biological capacity or biocapacity : The capacity of ecosystems to produce useful biological materials and to absorb waste materials generated by humans, using current management schemes and extraction technologies. "Useful biological materials" are defined as those used by the human economy, hence what is considered "useful" can change from year to year (e.g. use of corn (maize) stover for cellulosic ethanol production would result in corn stover becoming a useful material, and so increase the biocapacity of maize cropland). The biocapacity of an area is calculated by multiplying the actual physical area by the yield factor and the appropriate equivalence factor. Biocapacity is usually expressed in units of global hectares.

global hectare (gha) : A productivity weighted area used to report both the biocapacity of the earth, and the demand on biocapacity (the Ecological Footprint). The global hectare is normalized to the area-weighted average productivity of biologically productive land and water in a given year. Because different land types have different productivity, a global hectare of, for example, cropland, would occupy a smaller physical area than the much less biologically productive pasture land, as more pasture would be needed to provide the same biocapacity as one hectare of cropland. Because world bioproductivity varies slightly from year to year, the value of a gha may change slightly from year to year.

http://www.footprintnetwork.org/en/index.php/GFN/page/glossary

Towards sustainable and optimum populations

Defining an optimum population

An 'optimum' population, in dictionary terms, is the 'best or most favourable' population. But a dictionary cannot tell the whole story. Best for what purpose, and best according to which criteria? For OPT, a green think tank, an optimum population means, at its simplest, a population size which is environmentally sustainable in the long term, affords people a good quality of life, has adequate renewable and non-renewable resources necessary for its long-term survival and consumes or recycles them to ensure it will not compromise the long-term survival of its progeny.

Few would argue with the statement that *'population cannot continue to increase indefinitely'*. But how do we define the limit? Using a tool called *Ecological Footprinting**, which provides a snapshot of human ecological impact under given circumstances, it is possible to throw some light on this question.

(* Ecological footprinting data given in this paper have been taken from Global Footprinting Network research published in the **WWF Living Planet Report 2006**, using 2003 data.)

A sustainable population for Earth

1. Assuming the global biocapacity and average footprint [F1] remain stable at the 2003 level, then, to become sustainable, the world population needs to contract to a maximum of **5.1 billion**.
2. For a 'modest' world footprint of 3.3 gha/cap (without allowances for biodiversity or change of biocapacity), the sustainable population is **3.4 billion**.

3. For a 'modest' world footprint of 3.3 gha/cap, plus a 12% allowance for biodiversity (but none for attrition of biocapacity), the sustainable population is **3.0 billion**.
4. For a 'modest' world footprint of 3.3 gha/cap, plus a 20% margin for biodiversity and attrition of biocapacity then the sustainable population is **2.7 billion**.

A sustainable population for the UK

1. Assuming the UK's biocapacity and the average footprint of 5.6 gha/cap remains stable at the 2003 level, then the sustainable UK population is **17 million**.
2. If the UK achieves its carbon footprint reduction target of 60% by 2050, then, all else being equal, the resulting footprint of 3.7 gha/cap, with no allowance for biodiversity or change of biocapacity, will sustain a population of **27 million**.
3. Assuming the UK reaches its carbon footprint reduction target of 60% (by 2050), then, the resulting Footprint of 3.7 gha/cap, coupled with a 12% allowance for biodiversity, will sustain a population of **24 million**.
4. Assuming the UK reaches its carbon footprint reduction target of 60% by 2050, then the resulting Footprint of 3.7 gha/cap, coupled with a 20% combined allowance for biodiversity and attrition of biocapacity, will sustain a population of **21 million**.

Readers not familiar with such terms as *global hectares*, *biocapacity* and *footprint* will find these in [Appendix 1](#).

Introduction

This briefing deals with assessing *sustainable* and *optimum* populations. It differentiates between the terms sustainable and optimum.

The main difference is that here we take *sustainable* to mean the maximum sustainable values of populations in simple calculational terms and which are often used in such discussions. This is dealt with in the first part of this briefing.

Optimum, on the other hand, goes on develop a more realistic set of numbers to explore and include margins for unknowable but assessable future events. This is dealt with as a stand-alone section in Part II.

This briefing is not meant to be the last word on the subject, but is written to stimulate discussion and to underline that determining future populations (if major population crashes are to be avoided) whilst not rocket science, is neither simple nor straightforward. It also implies that there is no time to be wasted in getting things moving in the right direction since, whichever figures we use in a given circumstance, there is no escaping the fact that world population — as the sum of the parts of all nations' populations — must halt its growth and turn negative as soon as possible. Every day wasted makes the task more difficult and potentially impossible without increasing human suffering.

Part I

Background

Given OPT's definition of a sustainable population, it follows that a government or other body elected to protect, administer and ensure the long term good of such a population has the duty to take all steps necessary to bring about its sustainability [F2] .

It follows further that the maximum size of a population depends on the availability of renewable energy resources, as well as the consumption of energy needed to maintain a minimum acceptable lifestyle.

Sustainability has become an increasingly important issue over the last two or three decades. It has progressed from an esoteric subject within a few scientific and sociological communities to mainstream national and international political agendas and debates. Such interest has been triggered by:

i.   the continuing rapid growth of populations during the 20th century and beyond;
ii.   the increasing rate of pollution of the land and waters of the earth through excessive and ever-rapid exploitation of the world's biological and geological assets;
iii. the now-generally-accepted view that global warming — and thus climate change — is a direct result of human activity, and threatens the future of the human race and other species;
iv.   the growing realisation that collective human consumption has:
      a. exceeded the renewable resources available to it and that the human race is, as a result, in [F3] danger of a catastrophic collapse;
      b. by its sheer magnitude caused irreversible damage to many ecosystems and other species.

Although not generally accepted, OPT considers that it is indisputable that ii, iii, iv are all a direct consequence of i.

It is a logical conclusion from the above that the world population should not consume, in a year, more of the renewable resources than the planet can create (*biocapacity*) and data for this parameter is available for the period 1961 until 2003 from the Global Footprint Network.

Interrelationship between sustainable population and ecological footprint
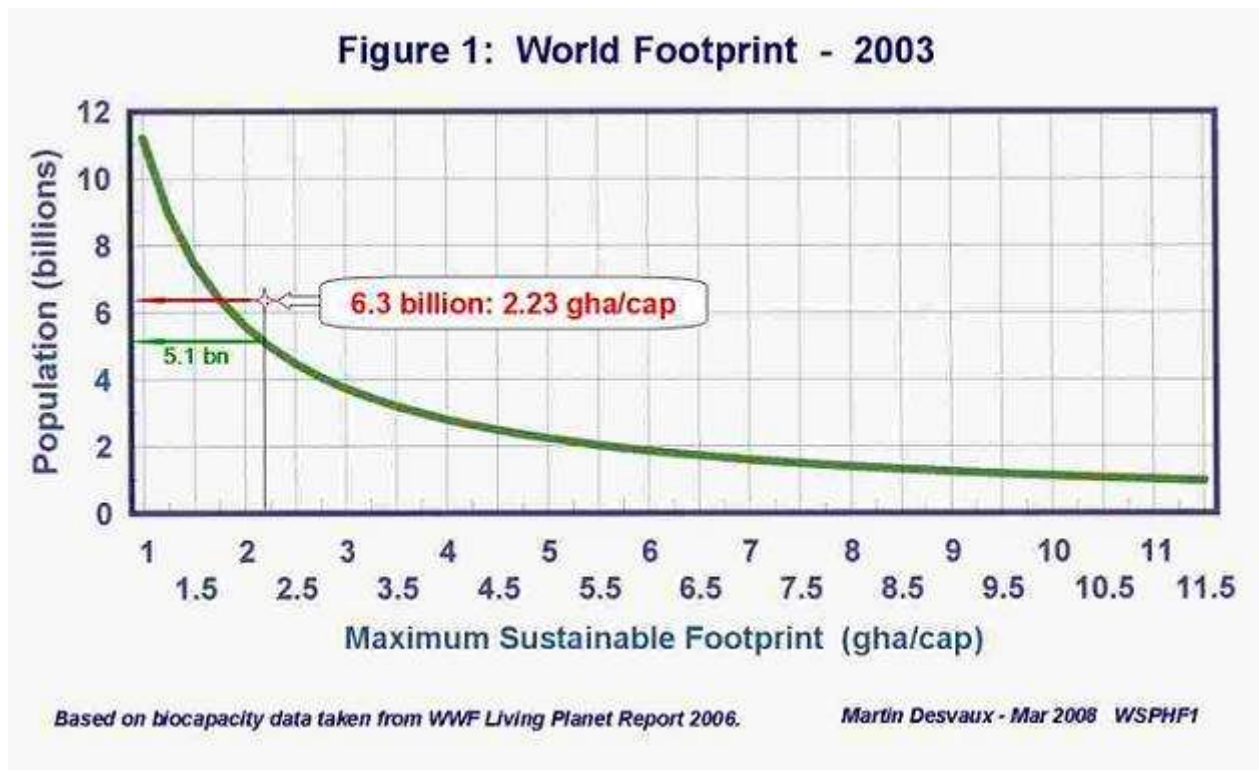
The following considerations apply generally to any isolated population - that is, one that cannot import, or control the supply of, resources outside its domain.

When the total consumption of a population is less than the available biocapacity, then that population is sustainable; any increase in its size can be accommodated without invoking a reduction in the per capita consumption (footprint). When total consumption exceeds biocapacity, then any increase in population means that average per capita consumption must reduce. The maximum average amount each person can consume depends purely on the size of the population and is expressed mathematically by the relationship:

Maximum per capita footprint × size of sustainable population = biocapacity of the earth

The equation is represented as an hyperbola (Figure 1) in # which the world population appears on the vertical axis and the per capita consumption on the horizontal axis (in global

hectares per person [F4] . The green curve, therefore, represents the relationship between a population and its ***maximum*** *sustainable* footprint. The data point for 2003 lies above the curve, indicating the the population was already unsustainable then. **It demonstrates that the sustainable population for the 2003 footprint of 2.23 gha/cap was 5.1 billion**.

Figure 1: World Footprint - 2003

6.3 billion: 2.23 gha/cap

5.1 bn

Maximum Sustainable Footprint (gha/cap)

Based on biocapacity data taken from WWF Living Planet Report 2006.   Martin Desvaux - Mar 2008   WSPHF1

Nevertheless, it is possible for a population to live unsustainably (above the maximum) for a relatively short period; it can use energy resources by cutting down trees faster than they grow or by using energy stored from much earlier biological activity (fossil fuels) to make up the shortfall [F5] . When such stored resources run out, then the population will have only three options to fall back on:

a. to increase the earth's biocapacity
b. to reduce its per capita consumption, or
c. to reduce its own size.

Since a is not possible in the long term — indeed the reverse is predicted to occur [F6] — then steps must be taken to implement b and/or c.

What is the future sustainable population for the earth?

The *sustainable population* is, in mathematical terms, a dependent variable — which is why it is represented on the vertical axis of the graph. The independent variables on which it depends are *biocapacity* and *footprint* (rate of consumption). Increase the footprint — and/or decrease biocapacity — and the maximum sustainable population decreases — and vice-versa.

It is clearly neither moral nor desirable to instantly reduce today's world population of 6.7 billion to a sustainable level of 5.1 billion by, for example, dispatching 24% of each country's population. It is, therefore, not helpful to discuss sustainable populations in *today's terms*. Assumptions need be made about conditions expected to exist when the sustainable level is

deemed to be achieved. Thus, Earth's sustainable population in (say) 2050 will depend on how much world population will be consuming each year *at that time*. This is not an *a priori* definable quantity, since the global biocapacity, collective consumption, expectations and behaviour of individual countries and social groups in response to changes in the environment will all vary over time. Thus managing population decline is like trying to hit a moving target.

The future maximum *sustainable population* of the planet is only definable subject to qualifying statements regarding the projected global biocapacity and footprint of its human occupants.

At this point, *choices* enter the discussion. Do we aim to reduce a) the footprint, b) the population or c) some combination of the two? Let us consider these in turn. To keep matters simple we shall assume, in what follows that biocapacity remains constant.

Footprint reduction

The global footprint is an average of a wide range of values ranging from 0.65 gha/cap (Afghanistan), through 4.8 gha/cap (Europe) and 9.6 gha/cap (USA), up to 10.2 gha/cap (United Arab Republic) [F7] . According to the GFN, the 956 million population of the high-income countries have a footprint of 6.4 gha/cap which is eight times higher than that of the 2.3 billion inhabitants of the lowest-income countries (footprint = 0.8gha/cap.) An estimate by Andrew Ferguson, Editor of the **OPT Journal,** is that if the 956 million people in the developed world cut their footprint by two-thirds, it would still not balance the effect of the lowest-income 2.3 billion increasing their footprint by half of the per capita cut in the developed world [F8] .

Population reduction

Based on GFN data, a maximum sustainable population in 2003 would have been 5.1 billion — assuming that one could live with the fact that around half the world's people were malnourished and about 800 million were hungry. Since then, the population has risen a further 6.6% to 6.7 billion by 2008. If the biocapacity has not changed during the intervening four years, then the population now needs to reduce by [6.7 - 5.1 =] 1.6 billion to revert to sustainability — a decrease of 24%. In such a scenario, the assumptions are: the average footprint remains constant; any increase in one country's wealth is funded by another's further decline into poverty. Although the history of humankind shows this has often been the case, in a civilised world it is no longer an acceptable policy.

We therefore have a benchmark:

On the assumption that the world's biocapacity and human footprint since 2003 remains constant, the sustainable world population is 5.1 billion.

Of course, this benchmark means that we either leave the distribution of wealth (or poverty — which ever way one wishes to regard it) as it is, or adopt a 'Robin Hood' strategy; funding the enrichment of the poor nations by reducing the footprint of the wealthy ones. Indeed, international aid programmes are a partial manifestation of this. Apart from aid, such convergence has a certain amount of mileage in it, since there is an enormous amount of waste in the high-income nations. For example, it would be quite possible to reduce individual footprints by at least 20% in the UK, just by making basic common sense energy savings and by changing careless habits. The government target is to reduce the carbon component of the

UK Footprint by 60% by 2050 (which would, if successful, reduce the overall Footprint by 33%.)

Thus, a 20% drop in the average world footprint of the 956 million people in higher-income countries would enable the 2.5 billion people in lower-income countries to increase their footprint by 62.5% from 0.8 to 1.3 gha/cap while simultaneously reducing the global population by 33% (to 5.1 billion) as outlined earlier. This illustrates the swings and roundabouts of '*contraction and convergence*'. The trap in this argument is, of course, that it requires the middle income countries to maintain a constant footprint of 1.9 gha/cap — not likely to happen.

A further issue is that it assumes a constant world biocapacity. This appears to be out of touch with reality for the following reasons:

- significant land loss is occurring as a consequence rising sea levels, desertification, general soil erosion and exhaustion;
- ground water levels are falling dramatically in many countries as demand grows with affluence and population increase. China and India are recent cases in point.
- Greenland, and other lands in the higher northern latitudes, may increase available hectareage as ice melts, due to global warming: such additional land area will make little impact on global biocapacity since that land will be relatively unproductive because of low average daylight and temperatures.
- climate change, as a result of global warming, is more likely to ruin more crops and forests through droughts, fires, storms and floods than by improving more favourable conditions elsewhere.
- attempts of countries to take measures to protect against such disasters will only increase — not reduce — their footprints since such major efforts expend significant quantities of CO_2.
- as our legacy of oil, gas and coal runs down during the 21st century, attempts to compensate for reduced availability of derived fertilisers as well as heating and transport energy by replacing these with biomass and biofuels will only reduce the land available to grow food. This process has already begun — as has the realisation, in many quarters, that it is not such an attractive idea.

Consequences of simultaneous reduction of population and footprint.

The considerations in the last section suggest that a reduction in the population to 2003 levels will not produce *sustainable population-resource equilibrium* since it ignores all the known trends of global resources in the forseeable future.

If we assume initially that the world will, in some unforeseen way, retain a constant biocapacity and that, in the longer-term, an average footprint of 4.6 gha/cap (similar to that of Europe today) would be both acceptable and achievable, then a sustainable population would be around 2.4 billion — roughly one third of the current level.

Alternatively, scenarios have been suggested by Ferguson [F9] :

i. If a 'Modest Footprint' of 3.3 gha/cap were adopted on the basis of reducing the 2003 carbon component of the footprint by 60%, then (with no allowances for biodiversity) a population of 3.4 billion could be sustainable.

ii. With a 12% allowance for biodiversity, the sustainable population figure drops to 3 billion.

Since those two numbers ignore any allowance for the attrition of global biocapacity, then they must both be considered optimistic, especially as there will be a delay in implementing any reduction in population. The level of attrition cannot be predicted with any accuracy at the moment, so the choice of 3 billion has something to be recommended since:

1. It sets an alarming (if inadequate) target *pro tem* and therefore conveys the urgency as well as the magnitude of the risk that the human race faces.
2. It incorporates a 12% allowance for biodiversity which can act as a temporary buffer against optimists until we see the way the wind is blowing on the attrition front.
3. At a trivial level it is a nice round number!

Another option is to make a compound allowance of 20% for biodiversity *and* attrition of currently productive land (or indeed for inertia in getting the whole policy moving in the right direction) and quote 2.8 billion as the target population.

Therefore any of the following statements would appear to provide a good starting point:

1. *Assuming the global biocapacity and average footprint remain stable at the 2003 level, then, to become sustainable, the world population needs to contract to a maximum of 5.1 billion.*
2. *For a 'modest' world footprint of 3.3 gha/cap (without allowances for biodiversity or change of biocapacity), the sustainable population is 3.4 billion.*
3. *For a 'modest' world footprint of 3.3 gha/cap, plus a 12% allowance for biodiversity (but none for attrition of biocapacity), the sustainable population is 3.0 billion.*
4. *For a 'modest' world footprint l of 3.3 gha/cap, plus a 20% margin for biodiversity and attrition of biocapacity then the sustainable population is 2.7 billion.*
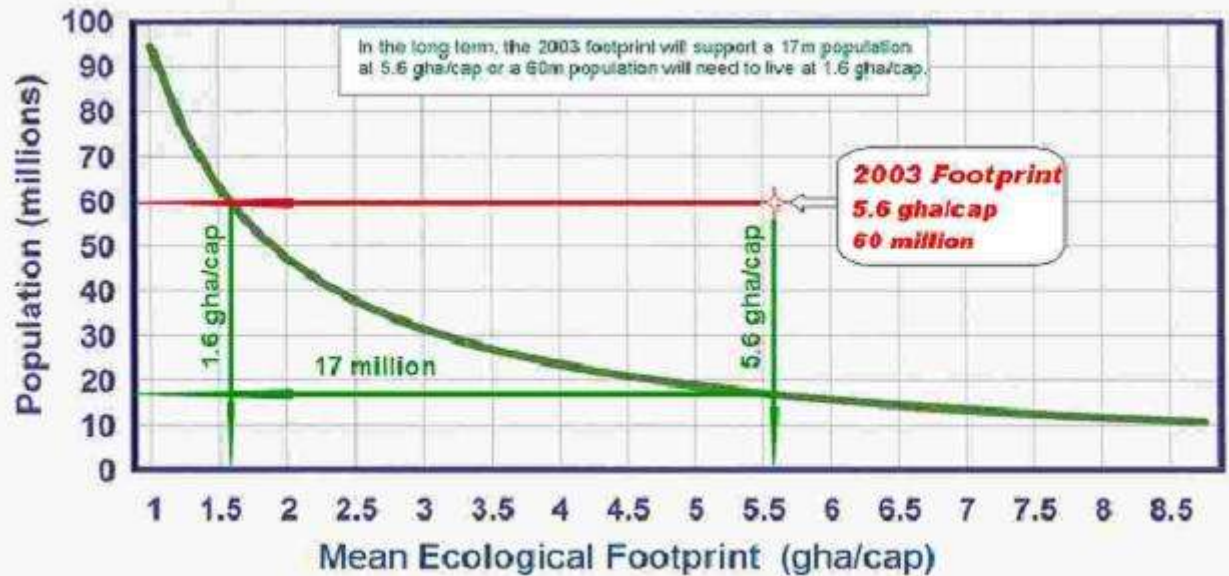
It could, and will, be argued that new initiatives (such as GM crops) will yield higher future biocapacity, but experience shows that such improvements more often than not constitute short-term gains which then wilt as the downsides appear. In the case of GM crops, the higher productivity will eventually be overwhelmed by loss of fertilisers through declining fossil fuel supplies; lack of water; attrition of arable lands; soil erosion and desertification. Land needs to rest and have time to recover, especially when natural fertilisers are used. Whipping it on to greater and greater productivity will only bring about its eventual and probably sudden collapse.

Sustainable populations for the UK

The UK population as a microcosm of the world can be treated in a similar fashion. Figure 2 shows the green sustainable population curve linking the maximum sustainable population for any given footprint and vice versa. In 2003 the UK had:

- a population of 60 million [F10] ,
- a footprint of 5.6 gha/cap
- a biocapacity of 95 million gha.

Figure 2: UK Sustainable Population - 2003

Based on biocapacity data taken from WWF Living Planet Report 2006.   Martin Desvaux - May 2007   UKSPH01F2

At this level, the sustainable population works out at 17 million without any allowances for biodiversity or attrition of biocapacity. The UK government has set a target to reduce the carbon emissions by 60% by 2050. As discussed elsewhere [11], this amounts to a reduction in the overall UK footprint to 3.7 gha/cap.

Along similar lines to the global case, this leads to the following statements:

1. *Assuming the UK's biocapacity and the average footprint of 5.6 gha/cap remains stable at the 2003 level, the maximum sustainable UK population is 17 million.*
2. *Assuming the UK can reduce its carbon footprint by 60% (by 2050), then, all else being equal, the resulting footprint of 3.7 gha/cap, with no allowance for biodiversity or change of biocapacity, will sustain a maximum population of 27 million.*
3. *Assuming the UK can reduce its carbon footprint by 60 (by 2050), then, the resulting footprint of 3.7 gha/cap, coupled with a 12% allowance for biodiversity, will sustain a population of 24 million.*
4. *Assuming the UK can reduce its carbon footprint by 60% (by 2050), then the resulting footprint of 3.7 gha/cap, coupled with a 20% combined allowance for biodiversity and attrition of biocapacity, will sustain a population of 21 million*

Part II

Optimum populations

The above treatment begs the question: "*Should we be discussing sustainable or optimum populations?*" Since OPT's name implies optimum, this should be addressed.

To start with, the set of sustainable populations comprises those at, or below, the limit of sustainability. Consider, as just one example, the statement taken from point 2 under **Population reduction**:

"For a 'modest' world footprint of 3.3 gha/cap (without allowances for biodiversity or change of biocapacity), the sustainable population is 3.4 billion."

On the assumptions stated, the *sustainable* population is any number up to and including the maximum value 3.4 billion. But where is the *optimum* value within that range?

The New Shorter Oxford Dictionary defines 'optimum' as the *'conditions most favourable for growth or some vital process ... the level regarded as most favourable'*. From the latter part of the definition we can infer that the maximum sustainable population is not the optimum. Considered rigorously, if a population is at maximum sustainable level, then one more birth without a corresponding death tips it into unsustainability, just as a single drop of water added to a brim-full glass will cause overflow — on a different time-scale, of course.

An optimum population level clearly needs to provide margin for fluctuations. In practical terms, it will never be feasible, nor desirable, to control the world population precisely. It seems reasonable therefore that, in a real future world with a) no cache of fossil fuels to draw upon and b) therefore entirely reliant on solar energy transmuting into food and other energy forms on an annual basis, a margin of error be considered.

Furthermore, the biocapacity of the planet will vary from year to year, just as the crops in any given country do today. Prudence dictates that a world population living (theoretically) in peace and free of natural disasters (considered in Appendix II) should store enough resources in each year of surplus to provide for the inevitable lean years.

Since, for a sustainable world

$$maximum\ population = \frac{total\ biocapacity}{per\ capita\ Footprint}$$

then, for a given *per capita footprint*, a 10% *population* margin implies a 10% total *biocapacity margin* (see **Appendix II**).

Therefore, based on the above illustration, to be sustainable we would need to produce 10% more food and other energy resources than are needed for a given year which, put another way, simply means that the world population should be 10% less than the number needed to consume the current world biocapacity. This, therefore, could define an *optimum population* — a number which takes into account the components of the catch-all margin or error. Work needs to be done (a good project for a team of PhD students) to evaluate or otherwise more carefully assess the contingencies that make up such a margin. Appendix II elucidates a little further. But subject to that more rigorous assessment OPT, when pressed, quotes a 10-15 % lower value for converting all the maximum sustainable populations statements made above into optimum populations. The example at the start of this section then reads:

"For a 'modest' world footprint of 3.3 gha/cap (without allowances for biodiversity or change of biocapacity), the maximum sustainable population is 3.4 billion; the optimum population would be around 3 billion."

Therefore to convert all statements on sustainable populations to ones on optimum populations requires only to divide the value of the '*maximum sustainable population*' by, say 1.1.

Conclusion

The above demonstrates OPT thinking on sustainable populations and the values give a starting point for future population policies for the world in general and the UK in particular. Such a methodology can be applied to any country. But, because such values of maximum sustainable populations are based on time-dependent assumptions, it will be necessary to reappraise them from time to time.

See also Sustainable numbers: Ecological footprinting.

FOOTNOTES

1. 'Ecological footprint' will be referred to as 'Footprint' throughout.
2. Conversely, failure to do so renders such a government in default of its social and economic responsibilities.
3. i.e. within the next several decades.
4. A global hectare is the total biological production of the earth divided by the global land area.
5. In the case of Earth, such resources are in the form of coal, oil and gas which accumulated over 200 million years.
6. WWF Living Planet Report 2006: At current rates of population increase and consumption (i.e. business as usual) biocapacity will remain within ± 2% remain the same for 20 years and then go into gradual decline.
7. WWF Living Planet Report 2006.
8. A 2/3 reduction in footprint of 1 billion in the developed world equates to $2/3 \times 6.4 \times 10^9 = 4.8 \times 10^9$gha. If the 2.5 billion poorest people increase their footprint by 2.4 gha/cap (i.e. 50% of the aforementioned 4.8 gha/cap reduction), the consequent increase in footprint will be $2.5 \times 2.4 \times 10^9 = 6 \times 10^9$ gha, which is bigger by 1.2×10^9 gha and equivalent to an increase of 25%.
9. Private communication.
10. Numbers have been rounded for simplicity throughout this paper.
11. Desvaux, M.P.E (2007) **The Sustainability of Human Populations.**

Appendix I

Glossary of terms — taken from the Global Footprint Network website

Global Hectare
    A productivity weighted area used to report both the biocapacity of the earth, and the demand on biocapacity (the Ecological Footprint). The global hectare is normalized to

the area-weighted average productivity of biologically productive land and water in a given year.

Biocapacity
> The capacity (usually expressed in units of global hectares) of ecosystems to produce useful biological materials and to absorb waste materials generated by humans, using current management schemes and extraction technologies.
>
> "Useful biological materials" are defined as those used by the human economy Hence what is considered "useful" can change from year to year (e.g. use of corn (maize) stover for cellulosic ethanol production would result in corn stover becoming a useful material, and so increase the biocapacity of maize cropland). The biocapacity of an area is calculated by multiplying the actual physical area by the yield factor and the appropriate equivalence factor.

Ecological Footprint
> A measure of how much biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the waste it generates using prevailing technology and resource management practices. The Ecological Footprint is usually measured in global hectares. Because trade is global, an individual or country's footprint includes land or sea from all over in the world. Ecological Footprint is referred to here in short form as 'footprint'.

Appendix II

Components of a margin of error for optimum populations

If the mean annual food production to sustain the world population is say, *F*, and varies, *on average*, by ± *v*% then it would seem wise to store each year's *surplus* above *F* (margin for variability or *Sv*) for use in leaner years.

Purely as an example, in what follows, the value of *Sv* is assumed to be 0.05 (or 5%). Add to that an attrition factor *Sa*, to take care of expected attrition of storage through accidents; granaries can catch fire or get flooded or food degrades if stored too long. This would also include the risk of extreme climate conditions (unknown, but increasing likely with global warming) which will swing local climates into unusually long periods of low food production [F12] . Assume therefore that *Sa* is 0.1 (20% of the margin for variability, *Sv*).

In addition to variability and attrition of stores (*Sv+Sa*), a further contingency is necessary since peace and absence of natural disasters cannot be assumed. Wars [F13] cause destruction of land, from which it can take years to recover. Floods, droughts, salinisation of land, fire and rising sea levels do the same. Without the luxury of fossil fuels to featherbed and insulate humanity against the rigours of such adversity, it will not be easy to rush foreign aid around the world in just a few days. It ought to be possible, from past records, to make a realistic allowance for lost bio-product due to both these additional causes. To make such estimates is beyond the scope of this paper, but the reader might accept an illustrative figure of say 5% (or 0.05) as a margin to provide for war and natural disasters (*Swnd*). Assuming no further margins are required, the total contingency on food production would be:

$$Sv + Sa + Swnd$$

If *Sv* is assumed to be 0.05 (5%) then *Sa* is 0.01 (i.e. one-fifth of *Sv*). Further assuming *Swnd* to be 0.04 (4%) then the total contingency, or safety margin, is ~0.10 (10%).