Footprints to the Future

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Summary:
A brief history of the impact of humans on the earth’s biosphere and a description of the more serious of these lead into a description of a method of quantifying the overall contemporary impact. The world’s available biological resources - assessed by global footprinting data published by the global Footprinting Network in October 2008 - are compared with the demand for more and more energy by the high, medium and low income group countries. The inescapable conclusion is that, without fossil fuels, the planet cannot support the current population of 6.8 billion, except at significantly lower average levels of consumption. As the population is projected to grow to 9.4 billion by 2050, by which time available energy and earth’s biocapacity will have diminished due to the adverse effects of global warming, there is an urgent case for encouraging people to limit family sizes to two or fewer children to avoid the worst effects of the intrinsic resource-consumption mismatch. Examples of countries which have already recognised the problem nationally are described to show that such actions are not only possible and successful, but are becoming increasingly necessary.

Keywords: Population, environmental impact, sustainability, biocapacity, ecological footprint, ecological overshoot, global warming, hyperbola, total fertility rate, renewable energy, Keeling curve, Brundtland report

Introduction

Human populations have been of concern to societies throughout history. In 470 BCE, Plato (Laws, V) wrote: “A suitable total for the number of citizens cannot be fixed without considering the land...” Even then – 2500 years ago - people felt pressure from populations which were much lower than now. In the 20th century, human population became a variable issue. Some countries (Italy, Germany, Russia for example), became concerned that their falling populations threaten future pensions and care of the elderly and are encouraging higher birth rates; others, such as Thailand and Iran, realising that their overpopulation threatened increased poverty and starvation, have promoted free birth control. China, faced with a high fertility rate, implemented a controversial ‘one-child’ policy. In 1972, Meadows et al.1 published ‘The Limits to Growth’ which was an extensive analysis of the consumption of resources and the consequences of not mitigating demands of overpopulation. In 1987, the Brundtland2 Report drew attention to the growing poverty in the third World calling for ‘a new era of economic growth – growth that is forceful and at the same time socially and environmentally sustainable.’

At the 1994 Cairo conference, the UN set a 20-year deadline to curb population growth3. Now, 14 years on, population is still rising as fast as ever. As a world, it appears that we cannot reach a consensus as to whether there are too many or too few of us on this finite planet. Up to the 1970s in the UK, population was discussed openly, expressing the need for a lower birth rate, only for it to become a taboo subject in the 1980s. Any talk of restraining family size smacked of China and India’s one-child policies - which demonstrated side-effects in relation to excess mortality amongst female children. In a liberal thinking political environment, coupled with increasing immigration from the 1980s, such moves were seen by many as a restriction of human freedom and an abuse of human rights. For those and other reasons, up until a few years ago talk
of limiting population was decidedly ‘off-limits’ by all but a few UK politicians: and solutions to the population-resources dilemma focussed on economic growth, recycling and technological progress.

Against this background, minority groups as well as many scientists have become increasingly uneasy with the extant situation. Statistics emerged, from which it became clear that the world population was growing unsustainably. It had taken a million years for the human population to reach 3 billion (1960), but only a further 39 years to produce the next three billion. From the 1970s, lobbying organizations started to emerge and express concern that we were not paying sufficient attention to the extra mouths to be fed and were placing too much trust in technology to solve the problem. But is there really a problem? Can the human population continue to grow at around 80,000,000 people per year, that is what this paper sets out to review – appropriately so, since in this journal which embraces the issues of conflict and survival.

To put future population sizes in perspective, it helps to look at the history of human populations and their impact on living space, other species and the current knowledge about the planet’s carrying capacity and the arrows of environmental and technological development.

**Impact of Human Development – An Historical Perspective**

Figure 1, (E.S. Deevey\(^4\), 1960 with embellishments in colour) illustrates how the human population has grown over the last million years. By using logarithmic axes, the data reveal three major phases of human population development:

**Pre-Neolithic Hunter-Gatherer Period**

Between one million BC to 8,000BC, human populations\(^5\) are estimated to have grown from 100,000 to seven million. Although these data, interpolated from archaeological findings, can not be precise, they do demonstrate the order of magnitude of Mesolithic populations.

Hunter-gatherers needed large tracts of land to supply their needs of fuel, food and clothing. They were constrained by the availability of edible vegetation and wildlife in a given area, as well as by their limited technology to exploit such resources. Hassan\(^6\) had calculated that 100 km\(^2\) of grassland, producing four tonnes/km\(^2\) of biomass, supported 17 people and subtropical savannah at 10 tonnes of biomass could support 43 people.

Because all their food, fuel and building resources were renewable, their extremely low population densities made little permanent impact on the environment or other species. The estimates suggest that the prehistoric human population grew at an average of seven people per
year during that period. This estimate masks the vast fluctuations that must have occurred as early man struggled to survive ice ages, floods, droughts and other natural disasters. Nevertheless, it suggests how close, and perhaps how frequently, hunter-gatherers may have come to extinction. Had the average annual number of early humans who died before reaching sexual maturity been eight more than it actually was, the human race would have died out long before it reached the Neolithic Revolution when it learnt to grow crops.

**Neolithic Revolution**

The Neolithic Revolution began around 10,000 years ago. Ponting summarises its impact, being that:

‘... in the space of a few thousand years a radically different way of life emerged based on a major alteration to natural ecosystems in order to produce crops and provide pastures for animals. ... Because it was capable of providing much greater quantities of food it made possible the evolution of settled, complex, hierarchical societies and a much faster growth in human population’

Over a period of several thousand years, European and Middle Eastern peoples slowly domesticated animals, developed agriculture, irrigation, building, transport, and other early technologies of civilisation. The perception by these early civilisations of the carrying capacity of their land would have been restricted to the area they knew. They could not have had any concept of the size of the earth beyond their immediate ‘world’ of perhaps up to about a thousand square kilometres. Throughout history, fear of starvation has driven humans to develop better ways of finding, growing and producing food and little thought, if any, was given to their environment. The transition to settled agriculture increased human impact since the need for building material and firewood as well as space for settlements and cropland led to increased deforestation. Over-irrigation caused salinisation and overuse of soil led to erosion desertification of large areas. Because these were essentially local events extending over at most a few thousands of square kilometres, they had relatively little effect on the planetary ecosystem as a whole. World population, constrained by nature to grow slowly, had only local terrestrial impact and none on the seas and atmosphere: life at that time was relative eco-friendly and as a consequence CO₂ emissions remained comparatively stable since the last ice age 10,000 years ago.

By the first century AD, Europe, the Middle East and Asia had been extensively settled. World population had grown to around 300 million, constrained mainly by pestilence, plagues, droughts and wars. By around 1600, it reached 500 million - a growth rate of over 7000 times faster than in the prehistoric period. Then, concurrent with the opening of overland trade routes between Europe and Asia as well as the development of better ships, came the growing realisation of the massive extent of the world. Columbus and others discovered and explored lands hitherto unknown to Europeans and lands already populated were exploited for their resources with little or no regard for the welfare of native populations.

**The Industrial Revolution**

The third phase, which Deevey called ‘Scientific Method’, emerged from around 1400 and, after
Columbus, the colonisation of new lands provided more food, wealth and land to settle for Europeans - creating the Third World in the process. The combined result of growing knowledge and access to increased resources incubated the industrial revolution by around 1750. Plotting the population growth on linear scales (Figure 2) shows the magnitude of the population change as the rate of exponential growth, as well as its environmental impact, increased.

The industrial revolution led to development of coal-fired engines, factories, more efficient agriculture and food production, as well as faster transportation between and across continents. The consequent increase in the food supply, coupled with emigration to new world countries, resulted in more and larger families.

In the 19th and 20th centuries, the industrialised world saw the rapid increase in inventions powered by the exponential exploitation of coal, gas and oil. These caused a positive feedback on the food supply by enabling, among many other technical innovations, the production of pesticides, fertilisers and automated farming to flourish. The parallel developments in medical science and public health measures reduced infant mortality and increased longevity. Inevitably, the control of death without a corresponding control of the birth rate, led to an 11-fold explosion in population to 6.8 billion between 1750 and 2008. Between 1600 (a rough estimate of the start of the scientific age shown in Fig.1) and 2000, this computes to an average growth rate of 15 million cap/year, roughly two million times higher than the prehistoric phase and some 2000 times faster than the rate of the Neolithic phase. Not surprisingly, the impact of the rapid population growth since 1750 has taken a severe and increasingly noticeable toll on the environment.

Human Impact on the Environment

Today, rarely a day passes without news of extinctions, droughts, floods, famines, health scares and conflicts over resources. There is nothing new about these events; the Old Testament describes many local instances of them. What is new is, not only the increased extent, frequency and severity, but also their global impact, of which global warming is perhaps the best example.

In 1896, Svante Arrhenius proposed that rising carbon dioxide emissions from the burning of fossil fuels would cause global temperatures to rise by trapping excess heat in the earth’s atmosphere. Then, in 1958, Charles David Keeling started collecting data on the rising level of atmospheric carbon dioxide at the Mauna Loa Observatory in Hawaii. Forty years later, the Keeling curve (Figure 3) shows clearly that, between 1958 and 2006, the CO₂ level is rising and that the rate of increase has almost
doubled over that time. It has also become clear from Antarctic ice core measurements that carbon dioxide levels and mean global temperatures have varied in step throughout the ages. During the last 420,000 years, atmospheric CO\textsubscript{2} concentrations in interglacial periods have remained within the range a 250\textsuperscript{13} to 290 ppm as ice ages came and went, driven by the Milankovic effect. The scientific data thus gathered show that during the last 120 years the CO\textsubscript{2} level has broken out of its traditional range and risen to 390 ppm (2007). Concurrently, mean global temperatures have risen by 0.7 deg. C.\textsuperscript{14}

Population and Global Warming

There is now a growing mountain of evidence to show that climate change is being driven by global warming which in turn is a direct result of human activity. That link has consequences which we will come to later.

FIGURE 4
CORRELATION BETWEEN MEAN GLOBAL TEMPERATURE (MGT), CARBON DIOXIDE AND POPULATION OVER THE LAST MILLENIUM

There is a causal dependency of mean global temperatures on CO\textsubscript{2} levels and in turn on population levels. Their relative changes since the year 1000 are summarised in figure 4. The upper line shows world population and is scaled by a factor of ten billion to range up to 6 billion by 2000. The middle line shows the change in atmospheric CO\textsubscript{2} and the lower line tracks the change in mean global temperature (MGT). The slight dip in the CO\textsubscript{2} concentration around 1500 to 1800 is associated with the little ice age when the Thames froze over in winter. It is not until after 1850, when the rate of population increases significantly, that the CO\textsubscript{2} level kicks upwards followed by the MGT. The lag between the effects of population growth and CO\textsubscript{2} emissions appears to be due to the time taken for the increasing affluence (and emissions) of that population increase to take effect. There is no lag between the CO\textsubscript{2} and MGT trends which correlate well after 1850 when more reliable direct measurements were made. Population
increase is now at such a magnitude that it is causing rising levels of CO\textsubscript{2} in the atmosphere which is having an immediate effect on global temperatures.

**Consequences of Global Warming**

There are many detailed accounts in the literature covering the effects of rising atmospheric temperatures. Searching the internet for ‘global warming’ returns 9.5 million references. The following summary is therefore not exhaustive.

Rising mean global temperature causes the following effects:

(a) *climate change* - since warmer air has more energy, convection rates intensify and cause weather patterns to change, leading to more frequent floods and droughts in places where they were previously rare events;

(b) *warming oceans and rising sea levels* - as oceans have absorbed heat from the atmosphere, they have expanded causing levels to rise by 0.7 mm/year since 1910\textsuperscript{15}. Already people in Bengal, as well as in other mega deltas and low lying islands such as Maldives and Tuvalu\textsuperscript{16} have had to retreat to higher ground. A serious consequence of rising sea levels is the long term loss of fertile land for growing food increasing the risk of famines;

(c) *ocean dead zones*\textsuperscript{17} - areas close to coasts and river mouths where excess nitrogen run-off (from agricultural fertilizers) occurs, causing water oxygen levels to become heavily depleted, stifling marine life. The area of dead zones doubled during the last ten years and, if this process continues, they will become a significant threat to the whole marine food chain;

(d) *extreme weather events* - as increasing sea temperatures feed back heat energy to the lower atmosphere, hurricanes and cyclones intensify their destructive force;

(e) *melting of ice caps and mountain glaciers* which further increases sea levels. In 2007 and 2008, Arctic ice receded significantly compared with the 1979 - 2000 average\textsuperscript{18} and is predicted to disappear by 2020. This is compounded by a *positive feedback* effect; as ice is lost from land/sea, the darker underlying land/water absorbs insolation more effectively (albedo effect) and speeds up the whole process. Earlier estimates of sea level rising by up to 80 cm by 2100 could be well short of reality, and rises of one metre every 20 years could happen\textsuperscript{19}. This could constitute a tipping point;

(f) *acidification of the oceans* - caused by the CO\textsubscript{2} dissolving in rain leads to leaching of coral reefs and dissolution of the shells of crustaceans and phytoplankton\textsuperscript{20}. The subsequent disappearance of these tiny creatures from the bottom of the marine food chain threatens its collapse – another potential tipping point;

(g) *instability of clathrates (methane hydrates)* which exist in frozen tundra and under the sea bed and, when warmed, will dissociate to produce large quantities of methane (over 20 times more potent than CO\textsubscript{2} as a global warming gas) which is emitted into the atmosphere. This instability generates a positive feedback since it is both caused by, and enhances, global warming. As such, it must be of great concern since it could potentially develop into a runaway situation – yet another potential tipping point;

(h) Coupled with the above, *deforestation* must be mentioned because it reduces the biosphere’s ability to sequester vast amounts of atmospheric CO\textsubscript{2}. By cutting trees down we remove one of nature’s major means for keeping the CO\textsubscript{2} level in balance. Reduction in forest area means higher rates of accumulation of CO\textsubscript{2} in the atmosphere and the oceans (not to mention serious loss of biodiversity) which - in conjunction with the above-mentioned threats – moves us faster to a tipping point from which there may be no recovery within the lifetime of the current population.
It goes without saying that loss of biodiversity and the acceleration of extinction rates are resulting from all the above.

**Other Impacts**

The above list gives the downside of anthropogenic global warming. However, there are other major threats from human action which, if not controlled, will threaten our survival. These include:

- soil erosion,
- increased salinity of the soil and loss of nutrients due to leaching and over-irrigation,
- desertification,
- chemical pollution of the land, air, sea, rivers and aquifers;
- declining fish stocks due to overfishing
- waste disposal to landfill

all of which lead to reductions in biocapacity and biodiversity as well to extinctions.

In short, human activity is leading to larger populations and simultaneously to the destruction of their ecological support systems.

Governments are invariably too slow in limiting fishing in, and pollution of, the seas as well as control of emissions into the atmosphere we all share. The path to international treaties for global action is bedevilled by national and large corporation self interests. The realisation of this has increased the environmentalist movement in many forms throughout the world over the last 30 years. Environmentalism makes waves and small differences, but it has failed to make governments take effective action. As Speth comments,

“Despite all the conferences and negotiations, the international community has not laid the foundation for effective action. … The bottom line is that today’s treaties and their associated agreements and protocols cannot drive the changes needed … the climate convention is not protecting the climate, the biodiversity convention is not protecting biodiversity…and the even older and stronger Convention on the Law of the Sea is not protecting fisheries. The same can be said for the extensive international discussions on world forests, which have never reached that point of a convention.”

It seems that governments will listen to economists, the vast majority of whom are concerned only with growth, irrespective of the environmental cost. When they do act, minor solutions are proffered: to insulate homes; change to efficient light bulbs; waste less food, recycle, etc. These are all very well. They create a feel-good factor for an otherwise ill-informed or half-hearted public, but they will make little impact so long as the big international actions are stalled.

**Quantifying Human Impact**

The major impacts of human activity and their consequences have been summarised above. However, to decide what, if any, action needs to be taken, the impact must be quantified, as does the earth’s capability for coping with it. Ecologist’s generally agree that *impact* of human activity on the environment can be expressed qualitatively by the Commoner-Ehrlich Equation:

\[ I = P \times A \times T. \] (1)
This states that the *impact* \((I)\) on the environment is proportional to: population size \((P)\); ‘*affluence*’ \((A)\) (the amount of resources a population consumes and wastes) and *technology* \((T)\) which was introduced to express that technological advance feeds consumerism, enables higher consumption and extends lifetimes.

To measure impact, we need to quantify the three variables on the right hand side of the equation. The \(T\) term, however, is obscure and difficult to quantify. There has been much debate as to whether it increases or decreases impact. This Jekyll and Hyde term, it seems, can do both. For example, *socially good* medical technology, through which we prolong and save lives, increases human impact by causing population growth and so can be *ecologically bad* unless the *ecologically good* contraceptive technology is used effectively to limit the birth rate appropriately. *Ecologically bad* technology, such as burning coal in power plant and increasing the level of \(CO_2\) gas in the atmosphere, can be reduced by using more *ecologically good* solar power and wind technologies. Technology is therefore a two edged sword. There can be no denying that the world population has exploded since advances in agricultural, food processing and transport technologies enabled production of cheap food. By enabling products to be produced more quickly and cheaply, and thereby encouraging a culture of consumerism and waste in the developed world, technology cannot avoid some blame for acting as a catalyst for the growth of affluence. *As Technology can only effect efficiencies in production after it has whetted consumers’ appetites for products in the first place, it is difficult to see how it can avoid increasing human impact, especially as its advances have been a root cause of population growth a hitherto unsurpassed scale.*

By combining the affluence and technology variables into a single variable ‘\(F\)’ to represent the overall per capita *consumption*, which we call the *footprint*, we arrive at a simpler equation:

\[
I = P \times F. \tag{2}
\]

While population is easy to measure, the footprint is more complex, but has been achieved by William Rees and Mathis Wackernagel who introduced it in the 1990s. It is now used extensively by the Global Footprinting Network (GFN) to measure the biocapacity and consumption of every country in the world. These ecological parameters are published at two year intervals in the *Living Planet Report* of the World Wildlife Fund. The latest report appeared in 2008 providing footprint and population statistics for 2005. Unless otherwise stated, it is these latest data which will be cited in the rest of this paper.

**Biocapacity**

To determine the planet’s biological income, GFN estimates the annual biological resource generated by the planet. This is referred to as the *total biocapacity*. Earth’s total biocapacity is defined as the biologically productive area of land and water arising from forests, croplands, grazing lands and fishing grounds available to produce all the biomass we use and to absorb all the waste produced, including \(CO_2\) emissions. Fossil fuels are not a part of the biocapacity. Biocapacity is the biological product of a prior 12-month period. In contrast, fossil fuels are the stored product from bygone eras which have been transformed, through bacterial activity over 200 million years, into an energy-dense and highly combustible organic hydrocarbon. They are a one-off legacy, never to be repeated in the human era.
Total biocapacity is measured in *global hectares* (gha). A *global hectare* is an average measure and is defined as the earth’s total biocapacity divided by the total physical area which generates it. In 2005, the earth’s total biocapacity was measured at 13.4 billion gha (Ggha). However, a more conceivable measure is the *biocapacity per head of population, namely, global hectares per capita* (gha/cap). Called simply biocapacity, this describes the average physical land area available to sustain each person. In 2005, the biocapacity was 2.1 gha/cap (~5.25 global acres per capita) since a population of 6.5 billion shared (not equally) the earth’s 13.4 Ggha.

Next, GFN measures how much we actually consume. This is called the *footprint* (analogous to expenditure). Like any other income-expenditure account, the planet’s biological account can be in balance, in credit or overdrawn.

**Ecological Footprint**

To find the per capita footprint of each country, GFN divides its total consumption by its population. The units of this quantity is also global hectares per capita. Summing the national footprints yields the global footprint. In 2005, the footprint of the world’s population was 2.7 gha/cap (Table 1), exceeding its biocapacity of 2.1 gha/cap by 29%. This deficit (ecological debt) represents the land equivalent of the energy provided by fossil fuels $^{25}$ plus the missing land needed to absorb waste CO$_2$ emissions. Since all CO$_2$ emissions cannot be absorbed by vegetation, the excess is retained in the atmosphere or transferred to the oceans where it causes global warming and acidification respectively. According to these estimations, in 2005, one and a quarter planet earths were needed to sustain indefinitely the population of 6.5 billion people. We arrive at the inescapable conclusion that, as there was an ecological deficit of some 29%, the world population is not sustainable.

**TABLE 1**

<table>
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<th>Biocapacity</th>
<th>Footprint</th>
<th>Overshoot</th>
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<td>gha/cap</td>
<td>ratio</td>
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<td>UK</td>
<td>1.6</td>
<td>5.3</td>
</tr>
</tbody>
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Source: Living Planet Report 2008$^{24}$

Table 1 shows examples of national and continental footprints. The footprint of the United States was double its biocapacity despite its massive land area, reflecting its extremely high consumption of fossil fuels (carbon footprint). In contrast, Africa’s footprint of 1.4 gha/cap was sustainable, being lower than its biocapacity (1.8 gha/cap) due to a very low carbon footprint. Europe and the UK were also both in deficit reflecting their high populations and affluence. The Latin American and Caribbean region is in credit since it has a high biocapacity attributable to the Amazon rain forest.
Graphical Representation of Sustainable Populations

For a given biocapacity, the relationship between population and consumption can be shown graphically and reveals how one depends on the other and where sustainability boundary lies. If we substitute the impact term with total biocapacity (B) in equation (1), we get $P \times F = B$. in which $P$, $F$, and $B$ are again in units of billions, global hectares per capita and billion global hectares respectively. Because B is now fixed, P and F are constrained to become inversely proportional to each other and their interdependence is described by the hyperbola shown in Figure 5.

It shows the graph of the equation $P \times F = 13.4$ where 13.4 Ggha is total biocapacity for the planet. This hyperbola has the characteristic that, as the size of one variable doubles, the other halves. All the points on that curve, therefore, represent the maximum world population size that is sustainable by a given footprint or conversely the maximum footprint available to a given population. If the population’s footprint is greater/less than its available biocapacity, its point will plot above/below the curve respectively. The curve therefore represents the boundary between sustainability and unsustainability for a given biocapacity and the further away a footprint lies to the right and above the curve, the more unsustainable it becomes.
In Figure 6, the point representing the world’s 2005 footprint (2.7 gha/cap) and population of 6.5 billion lies above the curve in *unsustainable* space. The maximum sustainable population corresponding to 2.7 gha/cap is 5 billion and any population below that would be sustainable. Plotting different national footprints on the world hyperbola shows how many people the world could sustain if they lived at each of those nations footprints.

Figure 7 shows that a maximum of 2.9 billion people could live on earth with an average EU lifestyle of 4.7 gha/cap.

The corresponding maximum world population that a U.S. lifestyle (9.4 gha/cap) could support is 1.6 billion. Such footprints are far in excess of the 2005 world biocapacity of 2.1 gha/cap and they emphasise that the developed world only enjoys its affluence because it consumes vast quantities of fossil fuels. People in underdeveloped countries, however, use relatively little oil, coal or gas, and have much lower footprints as a consequence. If the world lived with an African footprint if 1.4 gha/cap then 9.4 billion people could be sustained. Coincidentally, that number is close to the United Nations projection for world population in 2050. Food for thought indeed!

*Sustainability hyperbolae* show how *population* and *footprint* combine to magnify the global footprint. Any path...
to unsustainability is made up from increases in two components: footprint and population.

A country’s footprint can become unsustainable by increasing its population or its per capita consumption or, more devastatingly, by a combination of both. Figure 8 shows, by way of example, a population of 3 billion with a sustainable footprint of 2 gha/cap. If that population increases from three to eight billion, without increasing its per capita footprint (vertical line), it causes a population overshoot of ~ 40 per cent. Alternatively, if the footprint of a stable population increases from, say 2 to 5 gha/cap (horizontal line), an overshoot of ~ 35 per cent results. When both increase together, the combined effect is a 260 per cent overshoot (oblique line). Thus, population increase coupled with increase in consumption per head is the fast track to unsustainability, precisely the path taken by world populations over the last two centuries.

**Tracking the World Footprint**

In 1961, 3.1 billion people lived sustainably with a mean footprint of 2.2 gha/cap when the biocapacity was 4.2 gha/cap (see Figure 9). Throughout the next 25 years, the population remained sustainable as the population/biocapacity ratio was less than unity. The population/biocapacity ratio attained unity when both parameters reached the value of 2.7 gha/cap, through the combination of growth in both the population and its footprint. In the late 1980s, the sustainability limit was crossed and thereafter the world population had become unsustainable. It should be noted that, after 1980, the footprint locus stopped moving to the right; it progresses almost parallel to the population axis. Thus, population increase rather than the per capita consumption became the driver to unsustainability. This underlines the stark reality: if one nation increases its footprint faster than its available biocapacity (by increasing its numbers and/or its per capita consumption) then this can only be at the increased impoverishment of some other, usually poorer, nations.

It appears from the trend, evident in Figure 9, that the global per capita footprint is entering a period of decline. Unless wealthy countries share their affluence with poorer countries, ideally in exchange for a reversal of their population growth through the widespread adoption and encouragement of conception control measures, this will lead to continued increase in poverty which may only be ultimately reversed by a rapid involuntary decline in human numbers. As Bligh observes his book, *The Fatal Inheritance*: “Contraception is so much kinder than starvation and genocide.”
The Division of Unsustainable Wealth

In addition to providing footprint data for each country, GFN also shows data for three categories: high, medium and low income countries. These are given in Figure 10 to demonstrate the range of footprints implied by the range of populations in these groups. At one extreme, if the whole world lived at the 1 gha/cap footprint of the low income countries (LIC), it could sustain 13.8 billion people at a lifestyle typical of Bhutan or Sri Lanka. At the other extreme, the lifestyle of the high income countries group (HIC) would only sustain 2 billion people. In between these extremes, the footprint of the middle income countries (MIC) would support population of 6 billion, representing a living standard similar to Azerbaijan or China. This is a graph of consequences.

If we wish to ‘make poverty history’, there is a long term price to pay for the world to remain habitable. In reality, the HIC population will not willingly give up enough of its wealthy lifestyle to enable convergence with the LIC. That would entail cutting the HIC mean footprint by 70%.

FIGURE 10
SUSTAINABLE POPULATIONS FOR THE FOOTPRINTS OF THE THREE MAJOR INCOME GROUPS

In 2005, 63% of the HIC footprint was derived from the CO₂ emissions from fossil fuels. But our natural inheritances of oil, gas and coal will run out. The peak of oil field discoveries occurred around 1960 and there is strong evidence that the peak of oil production is happening now²⁸.

An extensive study by David Rutledge of Caltech²⁹ predicts that by 2076, 90% of fossil fuels will be depleted. This will leave us with only alternative renewable energy sources which either A) only produce energy in the form of electricity (wind, photovoltaics) or heat (geothermal – not renewable) or B) use large tracts of land at the expense of food production to produce biofuels. While some renewables may keep the lights on and electric motors running, they will not provide fertilisers, currently derived from hydrocarbons, to grow food. The more land area we
use to grow biomass for fuel or energy capture, the less will be available to grow food. We should, therefore, not be under the illusion that a lower carbon footprint, emerging from lower consumption of fossil fuels, will balance the biocapacity – footprint shortfall. The land footprint will have to increase significantly to provide the biomass and energy to replace the materials and energy currently derived from fossil fuels.

It is ironic that, with all our highly-evolved intelligence, we can indulge in the mass self-deception that economic growth and increased complexity of society is the only way to solve our problems. This only encourages that oxymoron called “sustainable growth”\textsuperscript{30}, when our resources are now so obviously limited in the long term.

**Renewable Energy**

Renewable energy is not the panacea many would wish. Unlike fossil fuels, renewable energy sources either require extensive land area (e.g. biofuels) or require somewhat less extensive land area but can only provide intermittent supplies (e.g wind or photovoltaic). Biofuel crops displace food crops and have a low rate of conversion of sunlight into liquid fuel; the move to biofuels as partially responsible for the increase in food prices in 2008. Solar panels only work during daylight hours, and their output depends on the daylight intensity; output is heavily reduced at more northern/southern latitudes in winter - just where and when it is needed most. Wind turbines only generate when the wind blows above a certain minimum speed – and then only up to cut-out wind speeds around 55 mph. To avoid instability of supply, the amount of electricity that wind energy can contribute to a grid is unlikely to much exceed 20%. Moreover, because wind can be absent for days on end, there must be additional flexible plant availability to cover that 20 per cent contribution.

Nuclear plant, which is not renewable and only suitable for base-load electricity generation, will have an essential role to play. Like all renewables trying to replace fossil fuels, it has a significant drawback. It only generates electricity. Oil, coal and gas are also sources of fertilisers, fungicides, pesticides, herbicides polymers and many other chemicals upon which today’s populations depend.

Without fossil fuels we will need to find alternative sources – which in the case of fabrics will mean diverting land to growing crops for natural fibres, which, as the reader will quickly realise, means even less land for growing food. The ecological data coming in from all around the world paint a picture of falling resources for an increasing demand. The Earth’s land must now increasingly provide its population with food, clothes, fertilizers and energy, where for an interlude in the 20\textsuperscript{th} century it only had to provide food and a limited amount of natural fibres. It will have to do that in a scenario where fertilisers and other production enhancers will become scarcer and the quality of the soil will deteriorate because of degradation, erosion and desertification. The continued decline of the land’s productivity will cause poverty on a scale larger than we have ever experienced. Ponting\textsuperscript{31} summarises how we are not coping with the current level of population:

“In the early twenty-first century the poorest 20 per cent of the world’s population (about 1.3 billion people) receive about 1 per cent of the world’s income. They are classified by the WHO as living in ‘extreme poverty’ and lack adequate food, housing and drinking water. Over three billion people ... have to live on less than $2 per day. A third of the world’s children are classified by the WHO as undernourished.”
Population Limitation Programmes

It is hard to see how our 6.8 billion people can survive at today’s average standards by mid-century - let alone the 9.15 billion people now projected for 2050. As the world footprint has increased so also has poverty, bringing more people in the underdeveloped world closer to starvation and disease. The depletion of fossil fuels will only exacerbate that situation, and steps to encourage smaller families in all countries are already long overdue. Undesirable outcomes can only be mitigated by encouraging and providing the means for people in all countries to appreciate the need to limit their family sizes to no more than two children – and preferably fewer.

It is, however, generally recognised that, as a population becomes more affluent, the sizes of families fall. That is because:

- as infant mortality rates fall so there is less need to produce more children to ensure that enough survive to support aging parents later on;
- the cost of rearing children is much higher in affluent societies because the expectations for education and quality of life are higher;
- to meet the costs of rearing, both parents have to work, leaving them less time for raising the children.

Some commentators, therefore, take the view that all that is needed is to let everyone become affluent and the population problem will look after itself! Such simplistic observations fail to take into account that the process of evolving out of poverty becomes increasingly difficult as available resources shrink. It also neglects the fact that such affluence has a cost in the form of increased rate of resource depletion and biodiversity. The developed world has been using resources such as fossil fuels and minerals to improve its own wealth since Columbus. Subsequent explorers and entrepreneurs found out where they were and just went and took them, with little interest in improving the lot of the aboriginal people (in Africa, the Antipodes, Oceania and the Americas) who were actually entitled to them. The HICs have basically helped themselves to the riches of the third world as their contemporary ecological footprints adequately demonstrate. The result has been that, while birth rates fell in the HICs during the 20th century, populations and poverty increased in underdeveloped countries. As we enter an era of depleting fossil fuels and unstable food prices, and arable land is given over to the production of renewable energy and other substitutes for the fossil fuel materials essential to HIC economy, it is becoming more difficult for many poorer nations to close the wealth gap. This is particularly so as many countries – and not just the poorest ones - are becoming vulnerable to the adverse effects of climate change.

Pathfinders

Some less-exploited countries with stronger governments have managed to break the mould described above. China, Iran, and Thailand, have had the foresight to escape this predicament to a significant extent. They implemented population policies and provided freely available contraception to couples in the latter half of the 20th century because leaders could see that higher populations would drive them further into poverty. Even though it achieved the objective, China’s ‘one-child’ policy was often carried out heavy-handedly which is typical of a dictatorial communist regime.

Guillebaud comments that encouraging a voluntary ‘stop at two’ policy for Iran meant that it:
“… succeeded in halving its TFR [total fertility rate] in just eight years, from a family size of 5.2 children in 1988 to 2.6 in 1996. This was through a conscious government decision in 1987, after a census, to reduce the country’s rapid population growth rate in order to aid its development. Iran’s reproductive health success story occurred in part through the removal of obstacles to women choosing to control their fertility, including perceived religious obstacles through Islam, which Iran’s own religious scholars issued edicts or fatwas to refute. A second key factor was ensuring a sufficient supply chain of a good range of contraceptives through a countrywide network of “health houses”. Importantly, this was a voluntary “two-child” population policy, yet the rate of decrease in Iran’s TFR was just as fast as that of China, whose “one-child” policy began in 1980.”

The rate of decline in Iran’s TFR has continued. In 2008 it stood at 2.13 and the rate of natural increase is now down to 1.4%.

Thailand provides a further example (Table 2) of the benefits of providing free contraception, especially when compared with the Philippines, which did not provide such a facility.

<table>
<thead>
<tr>
<th>Year</th>
<th>Population (M)</th>
<th>Total Fertility Rate</th>
<th>Rate of Natural increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thailand</td>
<td>Philippines</td>
<td>Thailand</td>
</tr>
<tr>
<td>1960</td>
<td>26.3</td>
<td>27.9</td>
<td>6</td>
</tr>
<tr>
<td>2000</td>
<td>60</td>
<td>81.8</td>
<td>1.9</td>
</tr>
<tr>
<td>2003</td>
<td>63.2</td>
<td>84.6</td>
<td>1.7</td>
</tr>
<tr>
<td>2008</td>
<td>65.1</td>
<td>91</td>
<td>1.6</td>
</tr>
<tr>
<td>2025</td>
<td>70</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>2050</td>
<td>69</td>
<td>150</td>
<td></td>
</tr>
</tbody>
</table>

In 1960, both countries had similar populations of about 27 million people and natural growth rates of 3% and 3.3% respectively. Thailand – a Buddhist country - made contraception freely available outside the medical profession and, by 2008, its population had reached 66 million and the natural growth rate had fallen to 0.5% per annum. Predictions for 2025 and 2050 indicate that the population for Thailand will peak at ~70 million in 2025 and fall thereafter. In contrast, the (90% Christian) Philippines population increased by 26 million more than Thailand by 2008 and will reach 150 million by 2050. Muir35 underlines the relevance of education in reducing TFR levels:

“Thailand provides a nice example of the apparent connection between educational levels, particularly of women, and fertility rates. Over the last 30 years or so, female literacy increased to 90% and nearly half of the work force is now female. While the TFR for Thailand in the 1960's was 6, it is now down to 1.6, or lower than replacement level!”
There is still a great unmet need for contraception, particularly in, but not restricted to, Africa where latest estimates show a TFR of 4.9 – 3.3 times higher than Europe’s 1.5 and about three times that of Thailand. If unchecked, Africa will have a population of 2 billion by 2050 – equal to the total world population in 1920. These countries are truly the pathfinders to future sustainability.

In 1994, Amartya Sen commented in a comprehensive review of population policies:

“There are reasons for worry about the long-term effects of population growth on the environment; and there are strong reasons for concern about the adverse effects of high birth rates on the quality of life, especially of women. With greater opportunities for education (especially female education), reduction of mortality rates (especially of children), improvement in economic security (especially in old age), and greater participation of women in employment and in political action, fast reductions in birth rates can be expected to result through the decisions and actions of those whose lives depend on them.

This is happening right now in many parts of the world, and the result has been a considerable slowing down of population growth in several countries. The best way of dealing with the population problem is to help to spread these processes elsewhere’.

The Future

The race towards primarily wind and solar energy as well as biofuels has started. These renewables represent part of the transition to a new order, the like of which we have never experienced before. Because the new energy sources will require land currently used for food, there will be less available for that purpose, as well as less fertiliser with which to maximise the crop yields. This means that human populations will have to decline. But to what level? The answer to that depends on what average footprint we consider reasonable and demonstrates the difficulties in calculating such a number. In 2000, Willey suggested a modest average world footprint of 3 gha/cap. From Figure 7, it can be seen that this implies a population of ~4.5 billion. A European-type footprint of 4.7 gha/cap, on the other hand, would sustain a population of only 2.9 billion. There is a caveat here. None of those calculations make any allowance for biodiversity as GFN data specifically exclude such an allowance. A figure of 12%, suggested in the Brundtland report would reduce the aforementioned world maximum sustainable population figure to around 4 billion and 2.6 billion for a ‘modest’ European footprint, respectively. Whichever figure is taken, it is clear that, at today’s 6.8 billion people, there is work to be done. It would be wise to plan for a sustainable world population of no more than three billion people – however distributed – because that is around where current footprinting science is pointing if we want to contract and converge to a reasonable lifestyle. It may be that in twenty years or so, some new and unforeseeable development will allow that objective to be modified to, say, four billion. We cannot rule out that it may point even lower depending on how seriously climate change affects the equation. Be that as it may, it will take many decades to decline naturally to even four billion. It certainly appears expedient, even urgent, that we start moving in the right direction now, especially as we need to first stop population growth before we can allow it to decline. Procrastination will only increase Nature’s ability to do it for us.
Conclusion

The GFN footprint statistics show that, globally, we have left sustainability behind during the 1980s. Since then, increasing world affluence and populations have driven us deeper into unsustainable territory. The carbon dioxide emissions of each country pollute the atmosphere for every other nation and the human urge to improve its affluence, and thus impact - no matter how well off it already is – seems set to continue. It follows that, if it is not possible to constrain humanity’s footprint and eliminate poverty, then the only parameter left to constrain is future population size by reducing the birth rate. The ecological footprinting data analysed in this paper have given guidelines: a sustainable global population is around three billion people – providing the world settles for a mean ecological footprint somewhere in the region of 4 gha/cap.

The detailed means of achieving such goals lie beyond the scope of this paper. However, there is extensive literature and research on the techniques involved in successful family planning and population limitation programmes, both on the website of the Optimum Population Trust and elsewhere. There are now several practical examples of states that have introduced them, and are beginning to reap the benefits. Politicians need to demonstrate courage and leadership on this issue: they must not only persuade their nations to accept the necessity for smaller families but also provide the means and culture for people to willingly and voluntarily limit their family size to two or less. Failure to do so risks the worst population crash in the history of humankind.

We urgently need to understand that, by trying to harness Nature to satisfy our own appetites, we humans are waging a war with ourselves – a war we can never hope to win. Walter Youngquist38 expresses the alternative:

“With the knowledge we now have and the unique ability above all other organisms to visualize what predicaments the present trends of resource use and population growth will lead us to, we should have the will and capability to adopt a course which will lead to a sustainable future at a reasonable standard of living for all.”.

John Bligh27 points out the consequences of not making the right choice:

The American poet Robert Frost once indicated that where the path divided he always took the one least trod – and that, he said, had made all the difference. That interesting comment might well be applied prospectively rather than retrospectively to the progress of humanity. We can choose the one pathway by which we allow ourselves to be driven thoughtlessly towards ultimate disaster, as our genes dictate, or we can choose to temper the proliferation of the human species, and our attitudes towards each other, and possibly thereby to avert that disaster.’
REFERENCES

3. Daily Telegraph, September 14, 1994
5. This includes homo *erectus* (well established by one million years ago ) and homo *sapiens* (dating from about 150,000 years ago).
7. This transition is still not complete; there are still hunter gatherers in the Amazon jungle (recently discovered in May 2008) as well as in far eastern forests
12. [http://earthobservatory.nasa.gov/Library/Giants/Arrhenius/arrhenius_2.html](http://earthobservatory.nasa.gov/Library/Giants/Arrhenius/arrhenius_2.html)
18. [http://nsidc.org/images/arcticseaicenews/20080811_Figure2.png](http://nsidc.org/images/arcticseaicenews/20080811_Figure2.png)
19. [http://environment.newscientist.com/article/mg19526141.600](http://environment.newscientist.com/article/mg19526141.600)
25. For the avoidance of doubt, fossil fuels are not a part of the biocapacity. Biocapacity is the biological product of a prior 12-month period. In contrast, fossil fuels are the stored product of biomass from bygone eras which has, through bacterial activity over 200 million years, been transformed into an energy-dense and highly combustible organic hydrocarbon. It is a one-off legacy, never to be repeated in the human era.
26. ‘Overshoot’ is defined as the ratio of the footprint to the biocapacity for a given population size.


28. There are many references for this but, for an overview see: http://www.peakoil.net/

29. Rutledge: http://www.youtube.com/watch?v=aTUcxYdMmj4


34. http://worldperspective.usherbrooke.ca/

35. Muir, P. http://oregonstate.edu/~muirp/changtfr.htm


37. Willey, D., Medicine, Conflict and Survival, Vol. 16, 72-94, 2000, Published Frank Cass, London


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