REVIEW

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Securing natural capital and expanding equity to rescale civilization

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In biophysical terms, humanity has never been moving faster nor further from sustainability than it is now. Our increasing population size and per capita impacts are severely testing the ability of Earth to provide for peoples' most basic needs. Awareness of these circumstances has grown tremendously, as has the sophistication of efforts to address them. But the complexity of the challenge remains daunting. We explore prospects for transformative change in three critical areas of sustainable development: achieving a sustainable population size and securing vital natural capital, both in part through reducing inequity, and strengthening the societal leadership of academia.

"For most of the last century, economic growth was fuelled by what seemed to be a certain truth: the abundance of natural resources. We mined our way to growth. We burned our way to prosperity. We believed in consumption without consequences. Those days are gone … Over time, that model is a recipe for national disaster. It is a global suicide pact." United Nations (UN) Secretary General Ban Ki-Moon addressing The World Economic Forum, 29 January 2011.

'Sustainability' has become a remarkably popular word, now featured on over 100 million websites, yet there are huge challenges in putting it into successful practice. Dictionaries define sustainability in terms of maintaining valued qualities without interruption, weakening or loss. The most widely used form of the concept can be traced to the Brundtland Report[1], where sustainability is described as human development that "meets the needs and aspirations of the present without compromising the ability of future generations to meet their own needs." Although there has been some dissatisfaction with this definition (for example, see refs 2–4), it has moved rapidly into the mainstream. The 2005 World Summit recognized that sustainability requires reconciling environmental, social equity and economic demands—the three 'pillars' or 'Es' of sustainability, or the 'triple bottom line'[5].

Given the contention associated with fertility decisions, it is amazing to see that reductions in fertility, and hence population pressure, have actually proven tractable. Many countries have achieved rapid fertility declines, with attendant social changes in equity that could potentially be spread much more widely[6,7]. By contrast, ever-rising consumption rates are proving extremely difficult to check. One barrier is that the consumer culture of developed countries represents the "needs and aspirations" of their populations today, but rarely considers the needs and aspirations of future people. A second pernicious obstacle is the inexorable spread of the developed world's consumption patterns to developing nations as they gain wealth[8]. If consumption is not brought in line with reduced population pressure, there is little hope of major gains in sustainability.

The urgency for the Rio+20 Earth Summit concerns whether we can find ways to change our economic and social systems, such that we reduce strains on the environment, that are durable and timely; that is, before severe impairment of Earth's 'life-support systems'. In some senses, the environmental demand pillar of sustainability is non-negotiable—we cannot change the physics of climate and other laws of nature—but we can change human social and economic systems. Here we briefly sketch some essential features of conceptual thought and quantitative analysis on sustainability, and explore promising pathways for deep and lasting transformation.

The fundamentals of sustainability

Numerous approaches have been developed to estimate the numbers of people and lifestyles that can be sustained. We highlight both the founding principles of sustainability and some key ideas that have emerged more recently.

Multiplicative drivers

IPAT—which posits that society's impact (I) on Earth's life-support systems is a product of population size (P), per capita consumption ('affluence'; A), and a 'technology' factor (T) that reflects the environmental impact caused by technologies, cultural practices, and institutions through which each unit of consumption is generated—was introduced just before the first Earth Summit, convened in Stockholm in 1972[9]. It's purpose was to counter claims on the one hand that global environmental problems were the result of runaway population growth in poor countries and, on the other, that the sole problem was environmentally damaging technologies[10].

Then, and still today, although the developing world contains the majority (approximately 80%) of the global population, the impact of the developed world is far greater. Using energy consumption as a surrogate for per capita impacts, the current average impact of each inhabitant of developed countries exceeds that of inhabitants of developing countries 2–14 fold[11]. The importance of the A and T factors in reducing impacts is even greater today than it was when the concept was first presented, and has stimulated innovative research, in the social sciences for example[12].

Limits of Earth's life-support capabilities

Carrying capacity is a foundational concept for characterizing the dynamics of populations and limiting resources. A famous, early analysis of humanity's interaction with limits received harsh criticism, but recent evaluation suggests that "the values predicted by the limits-to-growth model and actual data for 2008 are very close."[13]. Similarly, although carrying capacity is difficult to measure, it is clear that the human population's size and consumption patterns are well above what Earth could support without impairment of vital life-support systems[14,15],

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exceeding "planetary boundaries"[16]. According to ecological footprint analysis, rich countries use 2–5 times their per capita equitable 'Earth shares', were the carrying capacity of the planet divided into 7 billion equal parts[17].

An interesting new development is the extent to which the business world has started to worry about the implications of resource scarcity for their own enterprises[18]. The private sector's awakening to resource limitation has created recognition that improved management of natural systems could be key to addressing resource scarcity[18]. But their interest is broader, increasingly exploring what people would like to sustain and how to reach agreement on this, constrained by estimates of what is feasible. The question is whether societies can develop a widely supported vision of the targets for rescaling, in terms of population size, prosperity, equity and risk of reducing Earth's carrying capacity.

Sustainable futures and how to get to them

Backcasting is a way of exploring alternative desired futures (for 2050, say) and then determining in fairly specific terms the 'must haves' decade by decade in order to arrive at a given future. A procedural model is the Vision 2050 effort of the World Business Council for Sustainable Development[19]. Backcasting exercises could help people, governments and corporations to recognize the values of natural capital in supporting human well-being, and more routinely incorporate protecting these values, demographics, patterns of consumption and environmental constraints into planning and decision-making. Other approaches are needed to address the multitudinous problems of global governance[20].

Buffering as a goal

Resilience is defined as the ability of a system to absorb disturbance and recover from it or withstand it while maintaining the same basic structure and functioning. Through the lens of coupled human and natural systems, declines in resilience increase the risk that societies and their supporting ecosystems will not recover from a certain magnitude shock[21]. Resilience expands attention on economic growth and efficiency to encompass flexibility and capacity for recovery from inevitable shocks[22,23].

An emerging challenge to resilience is the global connectedness of ecosystems and economies, so that shocks in one place can rapidly spread across continents and around the world. Although the banking crisis is the most dramatic example of global propagation of shocks, demand for biofuels and food is now leading to massive conversion of forests[24], including by relatively rich nations purchasing and converting vast tracts of land in poor nations[25].

Equity and justice

The distribution of wealth and power permeates social, economic and ecological thinking[6,26–29]. If the biomass of an ecosystem is concentrated in a few species, the wealth of a nation amassed in one bank, or the environmental hazard of a place directed at one subpopulation, then there is little opportunity to absorb and mitigate disasters when they come[30]. The uneven distribution of climate risk, for example, poses especially severe challenges to political and social stability, as it falls most heavily on the world's poorest nations (Fig. 1). In particular, nations with the lowest Human Development Index (HDI) tend to be nations that in the near term will face the greatest risk of climate stress from impaired agricultural production, sea level rise, and extreme weather events. The combination of enormous inequity in wealth and environmental hazard means that there will be flashpoints for ecological and human disaster.

Natural capital and ecosystem services

Earth's lands and waters and their biodiversity can be seen as a capital stock from which people derive vital ecosystem services. These include the production of goods (such as food, timber and industrial products), regulating services (such as water purification, crop pollination and coastal protection), cultural benefits (such as inspiration and recreation), and preservation of options (such as genetic diversity for future use). This

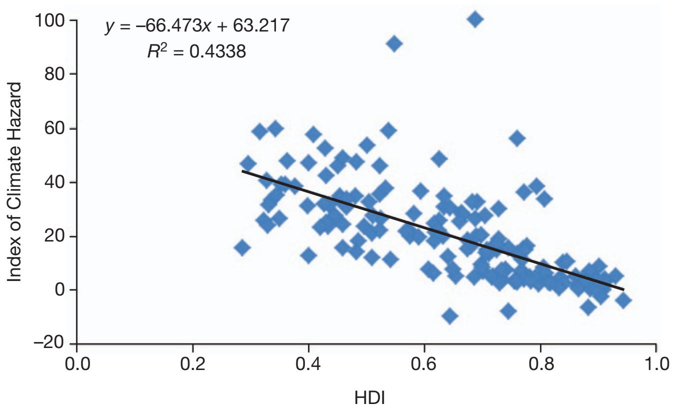


Figure 1 | The relationship between national-level poverty (as measured by HDI) and vulnerability (as measured by the Index of Climate Hazard). The HDI combines indicators of life expectancy, educational attainment and income into a composite index that ranges between 0 and 1 (data taken from the UN Development Programme Human Development Report; http://hdr.undp.org/en/statistics/hdi/). The Index of Climate Hazard combines three dimensions of climate risk: sea level rise and storm surge, extreme weather events, and reduced agricultural productivity, taken from D. Wheeler[99]; this climate hazard represents the expected near-term increase in risk (that is, from 2008 to 2015). The two outliers are China (0.687, 100) and India (0.547, 90.8), probably owing to their very large populations and large, climatically diverse land areas, serious water problems, and long coast lines.

basic framework, dating back at least to the 1970s[31–33], has recently been greatly enhanced with tools and approaches for quantifying the tradeoffs associated with alternative scenarios or choices, to inform business and policy decisions[34,35]. The Millennium Ecosystem Assessment evaluated for the first time the status of the world's ecosystem services, concluding that two-thirds were declining[36].

Taken together, these conceptual and analytical approaches assess the implications of human population and consumption trajectories, and help define the challenges for sustainable development. They reveal the great disparity between rich and poor nations in per capita appropriation of Earth's capacity to support human activity and in vulnerability to natural catastrophes. They indicate that increasing well-being in poor countries will require significant reduction in the deleterious environmental impacts by rich and poor countries alike, and that greatly narrowing the rich–poor gap will be key to achieving sustainability advances in many arenas. We next explore powerful options for achieving sustainable development, looking first at what population sizes are likely and how socially beneficial trajectories can be promoted.

Population futures

Median population projections from the UN Population Division and other sources[37] suggest that the world is most likely to have about 9.5 billion people in 2050 (range of projections: 8.1–10.6 billion), and slightly over 10 billion in 2100 (range: 6–16 billion). Demographer Ronald Lee points out that they implicitly assume no negative economic or environmental feedbacks, although "it is possible that desertification, global warming, shortage of fresh water, extinctions of species, and other man-made degradations of the natural resource base will lead to catastrophic effects on the population and its growth"[38]. He believes that the occurrence of those feedbacks will be determined in part by what policy measures are taken to ameliorate the environmental impacts of population and economic growth[38] (Fig. 2). We know that, in aggregate, each person added to the population will derive food and other resources from poorer sources, generally involving more energy and disproportionate environmental impact[9,39].

One important win–win way to reduce fertility rates is by meeting the 'unmet need' for contraception; that is, by supplying safe, modern means to those who do not want a child in the next two years of their lives but are not using any means of birth control[40]. On the basis of data

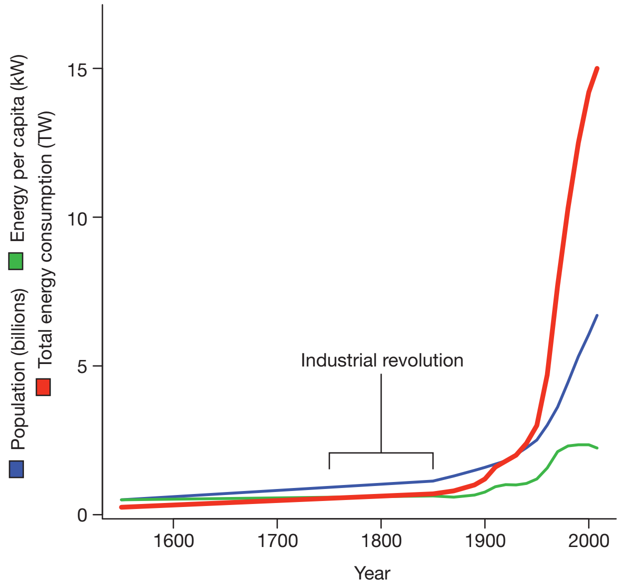


Figure 2 | History of growth in world population and environmental impact of *Homo sapiens*, indicated by its surrogates, per capita and total human energy use. Note the more than 20-fold increase in total energy use since the industrial revolution, with the growth caused slightly more by population increase than by expansion of per capita consumption[100] (Population Reference Bureau, UN, World Population Projections to 2100 (1998), and US Energy Information Administration).

from demographic and health surveys in 53 Asian, African and Latin American countries between 1995 and 2005, an estimated 7–15% of women have an unmet need for contraception. In sub-Saharan Africa, the region where unmet need is greatest, the estimate is about 25% of married women[41].

There are roughly 75 million unintended pregnancies in the world annually and almost half of them end in abortion[42]. Making reproduction education and family planning universally available in the developing world could theoretically avert 20 million or more births annually (estimates vary), avoid over 25 million abortions[43], reduce maternal mortality by 25–40% (ref. 44), and greatly reduce the population growth rate.

A second win–win way to reduce fertility rates is to raise levels of education, especially of young women. Lutz and Samir[45] considered four different educational scenarios. In the most pessimistic scenario, no new schools are built in response to population growth, and educational conditions and enrolment rates deteriorate. In the second, the education system expands just rapidly enough to accommodate the additional students produced by growth. In a third, educational investments permit school expansion rates that were experienced by countries further along in this process. Finally, in the fourth scenario, all countries are presumed to initiate ambitious but practical programs to maximize the rate at which the educational system is expanded and improved.

The results of the analysis are impressive. If there were a crash program of education globally, there would be roughly a billion fewer people in 2050 than if there were no effort to keep educational investment commensurate with population size. Education and subsequent empowerment of women lowers infant and childhood mortality, an effect that is more than offset demographically by the associated growing desire and ability to have fewer children. For example, for Kenya, Lutz and Samir show that the baseline population of 30 million in 2000 would, under the first scenario, "increase to an incredible 114 million." By contrast, adopting the third and fourth scenarios, the population would grow to 84 and 85 million by 2050.

Many potential benefits are associated with these demographic impacts of education. No nation has successfully developed without providing substantial education to women, and educating women leads to better health and nutrition for children, and higher productivity in agriculture and other sectors of society[46,47]. It is also a key step towards reaching the ideal, nowhere yet achieved, of a society in which women are fully equal to men.

Securing natural capital and human well-being

Given likely population trajectories, what natural capital is most vital for sustaining human well-being? This is a key question in many important sub-systems, including in food[48,49], fresh water[50], energy[11], climate[51] and health[52]. Over the past two decades, great advances have been made in each of these areas, with a growing effort at synthesis in the development of ecosystem service science, tools and decision-making approaches[36,53–55].

In theory, if institutions recognize the values of ecosystem services, then we can greatly enhance investments in the natural capital that generates them and foster human well-being at the same time. In practice, we are still in the early stages of developing the scientific basis, and the policy and finance mechanisms, for integrating natural capital into land use and other resource decisions on large scales. Relative to other forms of capital, assets embodied in ecosystems have been poorly understood and scarcely monitored, and are undergoing rapid, unchecked degradation[56–58]. Natural capital and the ecosystem services that flow from it are typically undervalued—by governments, businesses and the public—and recognized only upon their loss[59–62].

The urgent challenge today is to move from theory to real-world honing and implementation of ecosystem service tools and approaches to resource decisions taken by individuals, communities, corporations, governments and other organizations[63]. A great diversity of efforts to implement the ecosystem services framework has emerged worldwide (Box 1). Collectively, they represent a promising shift towards a more inclusive, integrated and effective set of strategies[64–66]. Taken together, these efforts span the globe and target a full suite of ecosystem services, such as carbon sequestration, water supply, flood control, coastal protection and enhancement of scenic beauty (and associated recreation/tourism values)[67,68].

The ecosystem service investments being made in China today stand out in their ambitious goals, scale and duration. Prompted by massive droughts and flooding in 1997–1998, China implemented several national forestry and conservation initiatives to address the nation's growing environmental crises, involving approximately 120 million households and investing approximately 700 billion yuan over 2000–2010[69]. China is currently also undertaking a first national assessment of ecosystem services, spanning a wide range of ecosystems, services and scales. Perhaps most ambitiously, China is establishing a new network of 'ecosystem function conservation areas' (EFCAs; Fig. 3). EFCAs are being zoned so as to focus conservation and restoration in places with high return on investment for public benefit; at the same time, high-impact human activities are being zoned to sustain or enhance natural capital values.

These initiatives have dual goals: to harmonize people and nature by securing critical natural capital, and to alleviate poverty. Specifically, the government aims to protect ecosystems and their biodiversity for flood control, hydropower production efficiency, irrigation supply, more productive agriculture and tourism. In addition, it aims to open non-farm sectors, increase household income and make land-use practices more sustainable in rural areas[70]. Although these initiatives represent a massive scientific and policy undertaking, there is still little understanding of the local costs of implementation, or their effects on poor and vulnerable populations in or near the target areas. The EFCA model represents a new paradigm for integrating conservation and human development, but for this policy innovation to have wide applicability, it will be important to assess and improve local livelihoods[71].

Gender and gender equity in sustainability

As evidence for the value of community-based resource management has accumulated[72], a special role for women in environmental sustainability has begun to emerge. Cross-national studies reveal a strong association between high levels of deforestation and impaired

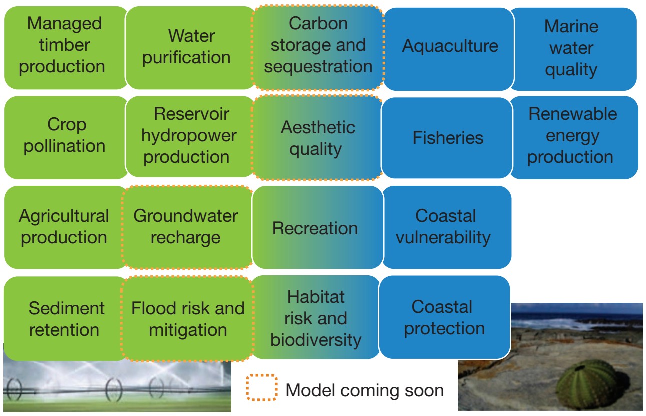
BOX 1

Quantifying the values of natural capital under future scenarios

The Natural Capital Project, an international partnership, is developing tools for the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST). These software-based models help decision makers visualize the impacts of potential policies by quantifying and mapping the generation, distribution and economic value of ecosystem services under alternative scenarios[35]. The models span a range of terrestrial and marine services (Box 1 Fig. 1a). They are designed for use in an iterative decision-making process, in which stakeholders identify critical management decisions and explore scenarios of change (for example, demographic, climate, technological). The outputs identify tradeoffs and compatibilities between environmental, economic and social benefits. The models are being applied in a wide range of decision contexts and scales (Box 1 Fig. 1b).

InVEST quantifies and maps

a



b

Box 1 Figure | Mapping ecosystem services. a, The suite of InVEST models, created and being improved through an open-source process. **b**, Applications of InVEST models in major policy decisions so far. Many new applications are now being initiated.

health for women, increased household labour and reduced income[73]. Conversely, studies of community-based conservation reveal that the more women are involved in local governance, the more effective forest protection and compliance with regulations[74]. Throughout the world there are differences in the roles of genders in terms of daily time use and activities. For example, in Africa, women are primarily responsible for providing food and childcare[75]. This means that women need to be explicitly targeted when designing strategies for promoting conservation and reducing environmental degradation. There is an interesting parallel between the empowerment of women in cities and reduced fertility, and the empowerment of women in rural poor communities and more sustainable resource use. Equally suggestive is the finding that CO_2 emissions per capita are lower in nations where women have higher political status, so that working to increase gender equity everywhere could interact positively with other steps to achieve sustainability[76].

Academic leadership for rescaling

For at least two decades, the scientific community has largely agreed that humanity is in the midst of an unprecedented slow-motion global emergency[77,78]. The question is then how the academic community can be more effective in stimulating innovation, and in testing promising new approaches in major demonstrations that integrate the biophysical, economic and social pillars of sustainability effectively. At the interface of science and policy, analysis and real decisions, we need ambitious scaling of efforts that embody three core elements, developed recently in the sustainability realm.

First, there is tremendous potential for innovation and real-world implementation in university partnerships with non-governmental organizations (NGOs), community organizations, government agencies and, increasingly, human development organizations and businesses, internationally. In many cases what is needed are boundary institutions that serve to link science and public policy[79].

Second, we need to test and hone ideas in compelling models of success, in the context of live policy opportunities and decisions. Such demonstrations would ideally involve (1) a major policy opportunity with clear and relevant objectives (for example, mainstreaming natural capital into decisions); (2) the strength and commitment among partners necessary for success; (3) a diversity of places and sectors; (4) potential for adapting, replicating and scaling up the approach; and (5) the opportunity for learning, involving input, evaluation and synthesis across academic disciplines, economic sectors and social classes, well beyond the realm of academia. Such demonstrations would involve an iterative process for engaging stake-holders in an 'end-to-end' way, so that the work is conducted jointly throughout[80,81].

Third, the traditional distinction between basic and applied research does not fit our modern sustainability challenge. Instead what is needed is best thought of as use-inspired research[82,83]. This type of research is conducted in a collaborative setting, takes advantage of existing and well-functioning institutions, and is aimed at widely recognized decision points or tradeoffs and conflicts.

By approaches such as these, academics can play major, collaborative roles in transforming the dominant social paradigm globally by opening new options and incentives to change[84,85]. Science indicates that continuing on our current course, or making just incremental changes, are great gambles, and gambles whose odds can be seriously miscalculated[86]. Biophysical problems interact tightly with human governance systems, institutions and civil societies that are inadequate to deal with them[25,87].

Meanwhile, there are aspects of society that require greater development and promotion—such as knowledge, education, health, security, equity and population stability[88]. Development in these sectors implies evolving new sets of norms that make redistribution of power and wealth more acceptable to the rich, and forgoing a full repeat of the Victorian industrial revolution more acceptable to the poor. In the past, the technical community has generally been good at alerting society to threats such as loss of biodiversity and climate disruption, but we know that simply describing an environmental situation scientifically does not necessarily change human behaviour, and that human beings cannot be counted on to behave rationally[89].

The Millennium Alliance for Humanity and the Biosphere is bringing social scientists and humanities scholars into the effort to understand and spark cultural evolution for rescaling. There is already much knowledge that could be used to accelerate the movement[90]. Culture change can involve the dissemination of provincial norms[91], the use of deliberative polling[92], applying lessons from history[93,94], using classroom exercises to change attitudes[95], decreasing the chance of large catastrophes through decentralization[96], and perhaps foremost developing new narratives to

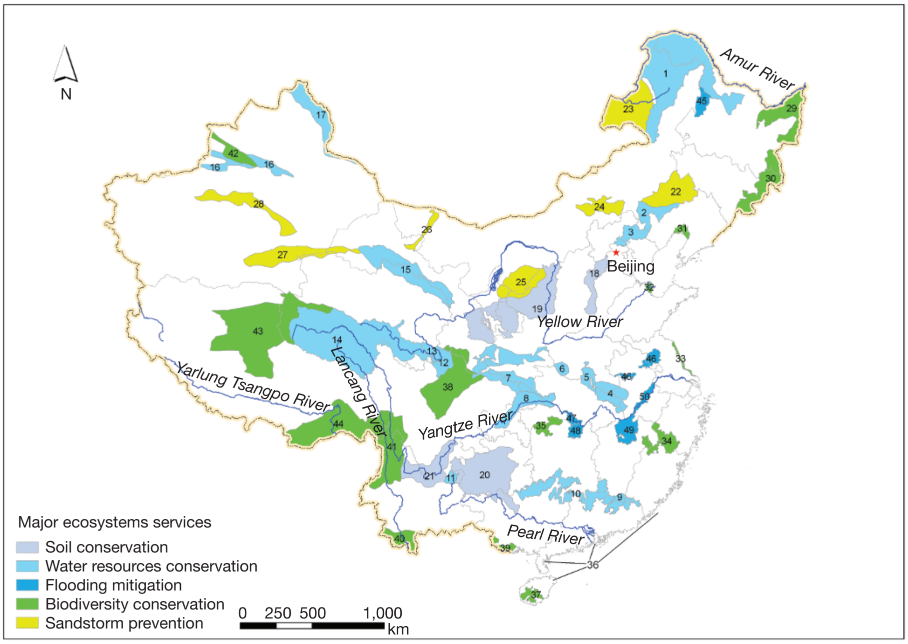


Figure 3 | China's new system of EFCAs. As delineated by the Ministry of Environmental Protection and the Chinese Academy of Sciences in 2007, EFCAs span 24% of China's land area and 25% (708) of its counties. EFCAs are designed to secure biodiversity, soils and water resources, and to mitigate floods and prevent sandstorms. The implementation of EFCAs also serves a major social goal of alleviating poverty. Figure is a modified version of a map provided courtesy of Z. Ouyang, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences.

communicate needs, goals and desired futures, for example see ref. 97. The embedding of environmental concerns into public discourse and policy less than a quarter of a century after 1960 is in itself a fine example of the speed with which cultural change towards sustainability can occur. Now we need to see if we can go much further, in far less time.

A crucial time

There will be a critical opportunity at Rio+20 to persuade leaders—individuals and institutions—to push for the high-level policy changes that are both practical (within reach) and that would greatly accelerate the rescaling of society[98]. The connectivity of the world is increasing and many of the most important environmental problems are global. As all individuals inevitably have an impact on Earth's life-support systems (although in different ways and to varying degrees), it is in everybody's interest to reduce ethically both the size of the population and our per capita impacts. The main uncertainty in the human future is tied to how equitable the pathways chosen for that rescaling are, the degree of overshoot that occurs, and the amount of irreversible damage that overshoot inflicts on Earth's life-support systems.

Rapid change has occurred enough times in human history in relation to fundamental aspects of culture to give hope that such change can be triggered now. One need only consider the advances in women's rights of the past century, the transformation of the racial situation in the United States such that an African American can be elected President, and the collapse of the Soviet Union, to see that cultural change does not necessarily proceed at a glacial pace. And, just as climate change is speeding the flow of glaciers, it should speed the transition of the human enterprise towards a sustainable scale—at which care for all human beings and the natural capital upon which they depend is at the top of the political agenda. The choice seems stark and clear enough: rescaling or global bust.

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