The sustainability of human populations

How many people can live on Earth?

We live on an over-crowded Earth whose population is 6 billion and rising. How many people can the planet feed, clothe and water? Is there a limit to the number that the earth can sustain? And have we passed that limit already? **Martin Desvaux** looks at the weight of our numbers.

There is nothing new about the relationship between population size and land. As early as 470 BC, Plato asserted that "A suitable total for the number of citizens cannot be fixed without considering the land". The Greeks, for all their knowledge, could not even begin to conceive of the vast tracts of land that existed for human exploitation. They were therefore justifiably concerned about the sustainability of their population by their limited view of what was available to them. Today, when we have come to know the extent of the world and its carrying capacity more fully, it seems that many people may have lost sight of Plato's wisdom. Here we set out to place the current world population trends in the context of "considering the land". But first, a bit of history.

A brief history of the impact of human development

In 1960, E. S. Deevey published a graph[1] (reproduced with embellishments in Figure 1) to illustrate how the world population had grown over the last million years. By plotting on logarithmic axes, the data show up three major phases.

The first phase relates to the dawn of human activity, the prehistoric hunter–gatherer period, during which the population is estimated to have grown from the order of 100 000 to around 7 million people over the 1 million years before 8000 BC. Because hunter–gatherers needed large tracts of land to supply their basic needs of fuel, food and clothing, their populations were constrained by the amount of edible vegetation and animals that nature provided in a given area, as well as their limited technology to exploit it. As a result, early man's impact on the environment was negligible and all his resources were renewable. It is worth reflecting that prehistoric society grew at an average of seven people per year. This startling estimate registers how close the hunter–gatherers actually came to extinction. Had the average annual number of humans who died before reaching sexual maturity been eight more, the human race would have died out around 900 000 years ago!

Human population cannot continue to increase without limit. But have we reached that limit?

The second phase started around 8000 BC with what has been termed the Neolithic transformation. European and Middle Eastern peoples slowly began to develop agriculture and to domesticate animals. The resulting increase in the food supply enabled the world population to grow to 500 million by 1600 AD; a growth rate which was 165 times faster than in the prehistoric period. The Neolithic transformation drove the development of building, transport, irrigation and many other technologies of the advancing civilisation. As a result, human impact increased, since the need

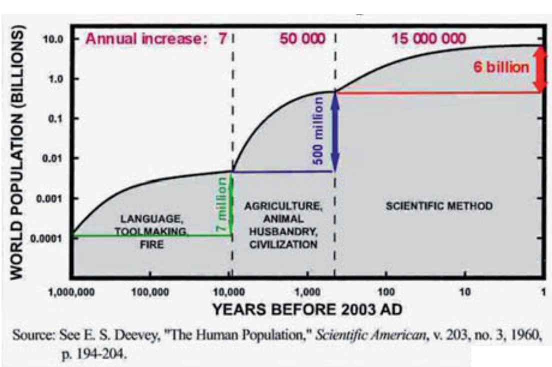

Figure 1. Increase in world population[1]

for firewood and space for settlements and cropland led to increased deforestation. Furthermore, over-irrigation caused salination and soil erosion, which led to desertification of large areas, notably in Africa and the Middle East.

The gradual emergence of science and its application through engineering in the 18th century led to the industrial revolution and the third phase of population growth.

A detailed look at this third phase on a conventional linear plot, as seen in Figure 2, shows the astonishing magnitude of the population change[2]. As a result, the impact of the third phase has been the most severe. After Columbus (1492), the colonisation of new lands provided more food and wealth for the European powers—creating the Third World in the process.

The industrial revolution led to the development of coal-fired engines, factories and more efficient agriculture and food production, as well as faster transportation between and across continents. The consequential increase in the food supply, coupled with emigration to new world countries, resulted in more and larger families. The 19th and 20th centuries saw the rapid increase in inventions empowered by the exponential exploitation of coal, gas and oil. These had a positive feedback on the food supply by enabling, among many other innovations, the production of pesticides and fertilisers and automated farming to flourish. In the industrialised world, the development of modern medicine lowered infant mortality rates and increased longevity. Inevitably, control of death without a corresponding control of birth rate caused an explosion in population: an 11-fold increase to over 6.7 billion in just 250 years. During this phase, the human population increased at an average annual rate of 15 million—two million times higher than the first phase of development.

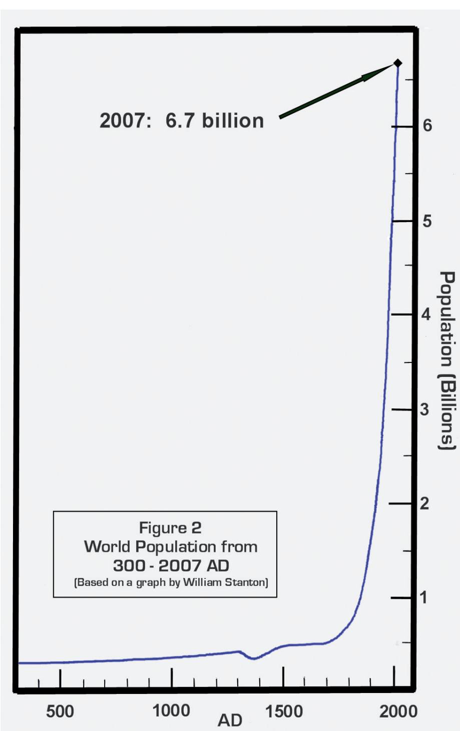

Figure 2. World population growth: key events

Human impact

Not surprisingly, the impact of this population growth on the environment since 1750 has been extensive. Now, not a day goes by but we hear of droughts, floods, famines, wars over resources, extinctions and, in the last 20 years, the increasingly evident effects of global warming. This *impact* has been expressed in what has become known as the Commoner–Ehrlich equation:

$$I = PAT.$$

This states that the impact (I) on the environment is directly proportional to the population size (P), the "affluence" (A) (defined as the resources a population consumes and wastes) and technology (T) through which we (a) prolong life, (b) produce things more quickly and cheaply (which feeds back into consumerism and affluence) and (c) grow food faster (which feeds back into "population"). All-in-all, this equation neatly summarises the impact of humankind on the planet.

Human impact on the planet has exceeded sustainability ever since the 1980s

The reality of the impact has already been mentioned: deforestation, soil erosion, salinity of the soil, waste disposal to landfill, desertification, declining fish stocks, rising sea levels and climate change. Politicians, unsure what to do, offer solutions that include suggestions such as the following: develop fuel-efficient cars; change to efficient light bulbs; fly less; build renewable energy and nuclear power plants; increase mass transit systems; plant trees. These solutions only address the reduction of the *affluence* and *technology* terms, but never the *population* term.

Reducing impact by decreasing affluence only partly addresses the problem since populations are growing faster than affluence decreases—as in Africa, India and the Philippines. Technology does not decrease, so, although it can be used to reduce the impact of *affluence*, it is likely that its benefits in developing energy-saving devices will be cancelled by its disadvantages, as businesses continue to use it to maximise their economic growth through consumerism. So, realistically, *impact* will continue to rise since economic growth demands it. This is bad news since human impact on the planet is already unsustainable.

Few would argue with the statement that "population cannot continue to increase indefinitely". But this begs the question: "Have we exceeded the limit?" This question demands a reply to: "How do we define the limit?". A reasonable answer, I suggest, is:

> The limit of population at any given time is determined by the planet's ability to support that population's impact indefinitely.

So, is the current population sustainable?

To throw some light on this, we need to use a tool called ecological footprinting, developed in the 1990s by William Rees and Mathis Wackernagel. It is now managed by the Global Footprinting Network (GFN)[3] and publishes, annually, the ecological parameters for every country in the Living Planet Reports of the World Wildlife Fund[4]. The latest of these reports appeared in 2006[5] and gives footprinting statistics for 2003. What follows is based on data taken from that report.

Ecological footprinting

Biocapacity

Ecological footprinting measures the impact of human population on the planet. It first measures how much resource the planet generates in a year and then calculates how much we use: a biological income–expenditure account. On the income side, the total biological product over a year is called the planet's *total biocapacity* and is defined as the biologically productive area of land and water arising from forests, croplands, grazing lands and fishing grounds needed:

(i) to produce all the biomass we use sustainably and

(ii) to absorb all the waste we produce, including CO_2 emissions.

Total biocapacity is measured in *global hectares* (gha), defined as the total biocapacity divided by the total physical area generating it. In 2003, the earth's total biocapacity was 11.2 billion gha (Ggha). However, a more useful measure is the *biocapacity per head of population* in units of *global hectares per capita* (gha/cap). Known simply as the *biocapacity*, it describes the *average* land area available to sustain each person. In 2003, since there was a population of 6.3 billion humans sharing the earth's 11.2 Ggha, the biocapacity was 1.78 gha/cap. (There are 2.5 acres to the hectare, so the sustainable footprint was about 4.5 acres per person.)

The ecological footprint

Looking at the expenditure side, what we actually use per head of population is termed the *ecological footprint*. The GFN measures this country-by-country, and by summing the national footprints the global ecological footprint is found. In 2003, the world's ecological footprint was 2.23 gha/cap, which exceeded its biocapacity by 25%. This overdraft of 25% represents the land equivalent of the energy provided by fossil fuels (our deposit account or biological inheritance) and the missing land needed to absorb our waste CO_2. In other words, because not all of our carbon waste can be absorbed by vegetation, it is being dumped into the atmosphere and causes global warming. At 2003, one and a quarter planets were needed to sustain the population of 6.3 billion indefinitely. (The carbon component of the world footprint was 1.06 gha/cap, meaning that, without fossil fuels, the world would have been living sustainably at 1.17 gha/cap in 2003, but at a lower comfort level in the developed world.) We have therefore been living beyond our ecological income by drawing on the fossil fuel legacy, which in the long term is unsustainable.

If everyone lived an American lifestyle, the planet could sustain only one-sixth of its present population

The data in Table 1 show that the ecological footprint of the USA was double its biocapacity despite its massive land area, reflecting its high consumption of fossil fuels. In contrast, Africa's ecological footprint of 1.1 gha/cap was sustainable, being lower than its biocapacity of 1.3 gha/cap) owing to very low fossil fuel usage. A further contrast: the UK's footprint is 3.5 times greater than its biocapacity, reflecting both its high population density and affluence. If the whole world consumed and generated waste like the UK does, it would require 3.5 planets—i.e. an additional two and a half earths—to sustain the human race! It should be noted that a serious side-effect of global warming will be a reduction in the earth's total biocapacity through shrinkage of productive land area due to rising sea levels, storms, droughts, floods and deforestation.

Table 1. Ecological footprints[2]

	Biocapacity (gha/cap)	Eco-footprint (gha/cap)	Overshoot ratio
World	1.78	2.23	1.25
USA	4.7	9.6	2.04
Africa	1.3	1.1	0.85
UK	1.6	5.6	3.50

Sustainable population hyperbolae

At the sustainability limit, the relationship between population and biocapacity is a hyperbola and this suggests a novel graphical way of presenting footprint statistics.

Consider the 11.2 billion hectares total biocapacity mentioned earlier, giving a global biocapacity of 1.78 gha/cap. At the sustainability limit, the total ecological footprint is equal to this 11.2 billion hectares of biocapacity. Thus, at the limit of sustainability, the following relationship holds true:

population (P) x mean per capita ecological footprint (F_m) = total biocapacity (B_t).

Population is therefore inversely proportional to per capita footprint, and the larger the population, the smaller the sustainable footprint and vice versa. Thus, for the *world*, the equation

$$PF_m = 11.2$$

is an hyperbola in which P, F_m and 11.2 are expressed in units of billions, gha and gha/cap, respectively.

Figure 3 shows this relationship plotted on a graph with population on the vertical axis. The hyperbola shows the maximum indefinitely sustainable mean ecological footprint of a population. If a population is sustainable, its footprint will lie on or below the curve. If the population is unsustainable, the footprint will lie above the curve.

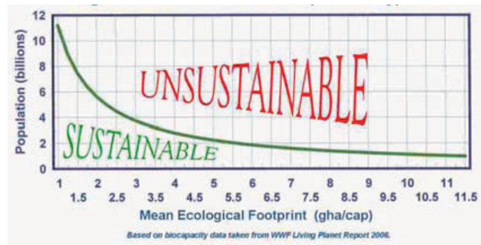

Figure 3. World sustainable population hyperbola (based on biocapacity data from the GFN[2])

Plotting the world's mean ecological footprint of 2.23 gha/cap (hereafter referred to as "footprint") against its population of 6.3 billion in Figure 4 shows that the footprint lies above the hyperbola: the population is therefore *unsustainable*. It can be seen that a footprint of 2.23 gha/cap will only sustain 5.1 billion people.

Plotting various national footprints on the world sustainable hyperbola (Figure 5) is instructive. For example, if everyone lived with an average European Union lifestyle of 4.8 gha/cap, then the Earth would sustain only 2.2 billion people; an American lifestyle at 9.4 gha/cap could only sustain 1.2 billion. Such values are far in excess of the 2003 world biocapacity of 1.78 gha/cap and they emphasise that the developed world only enjoys its affluence because people in the third world have much lower footprints.

Such hyperbolae demonstrate how the population and its affluence combine to magnify the global footprint. Consider a sustainable population of 3 million with a footprint of 2 gha/cap (the green star in Figure 6). In general, any pathway to unsustainability comprises two components. At one extreme we can increase the population (blue line) from, say, 3 billion to 8 billion keeping the footprint value constant and resulting in a 35% popula-

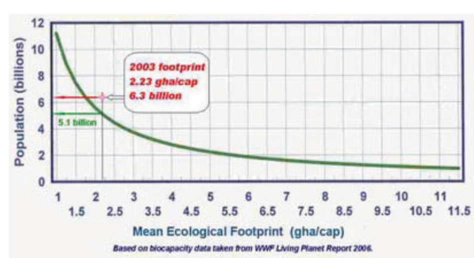

Figure 4. World footprint (based on biocapacity data from the GFN[2])

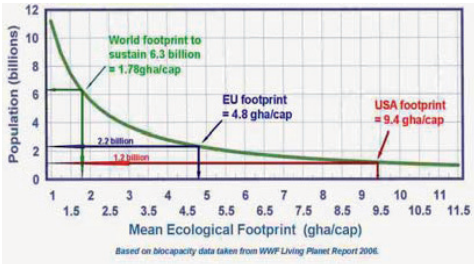

Figure 5. Sustainable populations versus footprints (based on biocapacity data from the GFN[2])

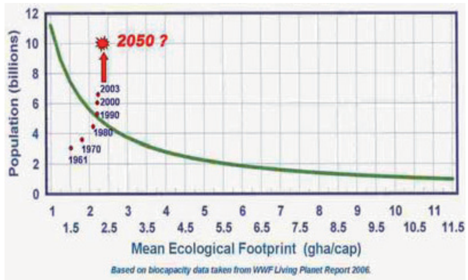

Figure 7. World footprint history

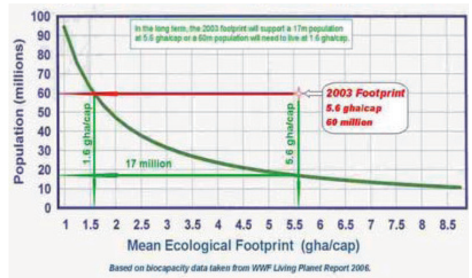

Figure 8. UK sustainable population hyperbola 2003 (based on biocapacity data from the GFN[2])

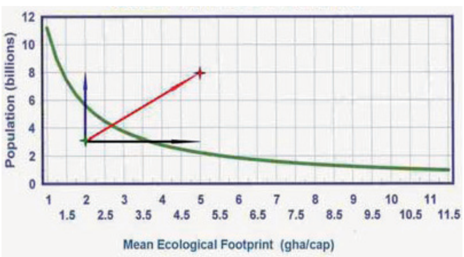

Figure 6. Paths to unsustainability

tion overshoot, where "overshoot" is calculated by dividing the total variable by the sustainable variable, where *variable* indicates *population* or *footprint*. Alternatively, the footprint of a stable population can increase from, say 3.4 gha/cap to 5 gha/cap (black line), resulting in an overshoot of 40%. More generally, if a combination of both applies, as in reality, we obtain the more drastic cumulative result shown in red. The footprint overshoot arising from the combined effect of population and affluence growth in this case is 260%. This is what happens when a growing population increases its per capita impact on its environment.

Tracking the world footprint

GFN world data go back to 1961 (Figure 7) when the population of 3 billion resided firmly in "sustainable space" with a mean footprint of 1.5 gha/cap. Between 1980 and 1990 it crossed the sustainability limit and, by 2003, had progressed into "unsustainable space". Up to 1990, the path into unsustainability was due to a combination of increasing ecological footprint and population. After 1990, however, population increase became the driver towards further unsustainability; the path stops moving to the right and progresses almost parallel to the population axis. This appears to be because increases in population have been predominantly in poor countries with low footprints. So the average footprint is being held steady due to low-end weighting. But because the world population continues to increase, the overall footprint becomes less sustainable.

The UN predicts that by 2050 the world population will exceed 9 billion. Combined with increased affluence (as the footprints of, for example, China and India expand rapidly), this could raise the world footprint to around 2.7 gha/cap. Without a serious international attempt to bring the world population back towards sustainability, the earth will become increasingly depleted of biological resources and will require humanity to conform to a reduced average footprint of 1.2 gha/cap. Because rich nations will not want to reduce their comfortable lifestyles significantly, this predicts an enormous increase in poverty and an incipient catastrophic population crash in the poorer nations. Superimpose on this scenario the impact of the predicted effects of further global warming and that outcome begins to look like a certainty. It is the author's view that the prediction of 9 billion will never be realised. Instead, the price will be extensive human suffering, through resource wars and starvation.

The UK footprint

Each country has a hyperbola constructed on its total biocapacity. We can look at the UK hyperbola in Figure 8 as an example.

The green curve is plotted using

$$P \times F_m = 0.095$$

where 0.095 is the UK's biocapacity of 95 million gha—effectively, its area of productive land. Rounding the population to 60 million and using the UK's ecological footprint of 5.6 gha/cap, we see that the UK is deeply embedded in unsustainable space with an overshoot of 350%. Put another way, with its 2003 footprint of 5.6 gha/cap, a sustainable population would be only 17 million.

This means that, currently, the UK has 43 million more citizens than it can sustain in the long term without relying on other countries to keep its larder stocked and to accept the global warming consequences of its waste emissions. To live sustainably, the UK population of 60 million would be forced to live with a mean ecological footprint of 1.6 gha/cap—a level corresponding to the average living standards in China, Paraguay, Algeria, Botswana and the Dominican Republic.

According to the GFN, the UK's footprint of 5.6 gha/cap is made up from 3.2 gha/cap attributed to carbon emissions and 2.4 gha/cap arising from all "other" sources (Table 2). The Labour government proposes to reduce carbon emissions by 60% by 2050, i.e. from 3.2 to 1.3 gha/cap. Assuming no change in the non-carbon ("other") element, the total footprint would reduce to 3.7 gha/cap. What would be the effect of such a change on the UK's sustainability?

To answer this, we refer to Figure 9, which shows the UK hyperbola with the associated footprint plotted as the red spot. The carbon footprint component is shown in black—accounting for 3.2 gha/cap—and the "other" non-carbon component of 2.4 gha/cap is shown in blue. As already mentioned, the total footprint of 5.6 gha/cap will only support 17 million people, but the footprint of 3.7 gha/cap, corresponding to a reduction in carbon emissions of 60%, would still only sustain a population of 27 million. Meanwhile, the Government Actuary's Department predicts that the UK population will grow by a further 10 million by 2050. The conclusion is that the government's aspirations to reduce carbon emissions by 60%—if they materialise—will only cancel out the extra growth in population and there will *still be 43 million citizens more than the UK can sustain*. Figure 9 also demonstrates that, in

Table 2. UK eco-footprint breakdown (rounded)

	Footprint (gha/cap) in the folowing years:		
Carbon	3.2	1.3	0.0
Other	2.4	2.4	2.4
Total	5.6	3.7	2.4

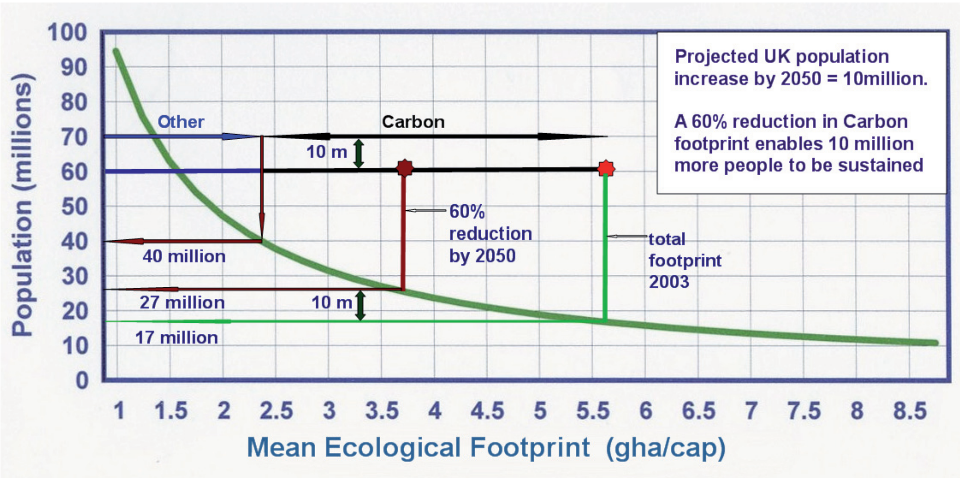

Figure 9. Effect of reducing UK carbon emissions by 2050 (based on biocapacity data from the GFN[2])

the highly unlikely event that the UK could reduce its carbon emissions to zero, the maximum sustainable population would be 40 million, assuming that the footprint remains constant. Therefore, even if the UK could eliminate carbon emissions, it could never reach sustainability without population reduction. The UK government needs to address this problem and to put in place a population strategy that avoids any further increase in the UK population and encourages it downwards towards the 17–27 million mark, depending on how far we are willing to reduce our footprint. To fail in this task is to condemn future generations to a miserable future.

A sustainable global population is somewhere between 2 and 3 billion people – less than half the current figure

Such statistics make it abundantly clear that there is an urgent need for national population strategies in all countries. It is the sheer weight of human numbers that is causing the overdraft on natural resources. If this continues uncorrected, a population crash will be inevitable. It is not sufficient to try to apply technology to solve the affluence term in the Commoner–Ehrlich equation. Humans will not willingly sacrifice their comfortable lifestyles for the greater good (especially for the greater good of other countries), so it must be taken from them, either through legal restrictions or, failing that, by nature through the misery and deprivation that must inevitably follow decades of collective waste and overconsumption. A more intelligent approach would be to bring about a reduction in the population of the world at the same time as trying to constrain affluence. Such a move would not be without economic consequence, but surely it would be the lesser of two evils.

Affluence, technology and population

The GNF statistics show that, globally, we left sustainability behind during the late 1980s. Since then, increasing world affluence and population have driven us deeper into unsustainable territory. The CO_2 emissions of each country pollute the atmosphere for every other nation and the human urge to improve its affluence, or impact through technology—no matter how well off it already is—is a driver that seems set to continue. It follows that if affluence and technology cannot decrease, then the only parameter left to reduce is population. The ecological footprinting data analysed in this paper have given guidelines; a sustainable global population is somewhere between 2 billion and 3 billion people; for the UK, the figure is between 17 million and 27 million. How such a goal is to be achieved is not rocket science. Spike Milligan once commented: "Contraceptives should be used on every conceivable occasion"; witty, and wiser perhaps than even he realised.

Failure of politicians to grasp this nettle and to lead their nations to accept the necessity of—and to provide the means to have—smaller families will be to threaten the world at large with the worst population crash in the history of humankind. Is it too much to hope that, with all the knowledge and technology at the disposal of the planet's most intelligent species, such an outcome could be avoided?

Acknowledgement

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