but needs rapid acceleration if we are to further increase GYLE and average living standards (Raskin et al, 2002).

Many of the previous substitution strategies are now exhausted. For example, because most of Earth is now colonised, populations with limited free human carrying capacity cannot migrate to under-populated territory (Flannery, 1994). Dreams of increasing total human carrying capacity by colonising outer space may one day come to fruition, but remain unrealistic on a significant scale for the next century. Furthermore, most increase in global population is occurring in poor countries, which, unlike their largely European predecessors,[27] lack the resources to successfully invade lands

[27] Europeans do not have any monopoly on successful dissemination, invasion or colonisation. The great European expansion found a world that was almost totally peopled. The Aryan people invaded and colonised India and other parts of Asia long ago. Melanesians settled islands in both the Pacific and Indian Oceans.

held by wealthy populations. Meantime, globalisation and neoliberalism are facilitating further increases in the living standards and consumption levels of many of the first and second clastes[28] (Butler, 2000a) – largely but not entirely of Old World origin. As with previous major increases in living standard for a minority of the global population, this is facilitated by comparatively cheap labour. Though the existence of slavery is rarely acknowledged and almost universally illegal, Bales (1999) estimates conservatively that at least 30 million people still live in slavery. His cases studies, including of water bearers in arid Mauritania, hereditary indentured labourers in India, and entrapped charcoal workers in Brazil all demonstrate how living standards are still being improved for populations that benefit from the cheap labour that slavery provides. Indeed, in part, the high human and social capital of the First World is contributed to by low-paid, comparatively disadvantaged, populations. Defenders may argue that inequality is irrelevant, because absolute living standards (including LE) are improving for the poor. The recent deterioration in life expectancy and RYLE in Sub-Saharan Africa calls this into question – and points to the following larger issue.

The world is now one in which roughly one billion live a comparatively segregated life from the other five billion. Interactions within the one billion are increasing, but so too are interactions within the five billion. The rising tide theory is unlikely, itself, be sufficient to lift all of the five (soon to be six or even seven) billion from poverty, without unprecedented global transformation, because of an insufficient supply of global capital, of many kinds. Furthermore, without more technological breakthroughs, progress for such populations will be slowed by their inability to find a ready source of cheap labour. If we cannot find ways to achieve, globally, such transformation and much greater equity, it is possible to imagine the living standards for part of this population slowly increasing, while another part remains extremely poor. Recent trends indicate that this may in fact be happening.

Conclusion

Recent mortality trends, globally and regionally, cannot, of themselves, tell us whether our socio-economic development trajectories are "sustainable". The problems of cause-effect lag-times, coexistent influences on population health, and uncertainties about the present and future determinants of environmental human carrying capacity, cloud the picture.

Several leading demographers have recently expressed concern that global population health may be at risk from the tensions, inequalities and environmental stresses in today's globalising world. For example, Horiuchi (2000) writes:

Possibly several waves of migrants came to Australia. In turn, Homo sapiens appears to have invaded a Europe already occupied by Neanderthal humans, possibly contributing to their extinction (Mellars, 1998).

[28] Clastes are populations occupying similar socio-economic, occupational and politically influential niches at global, rather than national scales. The poorest clastes have virtually no influence on global policy, except through intermediaries.

> "This prospect (of sustaining mortality decline) is not unconditional. New threats to health and survival are arising, including the emergence and re-emergence of infectious diseases, increasing pollution, and the proliferation of nuclear, biological and chemical weapons. If we fail to control these hazards, some of the large gain in the life expectancy of the past 150 years may well be lost."

Bongaarts et al (2002) recently warned:

> "Considerable uncertainty in projections stems from unexpected events. Wars, natural disasters, economic crises, and similar events can generate streams of migrants, suppress fertility temporarily, and produce many premature deaths. On the positive side, unexpected biomedical breakthroughs may lead to large increases in life expectancy or provide new fertility options. Environmental crises that may loom in the future are an additional concern. Events of such types are not within the competence of demographers to predict. Their involvement in interdisciplinary work is essential to obtain a better appreciation of the likelihood and demographic implications of such events."

We are, clearly, at one of history's great junctures. The conditions and events of today's world underscore the centrality of population wellbeing and health as both a development objective and, therefore, as a criterion of sustainable development.

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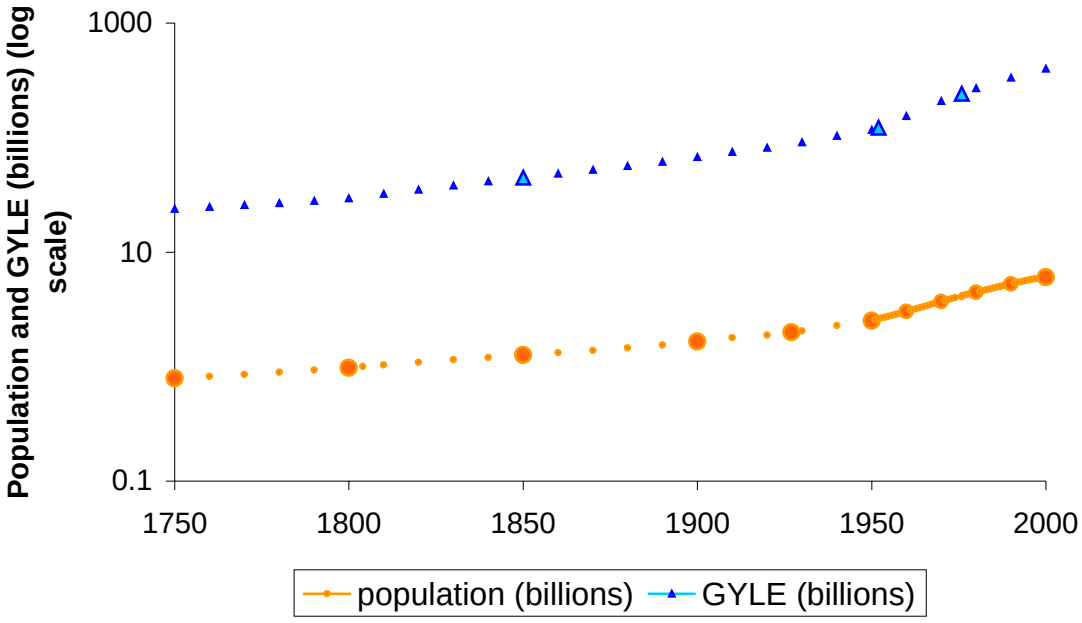

Figure 1. Global population and global years of life expectancy (GYLE) 1750-2000

Though data are incomplete (large dots are from the literature, other decadal points are estimates), (Riley, 2001) this figure (note log scale) shows the substantial increase in global population and the even greater increase in GYLE over the last 250 years.

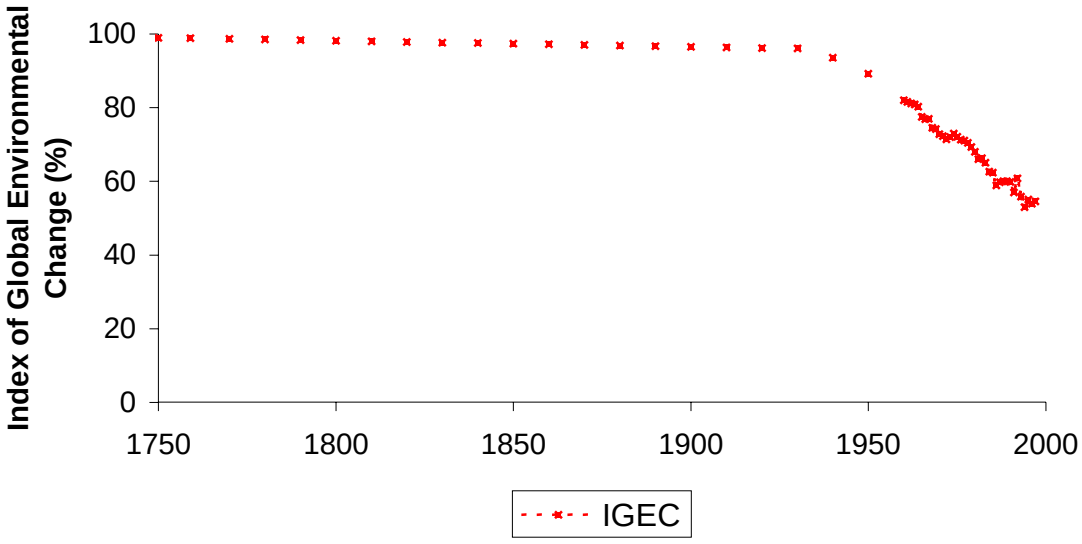

Figure 2. Index of global environmental change 1750-2000

Over a longer scale, the decline in the IGEC appears precipitous. Underlying processes have caused both the increase in GYLE and the decrease in the IGEC. Even if GYLE starts to plateau, the IGEC will continue to fall until major social and technological advances are made, so that long and healthy lives have a lighter environmental "footprint". Indefinite decline in the IGEC is unsustainable and at some point likely to be associated with a substantial decline in the global human carrying capacity, making maintenance of population health gains extremely problematic. Though science cannot predict this point with confidence, there is enough evidence for substantial concern that it is proximate. Lag effects, both environmental and social, will hinder reversal of the direction of trend of the IGEC. Uncertainty means also that other key "life support systems" could be eroding, not captured by the seven main indicators that compose the IGEC.

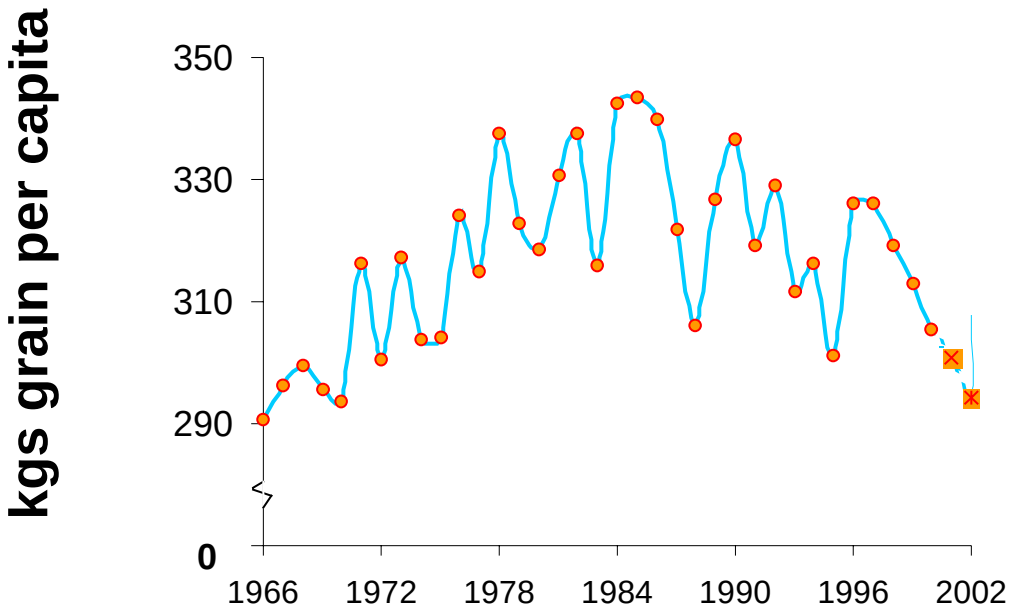

Figure 3. Global per capita grain production 1966-2002

In recent years, the global production of grain has not increased as fast as population growth. Several explanations are possible, but a decline in the rate of expansion of global carrying capacity, in part because of approaching biological and environmental limits cannot be excluded. These limits include to the efficiency of photosynthesis, the availability of high quality fertile soil, and the capacity of social systems to provide the fertilizers, knowledge and other infrastructure needed to generate consistently increasing yields. As well, heat and other weather stresses as a consequence of climate change may also be slowing yield increases. Further decline in per capita grain production does not necessarily threaten global food security, but it does underline the importance of regional cooperation and the distribution of food entitlement, so as to avoid regional famines and other possible other adverse effects. (Raw data FAO, UN Population Division and US Department of Agriculture reported in Brown (2001, 2002).

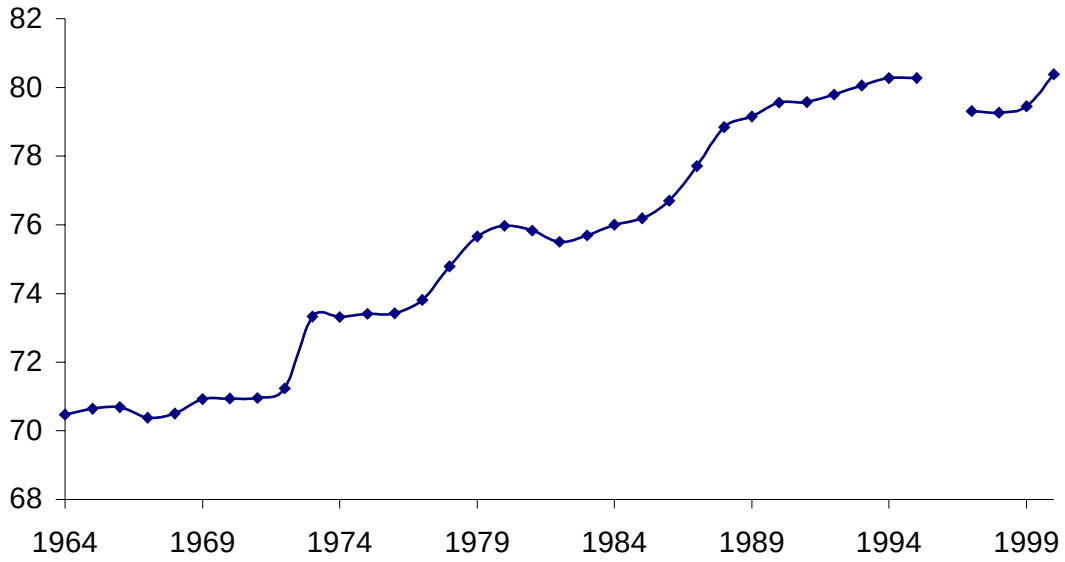

Figure 4. Global income distribution (US$) 1964-2000(Raw data World Bank)

The globalisation of trade, ideas, information and technology make the conceptualization of "global social capital" increasingly sensible. The distribution of resources, influence, wealth and opportunity are important elements of social capital. It is of concern, therefore, that global income inequality (in $US, which we argue is a better indicator of international influence than income adjusted for purchasing power) has increased so dramatically in recent decades, from its already high level in the 1960s (by comparison, most Western countries have Gini coefficients between 25% and 40%). Many influential leaders of government and business have linked the increase in global terrorism to global inequality. Self-destructive effects arising from exclusion, resentment and the use of increasingly powerful weapons may reduce global carrying capacity. These trends may intensify, particularly as per capita stocks of natural capital continue to decline. Reducing global inequality is likely to increase global social capital, improve health for disadvantaged populations and buffer the stresses of reducing natural capital. However, it is also likely to increase the average global consumption levels, thus increasing the total environmental footprint. This may be the major dilemma for our time, but is still only dimly appreciated.