PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B

Phil. Trans. R. Soc. B (2008) **363**, 467–475
doi:10.1098/rstb.2007.2164

Shrink and share: humanity's present and future Ecological Footprint

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Sustainability is the possibility of all people living rewarding lives within the means of nature. Despite ample recognition of the importance of achieving sustainable development, exemplified by the Rio Declaration of 1992 and the United Nations Millennium Development Goals, the global economy fails to meet the most fundamental minimum condition for sustainability—that human demand for ecosystem goods and services remains within the biosphere's total capacity. In 2002, humanity operated in a state of overshoot, demanding over 20% more biological capacity than the Earth's ecosystems could regenerate in that year. Using the Ecological Footprint as an accounting tool, we propose and discuss three possible global scenarios for the future of human demand and ecosystem supply. Bringing humanity out of overshoot and onto a potentially sustainable path will require managing the consumption of food, fibre and energy, and maintaining or increasing the productivity of natural and agricultural ecosystems.

Keywords: Ecological Footprint; sustainability; land use; future demand; ecological debt; scenarios

1. INTRODUCTION

As concern grows about the magnitude of human pressure on the biosphere, the global community is increasingly engaged in discussions about the meaning and importance of achieving global sustainability. While much of this discussion has focused on the depletion of non-renewable resources, there is increasing evidence that overuse and degradation of renewable resources pose a great risk to global society (e.g. MEA 2005). Collapsing fisheries, carbon-induced climate change, deforestation and the loss of cropland to erosion and salinization are some of the most prominent examples of challenges that threaten the ability of ecosystems to continue producing critical renewable resources and services.

The ecological accounts that measure overall human demand on the biosphere and the ability of the biosphere to meet these demands show quantitatively that human society is currently operating in a state of overshoot, with demand on ecosystems exceeding ecosystem supply (Wackernagel *et al.* 2002). To achieve sustainability before this overshoot causes potentially irreversible declines in the productivity of critical ecosystems, society will need to meet the dual challenges of shrinking global demand and sharing this reduction in a way that is acceptable and viable for the entire global community. As one of the largest-scale human land-use activities impacting ecosystems, agricultural practices will play a particularly critical role in meeting these dual goals.

This paper begins by examining the extent to which the global economy currently operates within the means of the biosphere, using the Ecological Footprint as an accounting tool. A formal definition of a shrink-and-share concept for bringing global society out of overshoot will then be presented. Implications will be illustrated by examining one potential path that would increase the gap between human demand and ecosystem supply and two that would close it. Different strategies for sharing this reduction in global demand are discussed along with the specific role that agriculture and agricultural systems play in sustainability.

2. OVERSHOOT AND THE NEED FOR GLOBAL SUSTAINABILITY

(a) *Ecological Footprint accounting*

Ecological Footprint accounting provides a comprehensive method for evaluating whether human populations meet a minimum condition for sustainability, namely that humanity's demands on the biosphere remain within the biosphere's regenerative capacity (Monfreda *et al.* 2004; WWF 2004; Wackernagel *et al.* 2005). Footprint accounts document the extent to which human society stays within or exceeds the regenerative capacity of the planet. This type of biophysical resource accounting is possible because resources and waste flows can be tracked and associated with the amount of ecological capacity they require (Wackernagel *et al.* 2002).

An Ecological Footprint measures the area of biologically productive land and water that a population (an individual, a city, a country or all of

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One contribution of 16 to a Theme Issue 'Sustainable agriculture I'.

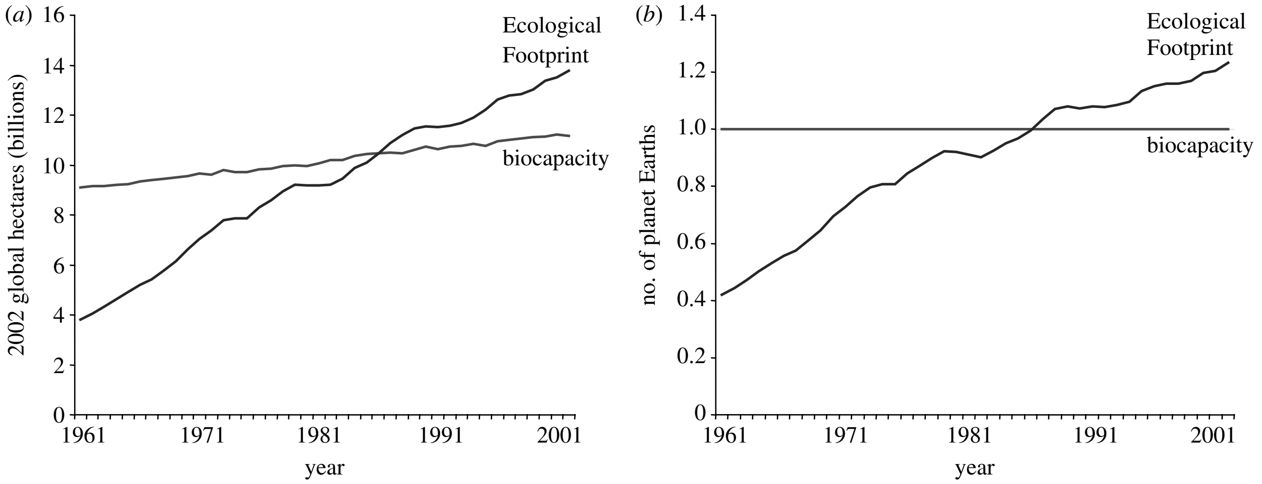

Figure 1. Humanity's global footprint: although the ecological capacity of the planet has increased over time due to changes in technology and management, human demand has grown faster, from half of the biosphere's total capacity in 1961 to 123% of its capacity in 2002. In the long term, this overshoot leads to the degradation and liquidation of ecological capital. Overshoot is depicted in: (*a*) units of 2002 global hectares and (*b*) as the ratio of global Ecological Footprint to available biocapacity.

humanity) uses to generate the resources it consumes and absorb its wastes under prevailing technology. At scales smaller than the world as a whole, a Footprint measures the resources associated with the final consumption activities of that population (e.g. national Footprints include the consumption of products that are imported from other nations and exclude products produced within the country, which are later exported).

Footprints can be divided into six major categories of demand: cropland; grazing land; fishing grounds; forest land; carbon-absorption land; and built-up area. Carbon-absorption land represents the amount of biologically productive land, currently calculated as forest, required to absorb carbon dioxide from combustion of fossil fuels, less the amount absorbed by the oceans.

A population's Ecological Footprint can be compared with available biocapacity, the amount of biologically productive area available to that population within a defined geographical area (a region, country or the globe as a whole). Similar to Footprint, biocapacity is divided into five major categories of biologically productive surface: cropland; grazing land; fishing grounds; forest land; and built-up area.

Biologically productive area is defined anthropocentrically as land and sea that are able to provide ecological resources and services used by humanity, rather than in terms of net primary productivity or other strictly biological metrics. Arid regions, open oceans, the cryosphere and other low-productive surfaces are thus excluded from this definition. Approximately one-quarter of the Earth's surface, just over 11 billion hectares, comprises the total global biocapacity.

Footprint, or human demand, and biocapacity, or ecosystem supply, are here measured and reported in units of '2002 global hectares', hectares with the productivity of one world average biologically productive hectare in 2002, the most recent year for which data are available (Kitzes *et al.* 2007).

(b) *Global overshoot*

The 2005 edition of national and global Ecological Footprint accounts shows that, at a global scale, humanity is currently operating in a state of overshoot, with demand on the biosphere exceeding the biosphere's regenerative capacity by approximately 23% in 2002 (figure 1; EEA 2005). This indicates that in 2002, humanity used the equivalent of the yearly production of one and one-quarter planet Earth's surface. Stated another way, it took the biosphere 1 year and three months to regenerate the capacity used by humanity in the year 2002. This represents a dramatic increase from 1961, when humanity demanded only one-half of the biosphere's total capacity. Humanity entered into global overshoot in the mid 1980s, and the demand has been growing faster than increases in biocapacity (the measured increase in biocapacity largely reflects increased productivity of cropland over this time period). In 2002, the most significant portion of humanity's total Ecological Footprint was the carbon Footprint, which has grown more than 700% since 1961.

Overshoot is possible for a short time, as resources can be harvested faster than they regenerate (e.g. deforestation) and wastes can accumulate (e.g. atmospheric carbon dioxide). If continued for too long, however, overshoot inevitably leads to the degradation and liquidation of ecological capital, the productive foundation on which the natural environment and human society depend.

(c) *Ecological Footprint of regions*

The Footprint and biocapacity story becomes considerably more varied at the level of regions (figure 2). Residents of North America and Western Europe, for example, live at levels of ecological demand that exceed the biocapacity available within those geographical areas. If everyone in the world had an Ecological Footprint equivalent to that of the typical North American or Western European, global society would overshoot the planet's biocapacity three- to fivefold. Eastern Europe lives within the biocapacity available in that region, but with a level of consumption that cannot be sustainably adopted at a global scale. The Asia-Pacific region lives beyond the biocapacity available within its borders, but with an Ecological

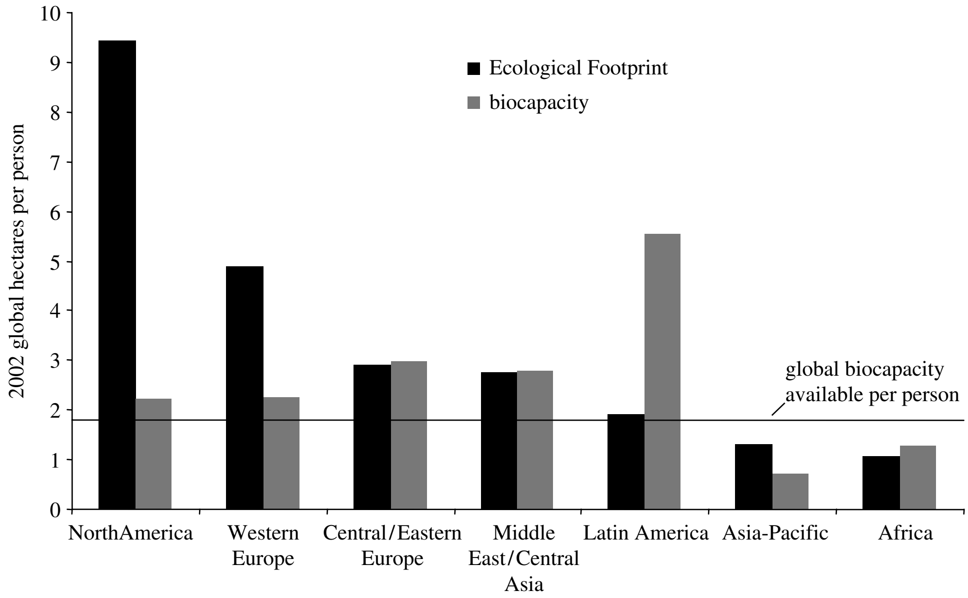

Figure 2. Per-person Ecological Footprint and biocapacity of world regions in 2002.

Footprint that would not cause overshoot if extended globally. Residents of Africa, on average, use less than the biocapacity available per person either regionally or globally.

At a regional scale, the Ecological Footprint reflects both the consumption of ecological capital within that region and flows of biocapacity between nations (table 1). Western Europe and Asia-Pacific, for example, are major net importers of biocapacity. North America and Latin America, conversely, are largely net exporters.

3. DEFINING ‘SHRINK AND SHARE’

(a) *Contraction and convergence*

The current state of global overshoot highlights the need for analysis and strategy to bring the human economy within the limits of the biosphere. Similar concerns about global emissions of carbon dioxide have led to a conceptual framework for reducing these emissions known as ‘contraction and convergence’. First described by the Global Commons Institute (Meyer 2000), contraction and convergence proposes a framework for stabilizing atmospheric carbon dioxide concentrations through two complementary approaches:

- *Contraction*. The need to reduce humanity’s carbon dioxide emissions to a level that will result in the eventual stabilization of atmospheric carbon dioxide at an agreed-upon level (e.g. 550 ppm).
- *Convergence*. The need to collectively negotiate how this reduction in greenhouse gas emissions will be allocated between nations.

Since its initial debut, the contraction and convergence framework has gained increasing recognition and sponsorship from decision makers, particularly in Europe. Influential organizations such as the European Parliament have passed resolutions using contraction and convergence as a basic principle (e.g. European Parliament 1998).

Table 1. Net trade in cropland, grazing land and marine area between regions. (Positive values indicate net exports, while negative values indicate net imports. All figures are in millions of 2002 global hectares.)

	cropland	grazing land	fishing grounds	total
Middle East/Central Asia	15	−7	15	23
Central/Eastern Europe	9	4	−11	2
Africa	−42	−1	1	−42
Latin America	54	21	41	116
North America	204	8	−6	206
Western Europe	−45	−9	−59	−113
Asia-Pacific	−165	22	−68	−211

Contraction and convergence, as originally conceived, focuses exclusively on the need to reduce global emissions of carbon dioxide and proposes only a single allocation scheme for convergence—an equal allocation of emission rights to each person on Earth. While climate change is a central and important sustainability challenge, the scope and scale of human impacts on the biosphere are larger than emissions of greenhouse gasses alone, as evidenced by ongoing and increasing pressures on cropland, forest land, fisheries and biodiversity. Additionally, there are likely to be tradeoffs between different types of pressure on the biosphere that must be considered, such as increasing demand for cropland to produce biofuels in order to alleviate pressures of carbon dioxide emissions from fossil fuel combustion. An additional, more comprehensive framework is therefore needed to fully address the broader sustainability challenge and measure progress towards reducing the material and energetic throughput of the human economy to a level that can be supported by the biosphere.

(b) *Towards shrink and share*

Expanding the contraction and convergence framework to include the larger scope of ecological demands measured by the Ecological Footprint gives a more comprehensive picture of the changes needed to meet the global sustainability challenge. This expanded approach is referred to as 'shrink and share'. *Shrink* means reducing Ecological Footprints, so that consumption of renewable resources does not exceed the regenerative capacity of Earth's productive ecosystems. *Share* refers to the way the Earth's biologically productive capacity is divided among individuals, nations or regions.

The need for shrinking is evidenced by the current state of global overshoot. Sharing implies that some regions or nations will need to reduce their Footprints, but does not preclude the possibility that others may need to *increase* their Footprints if their residents are to have rewarding lives with basic material standards. To remain within the global ecological budget on a limited planet and avoid the long-term depletion of ecological capital, increases in demand in some regions will need to be offset by the corresponding reductions elsewhere.

4. FUTURE PATHS

(a) *Three scenarios*

Figures 3 and 4 describe three possible Ecological Footprint and biocapacity paths that the global community might follow from today through to 2100: 'business-as-usual'; 'slow shift'; and 'rapid reduction'. The business-as-usual path is constructed using moderate consumption scenarios from the Intergovernmental Panel on Climate Change (IPCC) and United Nations Food and Agriculture Organization (FAO; IPCC 2000; FAO 2003; UNDESA 2003*a*,*b*). This path assumes that, in addition to increases in demand, improvements in technology and resource management will slowly increase total global bioproductivity at a rate similar to that of the last decade. In this scenario, humanity would consume approximately twice the biological capacity of planet Earth by 2050, the year in which many of the IPCC and FAO scenarios end.

The slow-shift path depicts a scenario in which changes in consumption and biocapacity achieve a steady phase-down of overshoot, levelling out at a 90% demand on global biocapacity by the year 2100. The rapid-reduction scenario shows the global economy coming out of overshoot before the year 2050 to meet a final target where humanity's Footprint occupies 70% of global biocapacity.

The final target of 90% occupation of global biocapacity selected for the slow-shift path follows the widely used target of reserving 10% of each biome on the Earth's surface as a protected area for biodiversity conservation. This target dates back to the 1982 World Park's Congress in Bali and was first proposed by Myers (1979). This 10%, or sometimes 12%, target is based largely on political considerations rather than any criteria from conservation science (Svancara *et al.* 2005). For the rapid-reduction scenario, a target set-aside of 30% of global biocapacity was selected based on conservation planning assessments and research finding that approximately 30–40% of a given area should be protected in order to ensure the long-term protection of biodiversity (Svancara *et al.* 2005).

These targets are intended to ensure the protection of all biomes or habitat types, not just those in the most easily designated areas. Currently, areas in high latitudes and mountainous regions are over-represented among the world's protected areas, although these areas tend to have lower biodiversity. Representativeness is an additional criterion that must therefore be met when applying these targets on a large geographical scale.

In addition to changes in Ecological Footprint, these paths also include changes in biocapacity. These biocapacity scenarios are all initially based on IPCC B1 scenarios for global biocapacity growth through 2050 (IPCC 2000). The business-as-usual path assumes that global biocapacity will follow the IPCC's B1 growth projection through 2050, an aggregate increase in ecosystem production of 8% compared with 2002. The slow-shift and rapid-reduction paths include additional biocapacity increases of 10 and 20%, respectively, over these IPCC B1 projections by 2100.

(b) *Constructing the scenarios*

The business-as-usual path shows absolute demand for cropland increasing by 60% and grazing land by 85% by 2050 (table 2; FAO 2003). Including median population growth projections suggests that *per capita* cropland consumption will increase by 11% and grazing land by 30% over this same time period. This is consistent with other United Nations FAO projections that suggest that the annual growth rate of demand for cereals, including animal feeds, will rise by 1.4% until 2015 and drop to 1.2% annually thereafter (FAO 2002). The FAO expects that this increased demand will most likely be met through the year 2030 by expanding the world's cropland area, increasing the frequency with which crops are planted (often through irrigation) and increasing crop yields (FAO 2002).

Following only moderate growth projections, this first path suggests that humanity will continue to increase its level of overshoot over the next 50 years, eventually reaching a point near 2050 where the productivity corresponding to that of two planet Earth's is demanded each year. Whether or not this level of consumption could actually be realized hinges on the ability of natural systems to remain viable and productive despite increasing human pressures. Given current trends in the degradation of ecological capital and climate change, as well as potential nonlinear ecosystem responses, this level of consumption may not be achievable in practice.

The slow-shift path shows a concerted effort to gradually bring humanity out of overshoot through both decreases in human consumption and moderate increases in the productivity of natural systems. This scenario reflects a reduction of 50% in global carbon emissions by 2100 relative to 2002, a more aggressive reduction than that called for under the Kyoto Protocol targets. The total harvest of wild fish is reduced by 50% by the same year to bring total wild catch down to within a sustainable level (Roughgarden & Smith 1996). Demand on cropland and grazing land increases by 25%, half the rate of population increase, while demand for forest products is allowed to increase by

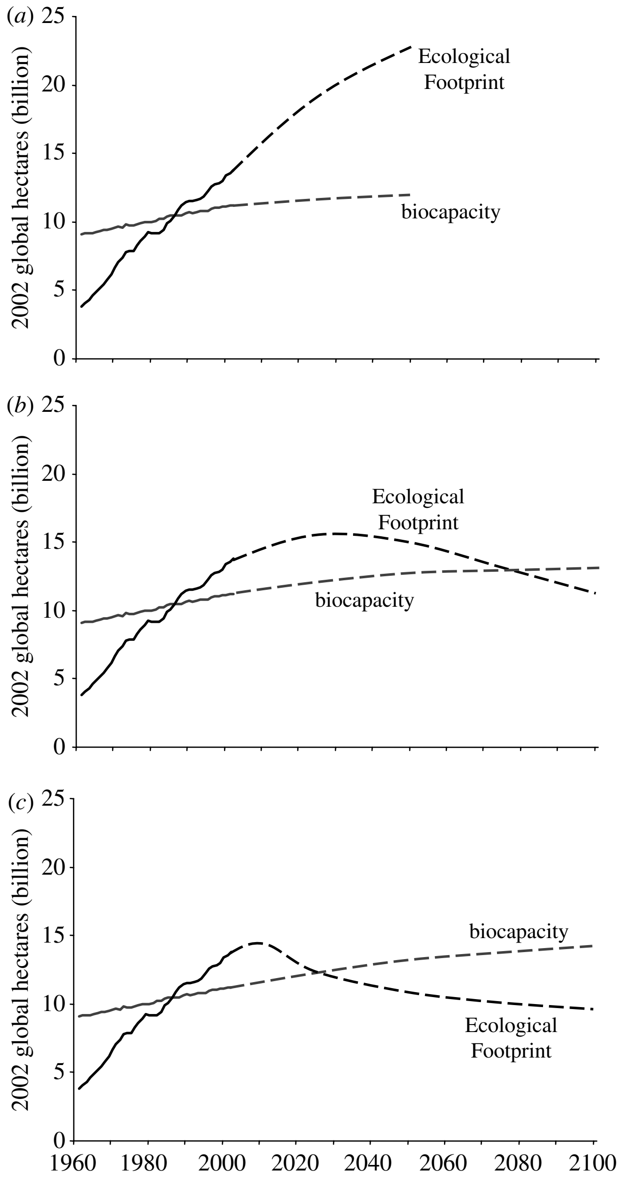

Figure 3. Three paths to the future: (*a*) the business-as-usual path here is based on projections for carbon emissions and resource demand through to 2050 from the IPCC and FAO. (*b*) The policy-driven path is intended to bring humanity out of overshoot and achieve a level of 90% use of global biological capacity by 2100. (*c*) The conservation-based path brings humanity out of overshoot before 2050 and stabilizes at a 70% use of global capacity.

50% to compensate for possible reductions in the availability of fuel, as well as oil-based synthetic products and carbon-intensive structural materials such as cement. The total extent of urban land increases by 25%. Under moderate scenarios of population growth, however, decreases in average per-person consumption will be required even for those land types for which total demand increases.

The rapid-reduction path reflects an immediate and concerted effort on the part of the global community to bring human society out of overshoot as quickly as possible. A faster reduction in carbon dioxide emissions is achieved, 50% by 2050, with a 70% reduction in place by 2100. The absolute consumption of cropland and grazing land increases only by 15% by 2100, despite the pressures of a growing population. Under median population projections, this requires a 25% decrease in per-person demand on cropland and grazing land. This will not necessarily require a 25% decrease in calories or weight of food products consumed, but can be achieved by increasing yields and reducing the proportion of global crop production that is grown for animal feed. The consumption of forest products increases by 50% by 2100, similar to the slow shift scenario, and urban land does not increase in extent.

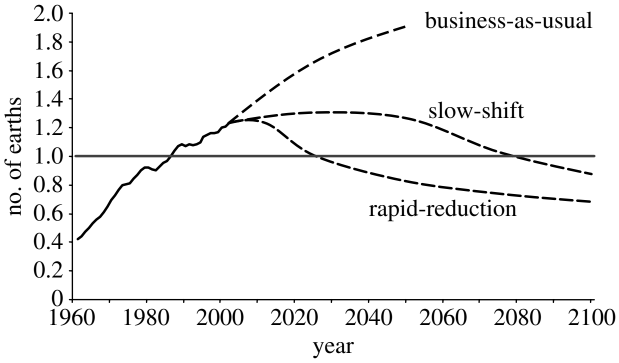

Figure 4. Overshoot scenarios: the level of overshoot associated with the business-as-usual, slow-shift and rapid-reduction paths. The grey horizontal line is drawn at one planet Earth—paths above this line show humanity operating in a state of overshoot.

Biocapacity scenarios for the slow shift and rapid reduction paths show increases in crop land, fisheries and forestry yields due to improved technology and management practices over time. For example, while wild fish populations are being harvested at an unsustainable rate, aquaculture yields (both marine and inland) could grow at rates of 5–7% a year in the short term to meet expected growth in demand for fish products worldwide (FAO 2002).

These paths all assume that no major shocks to the global economy or global biosphere occur over the next 100 years. Any number of major events, such as climate-change-induced damages, natural disasters, war, disease epidemics or sudden unplanned decreases in the availability of energy could drastically alter these paths.

5. ECOLOGICAL DEBT

One way to assess the potential risk associated with overshoot and exceeding biophysical limits is through the concept of ecological debt (Lovink *et al.* 2004; WWF 2004). Whenever the Footprint paths in figure 3 extend above available biocapacity (i.e. when demand for ecological goods and services exceeds supply), not only is the Earth's yearly biological production being consumed, but also its standing stock of ecological capital. This is similar to drawing down financial principal instead of living off the interest it generates.

Drawing down existing ecological capital creates ecological debt or the accumulated difference between the global Ecological Footprint and global biocapacity over time. This can be measured as the total area between the Ecological Footprint and biocapacity curves shown for each path in figure 3. Overshoot from the mid 1980s through to 2002 resulted in the accumulation of *ca* 2.5 planet years of ecological debt, with one planet year equal to the yearly useful

Table 2. Shrink-and-share scenarios: three paths for humanity's global Ecological Footprint and biocapacity through to 2100.

	2002	2050		2100	
	2002 gha (billions)	2002 gha (billions)	change from 2002 (%)	2002 gha (billions)	change from 2002 (%)
business-as-usual					
total Ecological Footprint	13.8	23.0	6	—	—
carbon Footprint	7.1	11.3	60	—	—
fishing grounds Footprint	0.9	1.6	85	—	—
cropland Footprint	3.0	4.8	60	—	—
grazing land Footprint	0.9	1.6	85	—	—
forest Footprint	1.4	3.0	110	—	—
urban land Footprint	0.5	0.6	20	—	—
biocapacity	11.2	12.0	8	—	—
overshoot	123%	191%	—	—	—
slow shift					
total Ecological Footprint	13.8	15.1	10	11.6	−15
carbon Footprint	7.1	7.1	0	3.5	−50
fishing grounds Footprint	0.9	0.8	−10	0.4	−50
cropland Footprint	3.0	3.6	20	3.8	25
grazing land Footprint	0.9	1.1	20	1.1	25
forest Footprint	1.4	2.0	40	2.2	50
urban land Footprint	0.5	0.6	20	0.6	25
biocapacity	11.2	12.0	18	13.4	20
overshoot	123%	120%	—	88%	—
rapid reduction					
total Ecological Footprint	13.8	11.0	−20	9.7	−30
carbon Footprint	7.1	3.5	−50	2.1	−70
fishing grounds Footprint	0.9	0.6	−30	0.4	−50
cropland Footprint	3.0	3.3	10	3.5	15
grazing land Footprint	0.9	1.0	10	1.0	15
forest Footprint	1.4	2.0	40	2.2	50
urban land Footprint	0.5	0.5	10	0.5	0
biocapacity	11.2	14.3	28	14.5	30
overshoot	123%	83%	—	68%	—

bioproduction of the global biosphere. This figure indicates that, if all human demand on the biosphere were to cease today, the Earth would take at least 2.5 years to bring ecological capital back up to pre-overshoot levels. This debt will continue to build until humanity reduces its demand below what the planet can produce each year. The moderate business-as-usual path shown in figure 3 shows the planet accumulating an ecological debt of *ca* 30–40 planet years by 2050.

Ecological debt can be loosely used as an indicator of the risk accrued by continuing to operate in a state of overshoot. A healthy forest, for example, can harbour a standing stock of timber perhaps 50 times the maximum annual bioproduction of this ecosystem. An entire planet Earth covered with forest would thus have an accumulated ecological stock of *ca* 50 years. This planet could then tolerate a maximum of 50 planet years of ecological debt before the entire resource base was exhausted and would need to be restarted. Since forests have one of the largest standing stocks of useful resources of any bioproductive land type, a planet that includes cropland, pasture and fishing grounds has less stock available for human consumption and could therefore tolerate fewer planet years of ecological debt.

A critical research and policy question will be evaluating the number of planet years of ecological debt that the planet's existing ecosystems can withstand. As ecological debt continues to accumulate, humanity runs an increasing risk of reducing ecological capital to levels at which productivity becomes so depressed that the accumulated ecological debt can only very slowly, or never, be paid back through the slow re-accumulation of ecological capital and standing stocks. An even more extreme risk is the possibility of degrading ecological capital past important tipping points beyond which the capital stock will collapse entirely. Thus, although the moderate business-as-usual path may be seen today as politically the most conservative, it may be the most ecologically radical option and the riskiest path for the global community in terms of both ecosystem stability and human welfare.

The ecological debt concept, while useful, represents only a first-order approximation of the liquidation of ecological stocks. The actual stock of ecological capital is unlikely to have been perfectly stable before overshoot began, and the rate at which ecological debt can be 'paid back' or re-accumulated may depend on the amount of productive ecological capital still remaining when humanity exits overshoot (e.g. a number of years of over-fishing is unlikely to be compensated by an identical number of years of under-fishing). Different types of ecological capital such as healthy forests, top soil or fish populations are also likely to recover from ecological debt at different rates based on the speed of regeneration of that particular component of the biosphere.

6. DIFFERENT WAYS TO 'SHARE'

If the global community agrees to shrink aggregate human demand on the environment, it will need to decide how the necessary Footprint reductions are to be shared among individuals or populations. Many allocation strategies are possible, and three examples that could be used either alone or in combination are described briefly here. Any of these strategies could be used either for a final allocation or for an initial allocation of rights or permits that could then be traded. Ecological Footprint accounting itself does not suggest that any particular strategy is best, as this is a question for policymakers and society at large. Any future policy choice will be influenced not only by ecological considerations, but also by ethical, moral and economic concerns.

(a) *Historical patterns*

Similar to the allocation framework adopted for greenhouse gases in the Kyoto Protocol, targeted reductions for national Footprints could be set relative to their current baselines. Critics of this approach might argue that it rewards countries with historically high levels of population growth and consumption and penalizes those that have already begun to take steps towards reducing their total demand on ecosystems.

(b) *Proportional to national biocapacity*

Each nation or region would be allocated a share of the global Footprint in proportion to its own domestic or regional biocapacity. This would not preclude international trade, as nations with less biocapacity than needed could trade with nations that have surplus biocapacity. Critics of this approach might argue that this strategy would need to address the currently very large discrepancies in available biocapacity between nations and regions (see figure 2).

(c) *Equal share per person*

The contraction and convergence framework suggests that rights to greenhouse gas emissions might be allocated equally to each person on the planet. A similar approach could be adopted for shrinking the global Footprint, whereby the available global biocapacity is shared on an equal *per capita* basis. As with any other allocation scheme, mechanisms could be established for nations to be able to trade their initial allocation of rights. While some consider this approach egalitarian and consistent with democratic principles such as 'one person one vote', others have argued that this approach rewards countries with larger populations (or even gives incentives for population growth), ignores historical circumstance and oversimplifies the varying development needs in different parts of the world.

Negotiating, selecting and combining these various allocation schemes will require unprecedented global dialogue and implementation efforts. Developing the logic behind global frameworks for reducing human demand, such as those proposed in this paper, is relatively straightforward when compared with the complexity and challenges of a true global negotiation process. When considering the costs and complexity of meeting this negotiation challenge, the global community must take into account not only how it can afford to undertake such a project but also the ecological and human welfare consequences of failing to do so.

7. THE ROLE OF CROPLAND AND AGRICULTURE

The challenge of satisfying the agricultural demands of the world's growing population while at the same time shrinking humanity's total Ecological Footprint to within the Earth's regenerative capacity is daunting. Agricultural responses might include increasing crop yields, maximizing the efficiency of fertilizer and water use and implementing ecologically based management and production practices (Tilman *et al.* 2002). The global community must consider carefully, however, how these demands will be met under the constraints of limited global biological capacity.

Food production on cropland, in particular, is tightly coupled to human demands on the biosphere beyond the actual land on which the food products are grown. The fertilizers, pesticides and machinery used in intensive farming systems have large carbon Footprints, and increases in cropland biocapacity may thus be tightly coupled to increases in the carbon Footprint. Decoupling the two will be a particularly difficult challenge regardless of whether the transition is consciously planned or imposed by lack of access to energy or other ecological resources. The declining availability of oil in the coming decades (e.g. USGS 2000), for example, could either decrease humanity's total Footprint by constraining available energy or conversely increase the use of more carbon- or Footprint-intensive substitutes such as coal.

Attempts to reduce other aspects of humanity's Footprint might also place new demands on agriculture. Strategies for reducing dependence on fossil fuels and shrinking humanity's carbon Footprint often consider the use of renewable energy resources such as liquid fuels derived from plant materials as alternative transportation fuels (e.g. ethanol). Ecological Footprint accounting, however, suggests that a switch from fossil fuel energy resources to biological sources may not always result in a reduction of total human demand on the biosphere, but instead simply substitute an increase in cropland Footprint for the decrease in carbon Footprint (Oliviera *et al.* 2005). A full analysis of the total ecological capacity required to support the use of both traditional and bio-based fuels would help ensure that discussions of energy sustainability are grounded in ecological reality.

In addition to increasing yields, agricultural biocapacity might also be increased through the expansion of total land areas under cultivation. Similar to substituting biofuels for fossil fuels, however, an increase in cropland biocapacity can often result in a decrease in other types of biocapacity (e.g. Houghton 1994). A well-known example is the incursion of cropland and pasture areas into tropical rainforest, with the poor forest soils often resulting in only marginal and often temporary increases in agricultural yields.

All of these considerations suggest that demands for increasing agricultural biocapacity will need to be balanced against the need to stabilize other forms of biocapacity as well as to reduce the net global Ecological Footprint.

8. CONCLUSIONS

Discussions of environmental sustainability must be grounded in sound assessments of the current state of human demand for ecosystem goods and services and the overall regenerative capacity of natural ecosystems. Global-scale Ecological Footprint accounting shows that the global economy is currently in a state of overshoot, demanding one-quarter more capacity than the biosphere can supply each year. This overshoot accumulates as ecological debt and results in the gradual liquidation of the Earth's ecological assets.

Reducing and eventually eliminating overshoot will require a complex and challenging global dialogue and, eventually, decisions on how the total human Footprint will need to shrink, and by when. Using quantitative tools such as the Ecological Footprint, targets can be set and progress measured towards reducing demand for agricultural, fisheries, forest, carbon-absorption and built-up land capacity.

A number of new research and policy needs emerge from this proposition. First, policy circles will need increasingly more robust and detailed resource accounting tools, such as Ecological Footprint accounts, to analyse aggregate human pressure on ecosystems. The serious application of these tools will require investments in the order of those currently devoted to calculating other widely used social and economic indicators.

Second, social scientists can study institutional arrangements to determine how to effectively facilitate and carry forward the global dialogue and decision-making needs described here. Economists in particular are needed to estimate how much of our global financial, human and ecological resource base will be required to shift humanity's current trajectory onto a potentially sustainable path within the biological capacity of the planet. Similar to estimates of how many dollars or how much of the world's GDP would be needed to meet the United Nations Millennium Development Goals, research is needed to identify how much capital investment would be required to redirect the global economy onto a sustainable path. Identifying strategies for achieving these goals in the most efficient and cost-effective manner will also be a critical contribution.

Third, engineers, architects and urban planners can contribute knowledge on ways to transform human infrastructure and the built environment, so that they enable a high quality of life for residents while keeping ecological demand within the available resource budget of the planet. Research and planning into ways to appropriately decelerate and eventually reverse continuing population growth will also play a key role. Considering infrastructure and human populations as stocks with slow replacement rates, bringing these two factors onto a sustainable path quickly will be particularly critical.

Fourth, ecologists, biologists, engineers and resource managers could find ways to continue to increase the Earth's biocapacity without putting further pressure on biodiversity. Energy as well as agriculture and food systems will play a particularly important role.

While these overarching issues of resource pressure are only slowly becoming a major priority on the world stage, continuously increasing ecological pressures will almost certainly make management of demand on and supply of biological capacity one of the central concerns of this century. Science, technology and innovation will play an ever more important role in helping humanity address the most important global challenge of the twenty-first century—finding ways for the global community to achieve high-quality lives on our one planet Earth.

The authors thank Josh Kearns, Brooking Gatewood, Michael Murray, Martin Kärcher, Gary Gibson, James Espinas, Nina Bohlen and Susan Burns of Global Footprint Network, Steven Lovink of Planet 2025 Network and the Institute for Environmental Security, and WWF International for supporting this analysis through the Living Planet Report series.

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