Environment and Development Economics 13: 1–20 © 2008 Cambridge University Press
doi:10.1017/S1355770X07004019 Printed in the United Kingdom

Key issues for attention from ecological economists[1]

PAUL R. EHRLICH
Department of Biological Sciences, Stanford University, Stanford, CA 94305, USA Email: pre@stanford.edu

ABSTRACT. This paper gives an ecologist's overview of the deteriorating environmental situation. It then describes areas where the activities of ecological economists seem appropriate (e.g., ecosystem service valuation, trade) and others requiring more attention (e.g., definitions of utility, social discounting, preserving population diversity, global toxification, the epidemiological environment, overpopulation, overconsumption, the economic impacts of nuclear explosions, and the equilibration of opportunity costs when attempting to solve global dilemmas). A general problem is the failure of ecological economists adequately to communicate their results and concerns to the general public and to decision makers. In view of the demonstrable failure of traditional economics to focus its attention on what will be the central issues of the twenty-first century, it is clear that ecological economics is in a position to become the central subdiscipline of economics. In order to do so, it is important for ecological economists to always keep the 'big picture' in view.

1. Introduction

Environment and resource economists (hereafter 'ecological economists', which I consider to be an identical group) are the scholars examining the most critical problems that will dominate economics in the twenty-first century. Economics' main focus likely will shift away from business cycles, maintenance of growth, 'development', narrowly viewed trade policy, the new financial architecture, game theory, management incentives, and the like. Instead economists will focus increasingly on very basic problems that will feed back on all the above areas: the consequences of the depreciation of natural capital and issues of ethics and equity. Because of the key position

[1] Based on a keynote address presented to the 15th Annual Conference of European Association of Environmental and Resource Economists in Thessaloniki, Greece. I thank Lisa Daniel (Department of Economics, University of Maryland), Timothy Daniel (NERA Inc.), Partha Dasgupta (Faculty of Economics, University of Cambridge), Anne Ehrlich (Department of Biological Sciences, Stanford University), and Lawrence Goulder (Department of Economics, Stanford University) for critical comments on the manuscript. My thinking about topics covered here has benefited greatly from conversations over the years with colleagues at the Beijer Institute of Ecological Economics, and recently with John List (Department of Economics, University of Chicago). The work was supported by a grant from the Mertz-Gilmour Foundation.

of natural capital, ecological economics ought to be at the front line of the economics profession today.

The purpose of this paper is to indicate, from the viewpoint of an ecologist who associates with economists, some areas that need more input from ecological economists in aid of that shift. These involve both research topics and communication needs that I believe are relatively neglected. A prime example of an area neglected in research is the global role of human population size as a contributor to environmental damages as expressed in the I = PAT equation (Ehrlich and Holdren, 1971; Ehrlich and Ehrlich, 1990). Communications neglect may be even more serious – ecological economists do not take their concerns and research conclusions to decision makers and the general public with nearly the force that is needed. This allows the false view to persist that economics has little of interest to contribute to solving the human predicament. The public gets the idea that economics is all about making profits or about how to spend money in the supermarket – rather than about the best ways of using scarce resources to meet human needs. A more technical example of the failure to communicate is the general lack of understanding by the business press that there are circumstances in which social discount rates should be very low or negative (e.g., Dasgupta, 2008).

2. The situation

I don't intend here to give any detail on the reasons for ecologists' pessimism about the human predicament, as these are available elsewhere (Ehrlich and Ehrlich, 2005, 2008). I will just point out some of the most worrying trends. I would claim that if the outcomes ecologists most fear only represent 10 (or even 5) per cent of the probability distribution, reducing the possibility of such results is well worth further expansion of the intellectual investment of economists. After all, if humanity ends up in those probability sectors, it could spell the end of civilization as we know it, resulting in a dramatic decline in the employment possibilities for both economists and ecologists.

Some of the potentially worst outcomes could occur in the area of climate change. My own 'mental meta-analysis' suggests that the recent IPCC reports on the possible impacts of climate change were very conservative. In my view, this traces both to the political pressure on the IPCC as well as to the reticence of many scientists to speak frankly about the probabilities (Hansen, 2007). Much attention has been paid recently as to whether the reports underestimate the speed of melting of the Greenland ice cap and the slipping of Antarctic ice sheets (e.g., Black, 2007). But I suspect that sea-level rise may be the least serious of the near-term effects of global heating. Much more immediately threatening is the probability that agricultural systems will be disrupted. The recent Australian drought (soon perhaps to be followed by temporary deluge), whether connected to global change or not, could be a harbinger of things to come. Climate change will not be just a 'redealing' of the cards with some winners and some losers, but in fact it will be centuries of continuous change in which such things as crop varieties, water-handling infrastructure, and coastal facilities will be under constant pressure, often incurring huge costs to adjust to changing conditions.

For instance, much of the wheat and rice in Asia is grown very close to the upper temperature limits of the crops. This is all the more serious because population growth – fated to add some 2.5 *billion* or more people to those needing to be fed by 2050 – will also disproportionately add greenhouse gases to the atmosphere. Furthermore, much of today's environmental disruption, loss of biodiversity, release of toxic substances, and climate change is traceable to humanity's environmentally incompetent, short-range-focused agricultural enterprise. Despite this, some planners seem determined to replicate that enterprise in order to feed automobiles rather than people. If plans to produce cellulosic ethanol are carried very far, it could be the death knell for biodiversity and, with it, humanity's life-support systems. Furthermore, it is clear that most people and virtually all politicians fail to grasp the far-reaching measures that will be required to reduce greenhouse gas emissions to a level likely to avoid the potentially most dangerous climatic consequences. There is, of course, substantial uncertainty about the actual impacts of climate change, especially at a regional scale. Both ecologists and economists should be helping the public to understand that scientific results always contain uncertainty and are open to revision. If changes in public policy must await 'proof' they will never be instituted. And not taking action on potential climate disruption must be viewed as a decision with consequences just as is taking action.

On top of this, climate disruption is not necessarily the most serious element of humanity's environmental problems. The partially related problems of land use change, the loss of biodiversity (especially population diversity) and ecosystem services, toxification of the planet, and decay of the epidemiological environment may alone or in combination prove to have more severe consequences. And, of course, if more resource wars, floods of environmental refugees, or other factors trigger a substantial exchange of nuclear weapons, the results would be ecological and social catastrophe. Add to this the growing economic inequity both within and between nations, and it is difficult to view the future with optimism.

Some economists may consider these views too pessimistic, and indeed they may be. But they are not mine alone – rather they amount to a consensus of the scientific community (National Academy of Sciences USA, 1993, Union of Concerned Scientists, 1993). As such, at the very least they call for much more careful attention from social sciences, and above all from the queen of those disciplines: economics.

3. Areas to which ecological economics is paying proper attention

There are some areas where the technical work of ecological economists seems, to an outsider, properly concentrated and ongoing. Perhaps the most outstanding one is resource management, where the literature is vast and sophisticated (for a fine example and partial overview, see Sterner, 2003). An area of this close to the hearts of ecologists, and one of the most important tasks of ecological economists, is the valuation of ecosystem services. This has been examined at a global scale (e.g., Daily, 1997; Costanza *et al.*, 1998; Toman, 1998; Villa *et al.*, 2002; Chiesura and de Groot, 2003; Straton, 2006; Azqueta and Sotelsek, 2007; Boyd and Banzhaf, 2007; Richmond *et al.*, 2007)

and at more local/regional levels (Seidl and Moraes, 2000; Zavaleta, 2000; Rodriguez *et al.*, 2006; Troy and Wilson, 2006). But this is an area where ecological economists must put much more effort into informing not just the general public but also decision makers and contributing to popular publications thought of as 'economic' such as the *Wall Street Journal* and *The Economist*, which frequently publish ecological and economic nonsense. Today, the average educated human being cannot define ecosystem services, let alone discuss the difficult problems of valuing them at different levels of aggregation. To the degree that ecological economists *can* monetize the value of ecosystem services, those estimated values can be used in benefit–cost analyses, which could give more support for policies to protect the environment. Research here is of great practical and political importance.

Another area to which attention is properly being paid by ecological economists is international trade, a topic where old-fashioned economists and the above-mentioned publications remain mesmerized under the sway of the Torrens-Ricardo notion of comparative advantage. That was a bright idea early in the nineteenth century, but is now employed as a dogma needing to be surrounded by caveats in the twenty first. While not opting for autarky, ecological economists are exploring those caveats, especially ones having to do with environmental effects (e.g, Muradian and Martinez-Alier, 2001). Movements of people, goods, and capital at speeds and over distances undreamed of in Ricardo's time are already having large economic effects, and likely will have much larger ones in the future as environmental refugees (and possibly refugees fleeing resource wars) become much more numerous. Here again ecological economists have at least outlined many if not most of the major issues (e.g., Røpke, 1994; Proops *et al.*, 1999; Cole, 2000; Costanza, 2000; Gale, 2000; Wackernagel and Silverstein, 2000; Andersson and Lindroth, 2001; Leclair, 2002; LeClair and Franceschi, 2006), from the impacts of free trade on the poor and the environment, the composition of trade, equity, and increasing demand, to the role of production methods, ecological footprints and trade, and the growth of the Fair Trade movement. Pleasingly, the treatments have tended to be reasonably balanced in the sense that they attempt to look at both the costs and benefits of globalization (e.g. Veen-Groot and Nijkamp, 1999; Shimamoto *et al.*, 2004; Aggarwal, 2006; Bardhan, 2006; Hecht *et al.*, 2006).

4. Areas where ecological economics should focus more attention

Ecologists and economists both tend to do research on topics that interest them, and that seems to me both natural and necessary. But both must be alert to keeping their work relevant to big issues – in particular the human predicament (Bazzaz *et al.*, 1998). And they should attempt to keep the dimensions of that predicament in public view. In discussing areas where more effort seems needed, I'll start with two close to the center of economics. Both, not unexpectedly, concern economists' views of the human future, and what our goals for it should be.

Utility

The first need is to pay more attention to what is the 'utility' that humanity wishes to maximize by the appropriate allocation of scarce resources. There

seems general agreement that until certain basic needs are met, that utility can reasonably be considered proportional to per capita GDP, in some sense equitably distributed. But beyond the point of adequate food, shelter, clothing, medical attention, and so forth, things become more problematic. For instance, there is little sign that 'satisfaction' increases with per capita GDP (e.g., Easterlin, 1973; Diener *et al.*, 1993; Diener and Diener, 1995), and this is certainly the case where competitive consumption prevails (Durning, 1992; Ehrlich and Ehrlich, 2005; Frank, 2007; Ehrlich and Goulder, 2008). There needs to be wider recognition that utility depends on much more than simply one's own consumption. Instead, it depends on one's consumption relative to others, one's status relative to norms, one's income relative to one's initially expected income, and on other social relationships usually ignored in economic analysis.

People also consider various sorts of security as components of their utility, and have some level of concern for descendents. It is traditional in economics to assume that individuals act in a fully self-interested manner, and that they have very good information. However, it is not clear that households (or nations) have the requisite information to make informed choices. Would, for example, Costa Ricans have chosen to operate to their comparative advantage and specialize in growing coffee while buying beans to eat from China, if they had known that the coffee market would collapse? A maximum production of coffee could well have been a much less resilient strategy than a more balanced agricultural policy that gave more flexibility and buffering against the vagaries of international markets. How should individuals and governments calculate appropriate policies that might be more sensible than practicing the religion of 'free trade?' In short, there is no reason to assume that economic plans should always attempt to maximize either efficiency or production as usually conceived. There is nothing wrong with the notion of maximization (or efficiency) *per se*, but the problem is that in practice too often critical variables such as resilience and externalities are omitted from the calculations.

Social discounting

Similarly, most economists should follow the lead of Partha Dasgupta and others in pointing out one likely consequence of the litany of environmental problems above: namely, there is a substantial probability that future generations will be *poorer* than those living today. If so, social discount rates, under ethical assumptions most of us would probably accept, in some circumstances should be *negative*. and the consequences for present policies should be thoroughly explored (Dasgupta, 2001, 2008). Establishing social discount rates is a tricky business, but there is no reason for economists to assume automatically that they must be positive as, for instance, did Cline (1992), Nordhaus (1994), and Stern (2007).

Power relationships

Ecological economists should be developing models of the most cost-effective ways of protecting the environment. For example, if legislation to accomplish this is to be passed in the United States, the least expensive way to do it may be by public education, organizing political action through

NGOs, or by bribing (legally) legislators with campaign contributions. This is fertile and unplowed field for sophisticated cost–benefit analysis. So is the related issue of the environmental impacts of international migration (Daly, 2006; Matutinovic, 2006), one destined to become even more prominent as increasing numbers of environmental refugees seem certain, and refugees from warfare and poverty flowing from skewed power relationships (Ehrlich and Ehrlich, 2005) highly likely. Besides the difficult local issues of calculating costs and benefits of migration (e.g., Ehrlich *et al.*, 1981), ecological economists need to be looking at global costs and benefits as, for example, streams of immigrants into the industrial world become absorbed into those superconsuming societies (Ehrlich and Ehrlich, 2005: 107–108) and multiply their impact on humanity's life-support systems. One chore for ecological economists would be to analyze how consumption of the rich should and could be reduced to allow for needed increases of consumption among the poor, whether refugees or stay-at-homes.

Population and ecosystem service conservation

In technical areas of ecology and conservation biology, economic input is badly needed in several areas. One of the most important is the conservation not of species but of *populations* (Hughes *et al.*, 1997, 2000; Ceballos and Ehrlich, 2002). This is closely related to the issue of the preservation of ecosystem services and of cost–benefit analyses in countryside biogeography. The importance of conserving multiple populations of species can be made clear with a thought experiment. Suppose that, miraculously, it were possible to preserve permanently only one small but viable population of each species on the planet. Then, by definition, there would be no further loss of species diversity, no crisis of species extinctions. But very soon civilization would collapse and all human beings would die, since we couldn't harvest even the small remnant populations of crops or domestic or game animals without destroying each species. And, even if those species that are directly useful as food were all to be exempted from the experiment, the civilization would still collapse, since all crops are dependent on other organisms such as fungi that transfer nutrients from soils into plants, pollinators that are required by many plant species to reproduce, predators that protect crops from pests, and so on.

To take a more realistic example, what if all the honey bees were exterminated everywhere in the United States, by, say, the disappearance of all colonies in the mysterious 'colony collapse disorder'? Global species diversity would not be diminished because those honey bees would still be present in Europe, Africa, and elsewhere. But pollination services would be drastically reduced for some 90 American crops, at a cost that could be higher than $14 billion.

There are some complex issues here such as how to evaluate the loss of resiliency in agricultural systems caused by extermination of native pollinators. In North America, substitution for pollination services of native bees by those of imported honeybees, and the subsequent loss of honeybees, threatens to impose those high costs. Economists could ask retrospectively how the cost–benefit analysis should have been done properly to account for

this possibility. The answer might inform future analyses aimed at projects involving loss of population diversity.

Extinction of populations can produce a problem in species conservation that also deserves some attention from economists: political endemism (Ceballos and Ehrlich, 2002). Allocation of funds to conservation of a species whose range includes several nations should include consideration of both the interest and the capability of each nation to protect populations within their political boundaries. Population extinctions resulting in endemism (sole occurrence in a locality or nation) in the wrong country can be the forerunner of species extinctions. Included in any analysis should be estimates of the costs in local-regional ecosystem services lost or gained in the different political units.

The extinction of populations of other organisms is, of course, intimately connected with the size, growth, and distribution of the population of *Homo sapiens.* That is clear in places like the United States, Europe, and Australia – but it is doubly clear in the world's poorest regions, especially in sub-Saharan Africa. The population–poverty–environment nexus (Dasgupta, 2003; Dasgupta *et al.*, 2005) in which the planet's poor find themselves requires much more economic and demographic investigation (as well as public explication) of how these endogenous variables co-move and interact with institutional failure to deepen the plight of the poverty-stricken. Treating those factors separately, as economists and demographers have tended to do, represents a grave intellectual failure, with negative consequences at the policy level. The Research Division of the World Bank should stop wasting its time and money trying to estimate precisely how many people live below $1/day, and start exploring and publicizing the *real* deep causes of poverty. And one can't do that while ignoring human population size and growth, what is happening to the natural environment, and the importance of power relations – the way the rich run the world primarily for their own benefit. Sadly, even when standard economists tackle an important subject like poverty, they tend to look only at proximate causes or describe in detail the horrible situations in which the poor find themselves (e.g., Mukherjee and Benson, 2003; Balisacan and Fuwa, 2004; Banerjee and Duflo, 2007).

A technical (and less-important) topic where comprehensive economic analyses would also be useful is that of the environmental impacts of decreasing household size on consumption patterns (Liu *et al.*, 2003) and of shifting population age structure on many relevant variables ranging from consumption to the threat of terrorism.

Toxification of the planet

Another crucial environmental-economic area is that of the toxification of the entire planet (as opposed to the impacts of single toxins, and ways of limiting flows of dangerous materials into the atmosphere – 'air pollution' – both of which receive considerable attention). We badly need an outline, with a great deal of economic input, of how to evaluate the costs and benefits of the release of tens of thousands of potentially toxic compounds into the environment. On the cost side, most of these compounds are never adequately tested for direct health effects, for ecosystem impacts, or for

the immense multitude of potential interactions (especially synergisms) in both areas. On the benefit side, the same can be said for what society (or individual firms) gains from the use of each chemical released (an especially difficult area for research because of proprietary rights). As a starter, we badly need a test case of what procedures might be used, perhaps based on a sample of compounds stratified by those that are released as final products for direct human use that often escape into ecosystems (e.g., deodorants, pharmaceuticals, plastic bottles), those used for human benefit in ecosystems (pesticides, cloud-seeding chemicals), and those that are intermediate products of manufacturing processes (solvents). The overall task is gigantic, but considering the global spread of thousands of such compounds, the fact that many of them are toxic, carcinogenic, or mimic human hormones, and given our total ignorance of interactions, thresholds, and lag times, it is high time both ecologists and ecological economists paid more attention to the issue and produced at least some boundary estimates on the world-wide comprehensive threat.

Resource shifting and the meta-resource depletion problem

Ecological economists should be doing careful cost–benefit analyses of shifts in resource use occasioned by market forces. For instance, the attempt of American oil companies and the wholly owned politicians in the Bush administration to gain control over Iraqi oil by military means has been a factor in pushing up oil prices. That, in turn, has suddenly made it possible to profitably exploit tar sands in western Canada as a source of oil. Unfortunately, however, that exploitation is very energy intensive (that's the main reason oil prices must be high to make extraction profitable), and the contribution to climatic disruption from the mining operations is much greater than from conventional oil drilling. At a more theoretical level, there remains much scope for modeling the meta-resource depletion problem, the idea that once one resource is exhausted there will always be a substitute for firms to start exploiting (Ehrlich, 1989). This is especially needed with respect to mineral resources. In that area questions of the limits to substitution may increasingly come into play in this century, especially in the case of rare metals such as platinum and tantalum, and even more common ones such as copper (Cohen, 2007), where the economic and environmental costs of extracting and smelting ever-poorer ores may become prohibitive. Issues of 'essentiality', opportunity costs, and externalities likely will become very challenging.

The epidemiological environment

Perhaps the second most dangerous environmental area that has received too little attention in a cost–benefit context is the decay of the epidemiological environment. How much benefit does the Chinese economy receive from farming methods that bring people, ponds, pigs, and ducks into close proximity – thus increasing the chances of a global 'killer' flu epidemic? Would it be cost effective for the international community to aid China in reducing or eliminating this dangerous agricultural practice? Would it not be worth doing a cost-effectiveness analysis of making an international agreement in advance to limit air travel in case of a lethal

flu pandemic caused by a novel virus strain or an entirely new highly pathogenic emergent virus?

Why have the global costs and benefits of abating the horrendous health costs of indoor air pollution in third world huts (Smith *et al.*, 2004; Smith, 2006) not been widely discussed by ecological economists? One would imagine that the losses in human capital are staggering. Fortunately, Michael Greenstone is starting to do research in this area, and that may stimulate the interest of other economists.

Nuclear war

The most important single area deserving attention may be the environmental impacts of nuclear war – what was once subsumed under the rubric 'nuclear winter' (e.g., Ehrlich *et al.*, 1983). One of the obvious environmental effects of increasing population size and per capita consumption is to increase the probability of even more resource wars in the future (Klare, 2001, 2004). Those wars carry with them the threat of use of nuclear bombs, whose environmental impacts would have massive economic consequences. Recent studies suggest that even a relatively small exchange of nuclear weapons, as might well occur between India and Pakistan, could have severe climatic impacts. One area that resource and environmental economists should be involved in is putting some broad numbers on the economic costs of such wars, since politicians tend to see the world through dollar-colored glasses and mostly acquire their outdated economic notions from sources like the *Wall Street Journal*. This is nothing new. Remember what Keynes said: 'Practical men, who believe themselves to be quite exempt from any intellectual influences, are usually the slaves of some defunct economist. Madmen in authority, who hear voices in the air, are distilling their frenzy from some academic scribbler of a few years back' (Keynes, 1936: 383). In a globalized world, economic effects would travel far and fast, and doubtless interact with ecological impacts with all the usual problems of non-linearities, thresholds, and discontinuities. It would, for instance, be interesting to calculate the cost to the US economy alone of the destruction of the Indian city of Bangalore, and the secondary environmental effects (from, for instance, reallocation of resources) in North America. Indeed, both epidemics and nuclear warfare would likely have severe consequences for the global economy through disruption of trade and travel, the direct reduction of human welfare (utility), and the loss of human capital.

Many years ago, during the nuclear winter studies, John Holdren and I did some back-of-the-envelope calculations on how many Hiroshima-sized (15kt) atomic bombs it would take to destroy either the United States or the Soviet Union as functioning entities. Our answer for the US was about a dozen. Destroying the centers of Washington DC and New York would severely disrupt governmental and financial operations. Taking out Atlanta, Chicago, Kansas City, Dallas, Houston, Denver, Los Angeles, San Francisco, and Seattle would create chaos in petroleum, coal, and natural gas distribution and destroy much of the road and rail transport systems. That would lead to massive deaths from starvation and cold (the severity of both depending slightly on timing). One has only to view the incompetent

performance of relief systems in New Orleans after hurricane Katrina to imagine what the nation's response would be to a catastrophe that caused tens to hundreds of thousands to a million or more of prompt deaths and multiples of those numbers of badly injured or radiation-sick individuals in each of a *dozen* cities simultaneously.

Our conclusion was that even fewer weapons would have dismantled the Soviet Union, which was more centralized. Remember, of course, that at the time each side had tens of thousands of much, much more powerful weapons – and thousands are, insanely, still targeted by the US on Russia and vice-versa. It is high time that economists examine quantitatively scenarios of the sort that Holdren and I considered, and produce some estimates of what may be at stake as resource wars between enemies with nuclear arms and as nuclear terrorist acts become more likely. At the very least, the costs of preparing for such wars should be calculated as externalities not captured in the market prices of petroleum products, for instance, as well as other increasingly scarce resources that might trigger wars, such as water in many regions. A rough guess was made a few years ago that internalizing the costs of maintaining the US military as a force to control petroleum flows would require a gasoline tax of about $.40 per gallon (Ehrlich and Ehrlich, 2005: 119). But a more sophisticated economic analysis would be very instructive, including a cost–benefit analysis of the use of petroleum *by* the US military in an attempt to gain ever-more control over an energy resource whose use, ironically, most environmental scientists think humanity should be reducing dramatically. A truly comprehensive first-cut evaluation of the externalities of gasoline usage in the United States (including, for example, some share of the loss of natural capital such as biodiversity that occurs with suburbanization) would also be a great contribution.

Finally, we need economic analyses of the likely effects of a single nuclear bomb exploded by a terrorist group in a first-world city. Analyses should be done for a stratified sample of cities: government centers, transport centers, research centers, symbolic targets, etc. Such analyses would be very useful to have on hand even if society is lucky enough to avoid such an event. Done properly, they would, for example, make it easier to assess society's stock of resilience. That might stimulate changes in organization that would make dealing with non-nuclear disasters, from comet-strikes and epidemics to catastrophic storms, easier. The costs of lacking such analyses are highlighted by the ongoing Katrina disaster in the United States.

5. The drivers

In considering the broad causes of environmental degradation, the most economically neglected are probably the first two drivers of the $I = PAT$ equation. I suspect the neglect of population both in communication and also in the research agenda of even ecological economists comes from a combination of uninformed optimism (we're still far from limits), lack of recognition of population impacts (with the notable exception of footprint analyses), and politics (population control is a sensitive issue). There is also, I believe, too much uninformed optimism about the degree to which

technological change (part of the T in I = PAT) can develop substitutes for ecosystem services (Ehrlich and Mooney, 1983), and the speed with which sensible substitution can take place. In the latter case, it is clear that many believe that if Congress were to stop subsidizing fossil fuels and apply massive subsidies to wind power, in a couple of years half of US energy would be coming from wind.

The good news here is that economists' and ecologists' view of humanity's future are starting to converge (e.g., Heal, 2000; Ehrlich and Goulder, 2008), but even ecological economists are doing far too little to educate the public about this trend, and the rest of society still basks in stunning ignorance. For example, the United States recently passed the 300 million mark in population growth with much celebratory comment in the media. There was essentially no discussion of the *disproportionate* impact of that growth on environmental systems. Since, after all, the most accessible and highest quality resources are used first, each added person, *ceteris paribus*, consumes more and does more environmental damage than the previous one. Where were the economic analyses of what US dependence on foreign oil or its greenhouse gas (GHG) emissions would have been if the population had remained at the World War II level of ~140 million? The good news is that in Europe population trends are toward shrinkage. But even so, there has been no campaign by economists to counter nonsensical complaints by government and business about the (inevitable) aging of the population (Ehrlich and Ehrlich, 2006). It would be a wonderful opportunity to educate politicians and industrialists on economic concepts such as externalities and intergenerational equity!

There is also much discussion of India's population soon surpassing that of China, and of its growing environmental impacts. But I have seen almost no economic analysis of the economic benefits, in terms of reduced GHGs, of investment in women's education and other fertility control methods as opposed to other strategies of emissions control (for an exception, see O'Neill *et al.*, 2004). And, of course, there has been no broad analysis of what the costs and benefits might be of gradually reducing the size of the total human population to a sustainable 1.5–2 billion people (Daily *et al.*, 1994).

The second problematic factor in the I = PAT equation, per capita consumption (= Affluence), is an even more difficult one to deal with than population (Ehrlich and Ehrlich, 2005). Most politicians are at least vaguely aware that there is a population 'problem', but to them consumption is an economic cure all. Despite various environmental voices pointing out the importance of overconsumption and a few individuals following 'voluntary simplicity' principles, most people in both rich and poor countries still view growth in consumption as an unalloyed good. This growth has been especially hallowed in the United States in recent decades. Indeed, during the twentieth century, the industrialized world became a world of triumphant consumerism. As historian Gary Cross put it in his fascinating book, *An All-Consuming Century* (Cross, 2000: 1), the dominant belief was 'that goods give meaning to individuals and their roles in society'. In the United States after World War II, consumption was believed to hold the key to the economic growth necessary to avoid a slide

back into the Great Depression. The key worked, and twentieth-century consumerism, in partnership with capitalism, was largely victorious over the rival ideologies of fascism, communism, and socialism.

This is another area in which ecologists and economists are converging (Arrow *et al.*, 2004; Ehrlich and Goulder, 2008), and ecological economists should be paying much more attention to how to measure and deal with overconsumption. This is a topic fraught with technical and ethical issues. For instance, potentially one of the greatest engines for expansion of per capita consumption is what Norman Myers and Jennifer Kent refer to as the 'new consumers' (Myers and Kent, 2004). There are more than a billion people in developing and transitional countries such as China, India, South Korea, Malaysia, Brazil, Argentina, Mexico, Russia, and Turkey who have a purchasing power of at least $2,500 per person annually. Thus they can afford to buy the equivalent of $2,500 or more worth of goods and services at US prices, a huge advance over the situation thirty years ago. In 2001, the new consumers around the world collectively had a purchasing power parity (PPP) of $6.1 trillion, essentially three-fifths of that of the American population, and that has increased significantly since then. New consumers by 2001 were driving some 125 million cars, almost a fourth of the world fleet, and by 2010 that could increase to more than 200 million.

In one sense, this is a great part of the human triumph – more and more people are getting access to the good things of life. But the usual downside of neglected social costs, pollution, climate disruption, resource wars over petroleum, wear on roads and bridges, increased lung diseases, and so on, associated with automobile use will need to be dealt with. Most of the countries in which new consumers live can ill afford the local environmental effects that a transition to a car-dominated transport system (like that of the United States) would cause. Increasing consumption by the formerly poor will also exacerbate global environmental and resource problems – unless, of course, the rich find ways to compensate by lessening our own negative effects.

There is much to occupy ecological economists in the area of consumption. For example, something that has already begun with footprint and trade analysis is examining how the superconsuming lifestyle of the rich impacts on the lives and prospects of the poor (Ehrlich and Ehrlich, 2005: 123–127). But much more economic analysis is required in this area, as well as in the definition and measurement of overconsumption and the development of policy instruments to deal with it. While the planned parenthood and zero population growth (ZPG) movements have had a global reach, substantial success, and some input from economists, there have been no 'planned consumption' or 'zero consumption growth' movements developed in parallel. Nobody is passing out 'consumption condoms' or 'morning-after-shopping pills'. It's high time that more economists started helping to develop their equivalents (maybe a very clever ecological economist could devise a system in which retail stores would, the next day, come and repossess the results of shopping sprees!).

6. Other challenges

Returning to a topic near to the hearts of some economists, there is the important issue of gross economic inequity and its impacts on our life-support

systems. Not only have I and many other environmental scientists argued that increasing equity would be an essential factor in uniting humanity to solve the human predicament (Daily *et al.*, 1995; Ehrlich *et al.*, 1995; Daily and Ehrlich, 1996), but recently it has been shown that there is a strong relationship between income inequality (both among US states and among nations) and the decline of biodiversity (Mikkelson *et al.*, 2007). More economists should be following in the footsteps of Partha Dasgupta and analyzing not just poverty, but the tight nexus mentioned above between population, poverty, and the environmental degradation that helps to perpetuate it (Dasgupta, 1993, 2000, 2001).

Perhaps the biggest problem of allocation is determining how to assign social effort across the wide range of problems that the human predicament comprises. How much, for example, should humanity devote to direct action to reduce habitat loss and save populations from extinction (and thus preserve ecosystem services) as opposed to, say, helping poor nations to build dikes to prevent city flooding or conducting research into developing heat-tolerant grain crops? A dizzying diversity of things could (should?) be done, and different nations are in different positions to do them. Economists should position themselves to help in what amounts to a series of attempts to estimate opportunity costs and offer policy solutions to equilibrate them.

It seems likely that in most cases the difficulties of estimating shadow prices will lead economists to simply fall back on stating a precautionary principle in lieu of even a boundary condition cost–benefit analysis. But since precautionary principles bear a family resemblance to insurance problems, there are places where economic analyses of past examples of use of precautionary principles could be of interest. For example, it should now be possible to compare the rough odds of a worst-case climatic disaster based on IPCC estimates with estimates during the Cold War of the probability of the Soviet Union launching a ground attack to the west in Europe (or a direct nuclear missile attack on NATO). My guess is that in both cases analysts were dealing with something approaching a zero-infinity problem, a risk where the probability of occurrence was near zero (my guess in both cases 5–10 per cent), but if the event occurred the consequences would be near infinitely bad (okay, I know that mathematically you can't get near infinity, but you get the idea).

One can calculate the costs the West incurred to insure against such an event, without causing economic catastrophe, and that could provide some context for calculating what might be reasonable to invest in avoiding climatic catastrophe. In the Cold War case, of course, many groups profited handsomely from defense preparations, but doubtless the same would hold true with climate (and a comparison of the economics, actual and potential, in the two cases could prove enlightening).

Perhaps the greatest challenges facing the ecological-economic community are the interrelated problems of the scale of the human enterprise, how long growth in the physical economy can (or should) continue, and the distribution of wealth. It's the classic issue of 'limits to growth' complexified by one of the 'limits to inequity'. Economists have considered various aspects of this through topics such as discount rates, internalization of externalities, substitution of human-made capital for natural capital, essentiality of resources, shadow prices, and *genuine*

wealth (the social value of a society's entire set of assets: human-made capital, human capital, and natural capital). But ecologists and economists have not done enough to estimate how close in time (or energy use, or any other metric) global society is to reaching the limit, and how technological optimism and maldistribution of wealth might be factored into that estimate.

This is, of course, an extraordinarily complicated issue, which might involve a careful examination of past examples of technological optimism. A casual examination seems to give little room for cheer, especially considering the unprecented scale and numerous irreversibilities in our current predicament. History and scientific analysis suggests that humanity cannot count on technological fixes alone being sufficient. The claim that 'technology will solve the problems' has been around for decades – decades in which the putative advantages of claimed 'fixes' have often failed to appear or proved to be offset by unforeseen nasty side effects. We're not feeding the world's poor people on leaf protein (Pirie, 1966) or algae grown on sewage sludge, as was once proposed (although the latter may become a significant source of renewable energy). Nuclear-powered agro-industrial complexes (Oak Ridge National Laboratory, 1968) are not solving human energy and hunger problems. A major exception to date has been the 'green revolution', the transfer of the technology of modern high-yield agriculture from rich to poor countries. So far, this has generally been adjudged a triumph, although it hasn't fed the poorest, and the final environmental verdict is far from in. But careful ecological-economic analysis might show my view of the potential of technological change to be too pessimistic. In any case, even more-or-less agreed-upon bounds on society's position relative to the limits to growth would be useful.

Perhaps more important, the issue of constraints on growth should be communicated much more effectively *by economists* to the general public. Many ecologists and ecological economists tend to believe that with anything like current behavior, humanity has reached or exceeded Earth's long-term carrying capacity for human beings (Daily *et al.*, 1994), although the topic has not received remotely the attention it deserves (Seidl and Tisdell, 1999). The general public, businessmen, governments, and many business economists appear to believe that population and per capita consumption can grow indefinitely, and that eventually all economic inequities can be eliminated by growth itself. To me and my colleagues, this is an entirely unwarranted assumption – and debunking it may be the single most important task of environmental and resource economists.

7. Pure vs. applied

Lest you think that as an ecologist I've been too demanding of ecological economists, let me assure you that my recommendations to ecologists are similar in direction. I, and numerous of my colleagues, think many ecologists are doing increasingly sophisticated investigations of increasingly trivial problems. In a contrasting minority, one distinguished ecologist has repeatedly said that those of his colleagues who have 'gone public' with their concerns about the human predicament are 'undermining

the scientific discipline'. This obviously isn't true, since public interest in and support for ecology has only increased since ecologists helped people to become aware of environmental problems. But even if ecology were being 'undermined', that would be a trivial cost compared with the benefit of awakening humanity to its peril. Many ecologists continue to pursue those trivial problems on the excuse that it is 'curiosity-driven research', and they also decline to get involved in 'applied' problems. This is a hangover from the past when science was divided by many into 'pure' (research with no immediate application to human problems) and 'applied' (that with obvious application). In those olden days, the most challenging science was thought to be pure, although there have been innumerable examples of pure science discoveries that later yielded practical applications. Nuclear physics is an excellent example – but the value of some of the applications is, to say the least, questionable.

Yet problems of trying to analyze and then deflect the potentially horrendous and interrelated consequences of human overpopulation and overconsumption by the rich minority – environmentally deleterious land-use change, biodiversity loss, toxification of Earth, global heating, and so on – are at least as basic and challenging as solving most apparently 'pure' scientific problems. A major test of any scientist's skill and ability is what he or she chooses to be curious about. Good choices can either be something that helps to solve a pressing problem or research that greatly enhances our understanding of how the world works, even with no immediate connection to the human predicament. Much the same can be said of the science of economics, with the problems of ecological economics falling largely into the first category.

8. Coda

In summary, the opportunities for ecological economics (or, if you prefer, environmental and resource economics) to both help humanity and become the leading area of economics are great. It looks as though you won't have much competition. The latest (Spring 2007) issue of a leading American economics journal (*Journal of Economic Perspectives*) contains articles on such essential topics as 'Disagreement and the Stock Market', 'Hedge funds: past, present, and future', 'Markets: gift cards'. These admittedly were accompanied by some useful articles on family economics, but the issue included nothing on the truly crucial questions facing society. The previous issue did somewhat better, with an interesting article on 'Taxing consumption and other sins' (Hines, 2007), and one on the poor, but of the 'solutionless' kind (Banerjee and Duflo, 2007). It also has, however, one, 'Corporate governance reforms in Continental Europe' (Enriques and Volpin, 2007) that looks promising but that asserts: 'The fundamental problem of corporate governance in the United States is to alleviate the conflict of interest between dispersed small shareowners and powerful controlling managers.' If only that were true! Other articles such as 'Markets: cartel behavior and amateurism in college sports', give you some flavor of how some economists, like some ecologists, can be in hot pursuit of the trivial.

I was able to stop my retrograde search through the journal in the Fall issue of 2006, where I discovered an article on 'What has mattered to economics since 1970' (Kim *et al.*, 2006). It was based on a survey of '41 prominent refereed economics journals', which, diagnostically, included no environmental or resource economics journals, i.e. ones with the words 'environment(al)', 'ecological', or 'resource' in the title. A search showed that the following words and phrases did not occur in the Kim *et al.* article itself, including in the list of titles of the journals and the titles of the top 146 articles (500 cites or more): abatement, adaptation, AIDS, aquifer, biotic, biosphere, cap and trade, carbon, carrying capacity, child, climate, depletion, discount(ing), disease, drugs, ecology, ecosystem, education, enjoyment, entropy, epidemic, ethics, fertility, footprint, forest, fossil, free-rider, fuel wood, gender, genuine investment, genuine wealth, Gini, global, globalization, health, inequity, infant, justice, life expectancy, literacy, maldistribution, market failure, Montreal, mortality, natural capital, natural resource, nuclear, open access, overdevelopment, ozone, Pigouvian, pollution, poor, population, poverty, property rights, public good, redistribution, satisfaction, shadow price, social capital, soil, solar, steady-state, substitute(ability), tax shifting, timber, toxic, trade, tragedy, treaty, utility, valuation, war, warming, water, well-being, women. 'Energy', 'Migration' and 'inequality' each appeared once (in the titles of 1970–75 papers) and 'externalities' once; 'environment' twice, once in the title of a 1975 paper, once as a category in a table caption. 'Opportunity' and 'power' appeared once and 'consumption' and 'distribution(al)' appeared twice, but none of the occurrences was in a significant economic context. It is difficult to imagine an article in a 'top' journal that could illustrate better than Kim *et al.* a profession on a rapid plunge to insignificance. Ecological economists – the field is wide open!

References

Aggarwal, R.M. (2006), 'Globalization, local ecosystems, and the rural poor', *World Development* **34**: 1405–1418.

Andersson, J.O. and M. Lindroth (2001), 'Ecologically unsustainable trade', *Ecological Economics* **37**: 113–122.

Arrow, K. *et al.* (2004), 'Are we consuming too much?', *Journal of Economic Perspectives* **18**: 147–172.

Azqueta, D. and D. Sotelsek (2007), 'Valuing nature: from environmental impacts to natural capital', *Ecological Economics* **63**: 22–30.

Balisacan, A.M. and N. Fuwa (2004), 'Going beyond cross country averages: growth, inequality and poverty reduction in the Philippines', *World Development* **32**: 1891–1907.

Banerjee, A.V. and E. Duflo (2007), 'The economic lives of the poor', *Journal of Economic Perspectives* **21**: 141–167.

Bardhan, P. (2006), 'Globalization and rural poverty', *World Development* **34**: 1393–1404.

Bazzaz, F., G. Ceballos, R. Dirzo, P.R. Ehrlich, T. Eisner, *et al.* (1998), 'Ecological science and the human predicament', *Science* **282**: 879.

Black, R. (2007), 'Arctic melt faster than forecast', BBC News website, 30 April.

Boyd, J. and S. Banzhaf (2007), 'What are ecosystem services? The need for standardized environmental accounting units', *Ecological Economics* **30**, in press.

Ceballos, G. and P.R. Ehrlich (2002), 'Mammal population losses and the extinction crisis', *Science* **296**: 904–907.
Chiesura, A. and R. de Groot (2003), 'Critical natural capital: a socio-cultural perspective', *Ecological Economics* **44:** 219–231.
Cline, W.R. (1992), *The Economics of Global Warming*, Washington, DC: Institute for International Economics.
Cohen, D. (2007), 'Earth's natural wealth: an audit', *New Scientist* 34–41.
Cole, M.A. (2000), *Trade Liberalization, Economic Growth and the Environment*, London: Edward Elgar.
Costanza, R. (2000), 'The dynamics of the ecological footprint concept', *Ecological Economics* **32**: 341–345.
Costanza, R. *et al.* (1998), 'The value of ecosystem services: putting the issues in perspective', *Ecological Economics* **225**: 67–72.
Cross, G. (2000), *An All-Consuming Century: Why Commercialism Won in Modern America*, New York, NY: Columbia University Press.
Daily, G.C. (ed.) (1997), *Nature's Services: Societal Dependence on Natural Ecosystems*, Washington, DC: Island Press.
Daily, G.C. and P.R. Ehrlich (1996), 'Socioeconomic equity, sustainability, and Earth's carrying capacity', *Ecological Applications* **6**: 991–1001.
Daily, G.C., A.H. Ehrlich, and P.R. Ehrlich (1994), 'Optimum human population size', *Population and Environment* **15**: 469–475.
Daily, G.C., A.H. Ehrlich, and P.R. Ehrlich (1995), 'Socioeconomic equity: a critical element in sustainability', *Ambio* **24**: 58–59.
Daly, H.E. (2006), 'Population, migration, and globalization', *Ecological Economics* **59**: 187–190.
Dasgupta, P. (1993), *An Inquiry into Well-being and Destitution*, Oxford: Oxford University Press.
Dasgupta, P. (2000), 'Population, resources, and poverty: an exploration of reproductive and environmental externalities', *Population and Development Review* **26**: 643–649.
Dasgupta, P. (2001), *Human Well-being and the Natural Environment*, Oxford: Oxford University Press.
Dasgupta, P. (2003), 'Population, poverty, and the natural environment', in K.-G. Mäler and J.R. Vincent (eds.), *Handbook of Environmental Economics*, Vol. **I**, Amsterdam: Elsevier Science, pp. 191–247.
Dasgupta, P. (2008), 'Discounting climate change', *Review of Environmental Economics and Policy*, in press.
Dasgupta, S., U. Deichmann, C. Meisner, and D. Wheeler (2005), 'Where is the poverty-environment nexus? Evidence from Cambodia, Lao PDR, and Vietnam', *World Development* **33**: 617–638.
Diener, E. and C. Diener (1995), 'The wealth of nations revisited: income and the quality of life', *Social Indicators Research* **36**: 275–286.
Diener, E., E. Sandvik, L. Seidlitz, and M. Diener (1993), 'The relationship between income and subjective well-being: relative or absolute', *Social Indicators Research* **28**: 195–223.
Durning, A. (1992), *How Much in Enough? The Consumer Society and the Future of the Earth*, New York, NY: W.W. Norton.
Easterlin, R.A. (1973), 'Does money buy happiness?', *Public Interest* **30**: 3–10.
Ehrlich, P.R. (1989), 'The limits to substitution: metaresource depletion and a new economic-ecological paradigm', *Ecological Economics* **1**: 9–16.
Ehrlich, P.R. and J. Holdren (1971), 'Impact of population growth', *Science* **171**: 1212–1217.
Ehrlich, P.R. and H.M. Mooney (1983), 'Extinction, substitution and ecosystem services', *BioScience* **33**: 248–254.

Ehrlich, P.R. and A.H. Ehrlich (1990), *The Population Explosion*, New York: Simon & Schuster.
Ehrlich, P.R. and A.H. Ehrlich (2005), *One with Nineveh: Politics, Consumption, and the Human Future* (with new afterword), Washington, DC: Island Press.
Ehrlich, P.R. and A.H. Ehrlich (2006), 'Enough already', *New Scientist* **191**: 46–50.
Ehrlich, P.R. and A.H. Ehrlich (2008), *The Dominant Animal: Human Evolution and the Environment*, Washington, DC: Island Press.
Ehrlich, P.R. and L.H. Goulder (2008), 'Is current consumption excessive? A general framework and some indications for the US', *Conservation Biology*, in press.
Ehrlich, P.R., L. Bilderback, and A.H. Ehrlich (1981), *The Golden Door: International Migration, Mexico, and the United States*, New York, NY: Wideview Books.
Ehrlich, P.R., A.H. Ehrlich, and G.C. Daily (1995), *The Stork and the Plow: The Equity Answer to the Human Dilemma*, New York: Putnam.
Ehrlich, P.R., J. Harte, M.A. Harwell, P.H. Raven, C. Sagan, G.M. Woodwell *et al.* (1983), 'Long-term biological consequences of nuclear war', *Science* **222**: 1293–1300.
Enriques, L. and P. Volpin (2007), 'Corporate governance reforms in continental Europe', *Journal of Economic Perspectives* **21**: 117–140.
Frank, R.H. (2007), *Falling Behind: How Rising Inequality Harms the Middle Class*, Berkeley, CA: University of California Press.
Gale, F.P. (2000), 'Economic specialization versus ecological diversification: the trade policy implications of taking the ecosystem approach seriously', *Ecological Economics* **34**: 285–292.
Hansen, J.E. (2007), 'Scientific reticence and sea-level rise', *Environmental Research Letters* **2** (024002).
Heal, G. (2000), *Nature and the Marketplace: Capturing the Value of Ecosystem Services*, Washington, DC: Island Press.
Hecht, S.B., S. Kandel, I. Gomes, N. Cuellar, and H. Rosa (2006), 'Globalization, forest resurgence, and environmental politics in El Salvador', *World Developmen*t **34**: 308–323.
Hines, J.R. (2007), 'Taxing consumption and other sins', *Journal of Economic Perspectives* **21**: 49–68.
Hughes, J.B., G.C. Daily, and P.R. Ehrlich (1997), 'Population diversity: its extent and extinction', *Science* **278**: 689–692.
Hughes, J.B., G.C. Daily, and P.R. Ehrlich (2000), 'The loss of population diversity and why it matters', in P.H. Raven (ed.), *Nature and Human Society*, Washington, DC: National Academy Press, pp. 71–83.
Keynes, J.M. (1936), *The General Theory of Employment, Interest, and Money*, New York: Harcourt Brace Jovanovich.
Kim, E.H., A. Morse, and L. Zingales (2006), 'What has mattered to economics since 1970', *Journal of Economic Perspectives* **20**: 189–A183.
Klare, M.T. (2001), *Resource Wars: The New Landscape of Global Conflict*, New York, NY: Henry Holt.
Klare, M.T. (2004), *Blood and Oil: The Dangers and Consequences of America's Growing Dependency on Imported Petroleum*, New York, NY: Henry Holt and Company.
Leclair, M.S. (2002), 'Fighting the tide: alternative trade organizations in the era of global free trade', *World Development* **30**: 949–958.
LeClair, M.S. and D. Franceschi (2006), 'Externalities in international trade: the case for differential tariffs', *Ecological Economics* **58**: 462–472.
Liu, J., G. Daily, P.H. Ehrlich, and G. Luck (2003), 'Effects of household dynamics on resource consumption and biodiversity', *Nature* **421**: 530–533.
Matutinovic, I. (2006), 'Mass migrations, income inequality and ecosystems health in the second wave of a globalization', *Ecological Economics* **59**: 199–203.

Mikkelson, G.M., A. Gonzalez, and G.D. Peterson (2007), 'Economic inequality predicts biodiversity loss', *PLoS ONE* **2**: e444.
Mukherjee, S. and T. Benson (2003), 'The determinants of poverty in Malawi, 1998', *World Development* **31**: 339–358.
Muradian, R. and J. Martinez-Alier (2001), 'Trade and the environment: from a "Southern" perspective', *Ecological Economics* **36**: 281–297.
Myers, N. and J. Kent (2004), *The New Consumers: Rich Lives of Richer Lifestyles*, Washington, DC: Island Press.
National Academy of Sciences USA (1993), *A Joint Statement by Fifty-eight of the World's Scientific Academies*, Population Summit of the World's Scientific Academies, New Delhi, India: National Academy Press.
Nordhaus, W.D. (1994), *Managing the Global Commons: The Economics of Climate Change*, Cambridge, MA: MIT Press.
O'Neill, B.C., F.L. MacKellar, and W. Lutz (2004), 'Population, greenhouse gas emissions, and climate change', in W. Lutz, W.C. Sanderson, and S. Scherbov (eds), *The End of World Population Growth*, London: Earthscan, pp. 283–314.
Oak Ridge National Laboratory (1968), 'Nuclear energy centers, industrial and agro-industrial complexes', ORNL-4291, Summary Report.
Pirie, N.W. (1966), 'Leaf protein as human food', *Science* **152**: 1701–1705.
Proops, J.L.R., G. Atkinson, B.F. Schlotheim, and S. Simon (1999), 'International trade and the sustainability footprint: a practical criterion for its assessment', *Ecological Economics* **28**: 75–97.
Richmond, A., R.K. Kaufmann, and R.B. Myneni (2007), 'Valuing ecosystem services: a shadow price for net primary production', *Ecological Economics* **30**, in press.
Rodriguez, L.C., U. Pascual, and H.M. Niemeyer (2006), 'Local identification and valuation of ecosystem goods and services from Opuntia scrublands of Ayacucho, Peru', *Ecological Economics* **57**: 30–44.
Røpke, I. (1994), 'Trade, development and sustainability – a critical assessment of the "free trade dogma"', *Ecological Economics* **9**: 13–22.
Seidl, A.F. and A.S. Moraes (2000), 'Global valuation of ecosystem services: application to the Pantanal da Nhecolandia, Brazil', *Ecological Economics* **33**: 1–6.
Seidl, I. and C.A. Tisdell (1999), 'Carrying capacity reconsidered: from Malthus' population theory to cultural carrying capacity', *Ecological Economics* **31**: 395–408.
Shimamoto, M., F. Ubukata, and Y. Seki (2004), 'Forest sustainability and the free trade of forest products: cases from Southeast Asia', *Ecological Economics* **50**: 23–34.
Smith, K. (2006), 'Health impacts of household fuelwood use in developing countries', *Unsylva* **224 57**: 1–4.
Smith, K., S. Mehta, and M. Maeusezahl-Feuz (2004), 'Indoor smoke from household solid fuels', in M. Ezzati, A. Rodgers, A. Lopez, and C. Murray (eds), *Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors*, vol. 2, Geneva, Switzerland: World Health Organization, pp. 1435–1493.
Stern, N.H. (2007), *The Stern Review of the Economics of Climate Change*, Cambridge: Cambridge University Press.
Sterner, T. (2003), *Policy Instruments for Environmental and Natural Resource Management*, Washington, DC: RFF Press.
Straton, A. (2006), 'A complex systems approach to the value of ecological resources', *Ecological Economics* **56**: 402–411.
Toman, M. (1998), 'Why not to calculate the value of the world's ecosystem services and natural capital', *Ecological Economics* **25**: 57–60.
Troy, A. and M. Wilson (2006), 'Mapping ecosystem services: practical challenges and opportunities in linking GIS and value transfer', *Ecological Economics* **60**: 435–449.

Union of Concerned Scientists (1993), *World Scientists' Warning to Humanity*, Cambridge, MA: Union of Concerned Scientists.
van Veen-Groot, D.B. and P. Nijkamp (1999), 'Globalisation, transport and the environment; new perspectives for ecological economics', *Ecological Economics* **31**: 331–346.
Villa, F., M.A. Wilson, R. de Groot, S. Farber, R. Costanza, and R.M.J. Boumans (2002), 'Designing an integrated knowledge base to support ecosystem services valuation', *Ecological Economics* **41**: 445–456.
Wackernagel, M. and J. Silverstein (2000), 'Big things first: focusing on the scale imperative with the ecological footprint', *Ecological Economics* **32**: 391–394.
Zavaleta, E. (2000), 'Valuing ecosystem services lost to Tamarix invasion in the United States', in H.A. Mooney and R.J. Hobbs (eds), *Invasive Species in a Changing World*, Washington, DC: Island Press, pp. 261–200.