

# Have increases in population, affluence and technology worsened human and environmental well-being?

Indur M. Goklany\*

\* Indur M. Goklany is the Assistant Director for Science and Technology Policy, Office of Policy Analysis, US Department of the Interior, and co-editor of the *Electronic Journal of Sustainable Development*. Views expressed here are his, not those of any unit of the US government.  
Email: editor =a= policynetwork.net (replace =a= with @)

## Abstract

This paper examines whether over the long term, empirical data supports Neo-Malthusian fears that exponential population growth would lead to increasing resource scarcity, and that increases in population, affluence and technology would worsen human and environmental well-being.

It finds that, in fact, global population is no longer growing exponentially. Second, from a historical perspective, food, energy and materials are more affordable today than they have been for much of human history. Third, despite unprecedented growth in population, affluence, consumption and technological change, human well-being has never been higher, and in the last century it advanced whether trends in environmental quality were up or down.

With respect to the environment, however, the record is mixed. Initially, in the rich countries, affluence and technology worsened environmental quality, but eventually they provided the methods and means for cleaning up the environment. As a result, after decades of deterioration, their environment has improved substantially. That is, these countries have undergone an “environmental transition” such that affluence and technology are no longer part of the problem, but are now part of the solution. In general, the world also seems to be on the verge of environmental transitions for cropland and water withdrawals.

Even developing countries have gone through their environmental transitions for access to safer water and sanitation, and leaded gasoline. But these countries have not yet made the transitions for other environmental indicators in many places, although technological diffusion, accompanied by some affluence, has moved them ahead of where developed countries used to be at equivalent levels of development.

If the past is any guide, affluence and technological change are indispensable to ensuring that advances in human well-being continue into the future even as environmental quality improves.

---

## 1. Introduction

Concerns about population growth historically revolved around the notion that there may be insufficient arable land, minerals or energy to meet the needs of an exponentially increasing population. Adding to these today are fears that as technologies become more powerful and wealth increases so too would consumption of natural resources, which are further compounded by worries about the wastes discharged to the air, land and water in the course of developing and using these resources. Thus, the fear is that even if we do not run out of resources, we might overwhelm the earth's assimilative capacities. Absent empirical information, it can be plausibly argued that together these factors conspire to increase environmental impacts with potentially disastrous effects on human welfare.

The general skepticism of population growth, economic development, and technology exhibited by many, if not most, environmentalists and Neo-Malthusians – henceforth Neo-Malthusians – is captured by the equation,  $I = PAT$ , where  $I$  is a measure of environmental impact,  $P$  is the population,  $A$  stands for affluence – a surrogate for per capita production or per capita consumption, often measured in terms of the gross domestic product (GDP) per capita – and  $T$ , denoting technology, is a measure of the impact per unit of production or consumption (e.g., Commoner 1972; Ehrlich and Holdren

1971; Ehrlich and Goulder 2007). [Technology, as used here, includes both hardware (e.g., scrubbers, catalytic convertors and carbon adsorption systems) and software technologies (e.g., policies and institutions that govern or modulate human actions and behavior, culture, management techniques, computer programs to track or model environmental quality, and emissions trading) (Ausubel 1991; Goklany 1995).]

According to the IPAT equation, if all else remains the same, an increase in population, affluence or technology would each act as multipliers for environmental impact (Commoner 1972; Ehrlich and Holdren 1971; Ehrlich and Ehrlich 1991; Ehrlich 2008). And as that impact increases, human well-being would necessarily deteriorate.

The IPAT identity has been remarkably influential. It has intuitive appeal because of its apparent simplicity and seeming ability to explain how population, consumption or affluence, and technology can affect human and environmental well-being. It serves, for example, as the “master equation” for the field of industrial ecology (e.g., Graedel and Allenby 1995). One of its versions underpins the Intergovernmental Panel on Climate Change’s emission scenarios that have been used to estimate the amounts and rates of future climate change and its impacts (IPCC 2000, pp. 83–84).

While noting that the IPAT equation is a simplified representation and sometimes acknowledging that the terms on the right hand side are not independent of each other, its formulators have nevertheless used it to support their contention that the human enterprise as currently constituted is unsustainable in the long run, unless the population shrinks, we diminish, if not reverse, “over-consumption” or economic development (particularly in the United States), and apply the precautionary principle to new technologies, which in their view essentially embodies a presumption against further technological change unless the technology involved is proven safe and clean (Ehrlich and Holdren 1971; Ehrlich and Ehrlich 1991; Myers 1997; Raffensperger and Tickner 1999).

Despite recognizing that “benign” technology could reduce some impacts, many Neo-Malthusians argue, to quote Jared Diamond (2005, p.504), it is a mistake to believe that “[t]echnology will solve our problems.” In fact, goes this argument, “All of our current problems are unintended negative consequences of our existing technology. The rapid advances in technology during the 20th century have been creating difficult new problems faster than they have been solving old problems...” Diamond (2005, pp. 505). Ehrlich and co-workers argue that for most important activities, new technology

would bring diminishing returns because as the best resources are used up (e.g. minerals, fossil fuels and farm land), society would increasingly have to turn to marginal or less desirable resources to satisfy demand which would increase energy use and pollution (Ehrlich and Holdren 1971; Ehrlich et al. 1999).

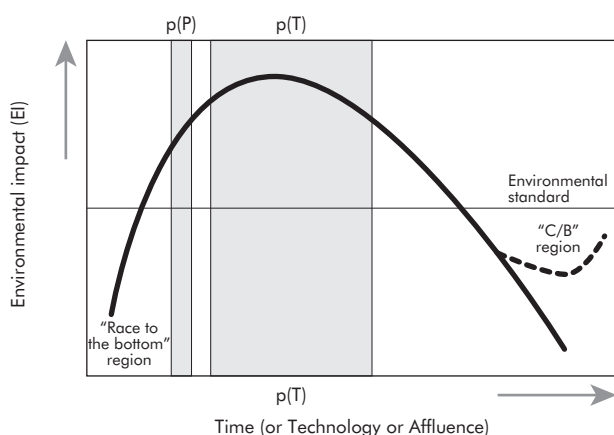
It has also been argued that technological advances could be, and have been, counterproductive. First, such advances can reduce the cost of resource exploitation which, then, increases environmental impacts – for example by using chain saws and bull dozers to create clear cuts of timber. Second, improved technologies can reduce the prices of consumption goods which stimulate greater demand and further increase resource extraction.

There are alternative views of the impact of technological change and economic growth regarding human and environmental well-being. Simon, for instance, argues that economic growth and technological innovation conceived by more abundant brains in a more populated world tend to improve human and environmental well-being (Simon 1995). Others, such as Jesse Ausubel, argue that additional technological change has to be part of the solution, in order to reduce environmental impact, but nevertheless view economic growth as a multiplier of impacts, rather than a contributor to the solution (Ausubel 1998; Landes 1998; Ryan 1999).

In the 1990s, several economists undertook empirical analysis of the relationship between economic growth and environmental impact. Analysing a cross-section of countries, they found that the relationship between per capita GDP and environmental impact followed an inverted “U” shape similar to that identified by Simon Kuznets for income inequality. On the basis of this empirical relationship they posited the environmental Kuznets curve (EKC) hypothesis, which says that as countries grow, the environment first gets worse, then, as they achieve a certain level of development, the damage peaks and begins to improve again (Shafik 1994; Grossman and Krueger 1995).

In the “environmental transition” hypothesis, Goklany (1995, 1998, 2007a) has generalized the EKC hypothesis to attempt to account for both economic development and technological change. Under this hypothesis, initially societies opt for economic and technological development over environmental quality because it allows them to escape from poverty and improve their quality of life by making both needs and wants (e.g. food, education, health, homes, comfort, leisure and material goods) more affordable. But once basic needs are met, over time members of society perceive that environmental deterioration compromises their quality of life and they

Figure 1 **A stylized depiction of the Environmental Transition Hypothesis, a generalization of the Environmental Kuznets Curve**



It shows the evolution of environmental quality – the negative of environmental impact (EI) – as a society evolves from a low to a high level of economic development. The figure assumes that affluence and technology advance with time, which is broadly consistent with historical experience since the start of the Industrial Revolution. NOTE: p(P) = “period of perception,” the period during which the notion that environmental degradation can compromise human well-being gains acceptance; p(T) = “period of transition,” the period over which that perception leads to actions which eventually reduce environmental degradation; “Race to the Bottom Region” (where society strives to increase economic development despite increasing EI); NIMBY Region = “not in my backyard region” (EI enters this region if benefits far exceed costs to beneficiaries); C/B Region = cost/benefit region (where benefits and costs have to be more carefully balanced). Source: Goklany (2007a)

start to address their environmental problems. Being wealthier and having access to greater human capital, they are now better able to afford and employ cleaner technologies. Consequently, environmental deterioration can, first, be halted and, then, reversed. Under this hypothesis, technological change and economic growth may initially be the causes of environmental impacts, but eventually they work together to effect an “environmental transition” – after which they become a necessary part of the solution to environmental problems. Such a transition, if it occurs at all, would be evident as a peak in a stylized curve of environmental impact versus time, assuming that both economic development and technology advance with time. This assumption, while true in general since Malthus’ time, hasn’t always been so, nor is there a guarantee that it will hold for all places at all times in the future. Figure 1 provides a stylized rendition of the environmental transition hypothesis.

In the following, I examine whether long term empirical data support the Neo-Malthusian notion that as

populations increase, become wealthier, and technology advances, we will run out of resources, leading to a deterioration of environmental quality, and human well-being. I inspect trends that typically span several decades, because short term trends can be misleading. My examination, which is illustrative rather than exhaustive, focuses mainly on the U.S. because of the better availability and accessibility of long term data for that country and because it has traveled furthest on the path of economic development of any large economy. In addition, I use global data, where available, and also data from a selection of less developed countries, mainly India and China, in order to compare and contrast their experience with that of the U.S.

With respect to human well-being, although I briefly touch on indicators such as poverty, education, child labor, level of economic development, and economic and social freedom, I will use life expectancy as the major indicator of human well-being. This is consistent with its use as one of the three factors in the United Nations’ original Human Development Indicator (see e.g. UNDP 2008).<sup>1</sup> Some may object to the use of life expectancy as an indicator of human well-being on the grounds that a longer life expectancy does not necessarily translate into better health. While theoretically this may be correct, real world experience shows that as populations live longer they also live more healthily, as evidenced by the fact that the health-adjusted life expectancy, i.e., life expectancy adjusted downward partially to discount life years spent in poor health, is generally higher today than unadjusted life expectancy in times past (Goklany 2007a, p. 40).

Regarding environmental quality, I examine trends in various indicators of humanity’s impacts on land, air and water. Specifically, regarding the impact on land, I use cropland as the major environmental indicator, since conversion of habitat to cropland is generally deemed to be the most significant pressure on species, habitat and ecosystems (see MEA 2005; Goklany 1998, and references therein). With respect to water, I focus on water withdrawals and use because water diversion to meet human needs is generally regarded as the greatest threat to freshwater biodiversity (e.g., IUCN 1999, 2000; Wilson 1992; see also MEA 2005, p. 117). Regarding air and water pollution, the selection of indicators is guided largely by the World Health Organization’s (2002) analysis which estimates that water related diseases, indoor air pollution, and urban outdoor air pollution are the largest environmental contributors to the global mortality and disease burden. I also look at indicators related to climate change, not because it is among the

highest contributors to the global mortality and disease burden – it ranks below the top ten – but because of the current interest in all matters related to global warming (Goklany 2007a, pp. 355–356).

Based on the long term environmental trends, I will estimate both the absolute amount and rate of technological change, assuming the validity of the IPAT identity. This will allow me to verify whether empirical trends support the Neo-Malthusian worldview represented by the IPAT identity that technology makes matters worse for the environment. These estimates also provide an indication of how much credence should be given to estimates of long term future environmental consequences that do not fully account for technological change, as frequently seems to be the case for analyses of the impact of climate change, for instance (e.g., Goklany 2007d). I do not, however, attempt to dissect the factors that may or may not be responsible for changes in affluence and technology.

Note that long term data are unlikely to be homogeneous, and are plagued with numerous uncertainties which increase the further one goes back in time or during periods of unrest, wars and social tensions. Therefore, such data are best used to draw qualitative rather than quantitative conclusions. Also, unless noted otherwise, GDP in this paper is provided in terms of constant 1990 International dollars (adjusted for purchasing power parity, PPP), per Maddison (2003) and GGDC (2008). Finally, note that the analysis presented here draws liberally from, and updates, Goklany (2007a).

Following is a roadmap for this paper.

In Section 2, I examine whether, consistent with Malthusian fears, the population continues to increase exponentially, and whether population growth rates have increased with both affluence and technological change.

In Section 3, I look at the original concern of Malthusians, namely, that greater consumption driven by larger populations, greater affluence and new technologies would make food and non-renewable resources, specifically metals, scarcer. In this section, scarcity is measured by real prices relative to an indicator of income (e.g., wages, disposable income, or GDP per capita).

Section 4 investigates whether greater affluence and consumption of material goods, chemicals and fossil fuels have indeed reduced human well-being, as feared by Neo-Malthusians.

In Section 5, I examine trends in various environmental indicators that represent human impact on land, water, and air to determine whether environmental well-being is, in fact, deteriorating as population, affluence and technology have changed. Sections 5.1 and 5.2

explore trends in land converted to cropland, and in water withdrawal and consumption, respectively. These indicators are proxies for the (inverse) pressures exerted by humanity on terrestrial and freshwater biodiversity. Section 5.3 focuses mainly on trends in water-related diseases, and Section 5.4 on air pollutants. Section 5.5 examines various global warming related trends, specifically trends in carbon dioxide emissions, and in deaths due to extreme weather events, which, it has been suggested may rise due to future warming.

Section 6 provides, for the environmental indicators addressed in the previous section, estimates of technological change, assuming that the IPAT identity is valid.

Section 7 discusses the findings of the preceding analyses, and Section 8 offers some conclusions.

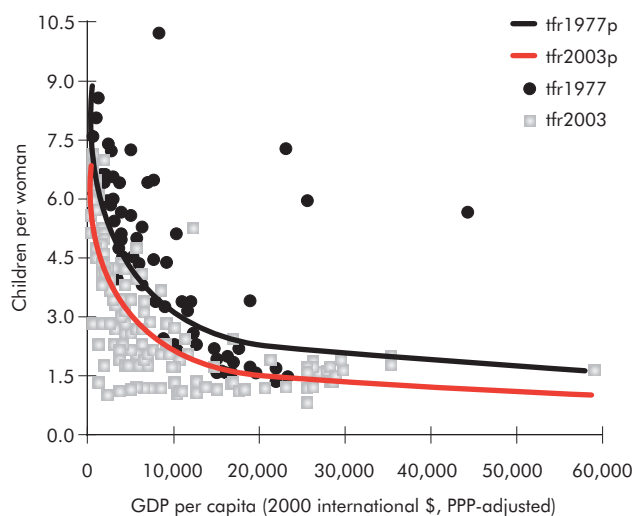
## 2. Trends in population growth and total fertility rates

The original Neo-Malthusian premise was that population would grow exponentially. Indeed until the latter decades of the 20th century, these concerns seemed well founded, as technological change increased the rate of population growth by reducing mortality rates. However, the rate of population increase has slowed in recent decades. In the five years from 1965 to 1970, the World's population grew by 10.6 per cent. By contrast, the current rate of population growth has fallen to 6.0 per cent every five years and is expected to fall further (UNPD 2007). Accordingly, recent population projections show that population should peak during this century, perhaps at less than 9 billion. Lutz *et al.* (2007) claim that there is a 90 percent probability that global population will not exceed 11.5 billion in 2100.

Nevertheless, while most experts currently discount the possibility of exponential population increase, the notion lingers on in the popular mind (see, e.g., Revkin 2008). This tends to color discussions on environmental matters. In any case, Neo-Malthusians insist that even current population levels may be catastrophic for humanity, with some suggesting that the earth's sustainable limit may be anywhere between 0.5 to 2 billion (Dahl 2005).

The onset of the decline in growth rate was more or less concurrent with mortality rate declines in general, and preceded the appearance of AIDS. The proximate cause is obviously a decline in total fertility rate (TFR), that is, the number of children borne by a woman, which seems to have occurred worldwide, but to a differing extent in each country and culture. What are the underlying causes of the decline in TFR?

Figure 2 **Total fertility rate (TFR) vs. per capita income, 1977–2003**



Source: Goklany (2007a)

Figure 2, based on cross country data from the World Bank (2005), shows that TFR is inversely related to the level of economic development (as measured by GDP per capita) and falls over time (a crude surrogate for technological change).<sup>2,3</sup> Goklany (2007a, 2007b) argues that the underlying relationships are more complex, with the conditions supporting economic and technological development and, significantly, the desire for such development, also important drivers.

First, since lower poverty – the not-so-surprising consequence of economic growth – means lower infant mortality rates and higher survival rates, it reduces pressures for more births. This is particularly important because children are among the few available forms of insurance in poorer countries, which is one reason why they have the highest TFRs. Richer societies tend to have social security programs which can reduce the pressure for more children. Second, higher incomes mean greater access to technology, which reduces the value of child labor. Third, richer societies offer greater educational and economic opportunities for women, which also increases the opportunity costs of their child bearing and child rearing years. Fourth, the time and cost of educating children to be competitive and productive in a richer and more technologically advanced society encourages small family sizes.

Apart from economic and technological development, factors that contribute to economic growth and the desire for greater wealth can help create conditions that tend to lower TFR. In particular, literacy and the

amount of education, especially of women, helps propagate good habits of diet, nutrition, sanitation and safe drinking water. This improves health and reduces mortality, in general, and infant and maternal mortality, in particular. As noted, this reduces pressures to maximize birth and enables couples to plan the size of their families. At the same time, improved health leads to greater wealth (or economic growth).

Finally, many couples – arguably swayed by commercials and lifestyles depicted by a ubiquitous, globalized and globalizing visual mass media – defer child birth in favor of current consumption (Goklany 2007a).

Together these factors explain why TFR has dropped progressively with both economic development and time. Thus, in the IPAT equation, P is not independent of A and T: sooner or later, as a nation grows richer, its population growth rate falls (e.g., World Bank 1984), which might lead to a cleaner environment (Goklany 1995, 1998, 2007b).

Therefore, while economic development and technological change might initially increase the rate of population growth by reducing mortality rates, in the long run, they moderate population growth by helping directly or indirectly create the conditions for many families to voluntarily opt for fewer children (and lower TFR).

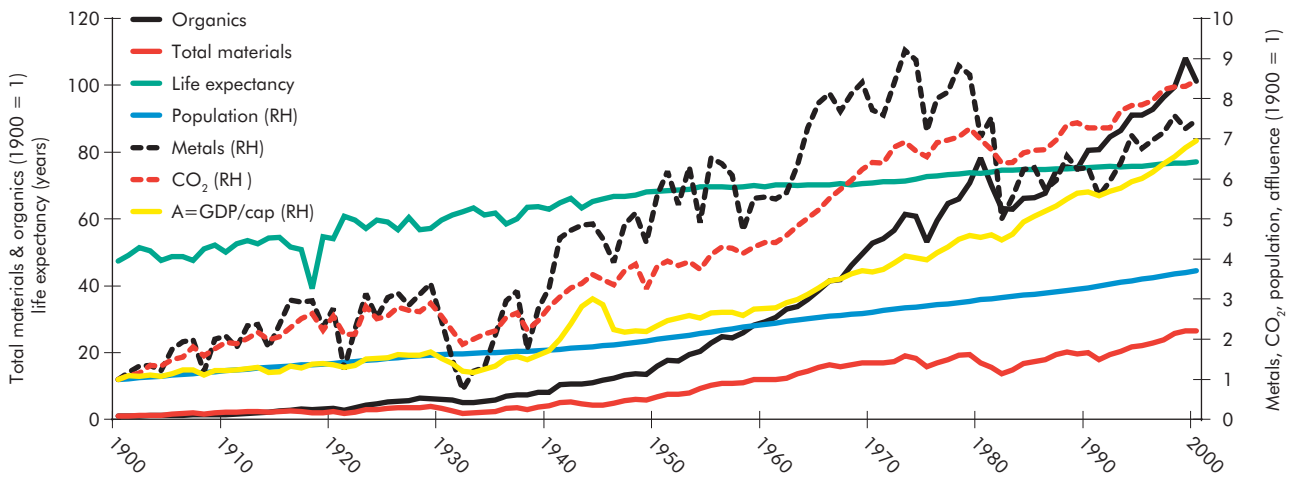
### 3. Trends in human well-being

Although global population is no longer growing exponentially, it has quadrupled since 1900. Concurrently, affluence (or GDP per capita) has sextupled, global economic product (a measure of aggregate consumption) has increased 23-fold and carbon dioxide has increased over 15-fold (Maddison 2003; GGDC 2008; World Bank 2008a; Marland et al. 2007).<sup>4</sup> But contrary to Neo-Malthusian fears, average human well-being, measured by any objective indicator, has never been higher.

Food supplies, Malthus' original concern, are up worldwide. Global food supplies per capita increased from 2,254 Cals/day in 1961 to 2,810 in 2003 (FAOSTAT 2008). This helped reduce hunger and malnutrition worldwide. The proportion of the population in the developing world, suffering from chronic hunger declined from 37 percent to 17 percent between 1969–71 and 2001–2003 despite an 87 percent population increase (Goklany 2007a; FAO 2006).

The reduction in hunger and malnutrition, along with improvements in basic hygiene, improved access to safer water and sanitation, broad adoption of vaccinations, antibiotics, pasteurization and other public health

Figure 3 **U.S. material, chemical and energy use, population and affluence compared to life expectancy, 1900–2000**



Source: Adapted from Goklany (2007a), based on Matos (2005), Marland *et al.* (2005), Maddison (2003)

measures, helped reduce mortality and increase life expectancies. These improvements first became evident in today's developed countries in the mid- to late-1800s and started to spread in earnest to developing countries from the 1950s. The infant mortality rate in developing countries was 180 per 1,000 live births in the early 1950s; today it is 57. Consequently, global life expectancy, perhaps the single most important measure of human well-being, increased from 31 years in 1900 to 47 years in the early 1950s to 67 years today (Goklany 2007a).

Globally, average annual per capita incomes tripled since 1950. The proportion of the world's population outside of high-income OECD countries living in absolute poverty (average consumption of less than \$1 per day in 1985 International dollars adjusted for purchasing power parity), fell from 84 percent in 1820 to 40 percent in 1981 to 20 percent in 2007 (Goklany 2007a; WRI 2008; World Bank 2007).

Equally important, the world is more literate and better educated. Child labor in low income countries declined from 30 to 18 percent between 1960 and 2003. In most countries, people are freer politically, economically and socially to pursue their goals as they see fit. More people choose their own rulers, and have freedom of expression. They are more likely to live under rule of law, and less likely to be arbitrarily deprived of life, limb and property. Social and professional mobility has never been greater. It is easier to transcend the bonds of caste, place, gender, and other accidents of birth in the lottery of life. People work fewer hours, and have more money and better health to

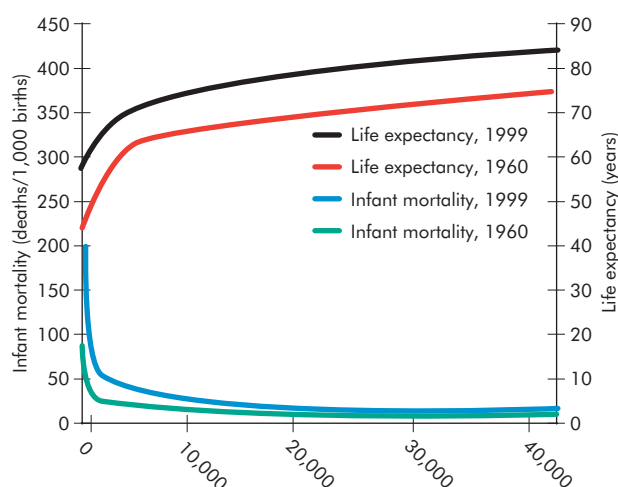
enjoy their leisure time (Goklany 2007a).

Figure 3 summarizes the U.S. experience over the 20th century with respect to growth of population, affluence, material, fossil fuel energy and chemical consumption, and life expectancy. It indicates that population has multiplied 3.7-fold; income, 6.9-fold; carbon dioxide emissions, 8.5-fold; material use, 26.5-fold; and organic chemical use, 101-fold. Yet its life expectancy increased from 47 years to 77 years and infant mortality (not shown) declined from over 100 per 1,000 live births to 7 per 1,000.

It is also important to note that not only are people living longer, they are healthier. The disability rate for seniors declined 28 percent between 1982 and 2004/2005 and, despite better diagnostic tools, major diseases (e.g., cancer, and heart and respiratory diseases) occur 8–11 years later now than a century ago (Fogel 2003; Manton *et al.* 2006).

If similar figures could be constructed for other countries, most would indicate qualitatively similar trends, especially after 1950, except Sub-Saharan Africa and the erstwhile members of the Soviet Union. In the latter two cases, life expectancy, which had increased following World War II, declined after the late 1980s to the early 2000s, possibly due poor economic performance compounded, especially in Sub-Saharan Africa, by AIDS, resurgence of malaria, and tuberculosis due mainly to poor governance (breakdown of public health services) and other manmade causes (Goklany 2007a, pp.66–69, pp.178–181, and references therein). However, there are

Figure 4 **Life expectancy & infant mortality as a function of economic development and secular technological change, 1960–1999**



Note: MXR = market exchange rates.

Source: Goklany (2007a), based on World Bank (2001)

signs of a turnaround, perhaps related to increased economic growth since the early 2000s, although this could, of course, be a temporary blip (Goklany 2007a; World Bank 2008a).

Notably, in most areas of the world, the health-adjusted life expectancy (HALE), that is, life expectancy adjusted downward for the severity and length of time spent by the average individual in a less-than-healthy condition, is greater now than the unadjusted life expectancy was 30 years ago. HALE for the China and India in 2002, for instance, were 64.1 and 53.5 years, which exceeded their *unadjusted* life expectancy of 63.2 and 50.7 years in 1970–1975 (WRI 2008).

Figure 4, based on cross country data, indicates that contrary to Neo-Malthusian fears, both life expectancy and infant mortality improve with the level of affluence (economic development) and time, a surrogate for technological change (Goklany 2007a). Other indicators of human well-being that improve over time and as affluence rises are: access to safe water and sanitation (see below), literacy, level of education, food supplies per capita, and the prevalence of malnutrition (Goklany 2007a, 2007b).

#### 4. Are food and non-renewable resources becoming scarcer?

Neo-Malthusians are also concerned that as populations

increase and become more affluent, basic resources will become scarcer, and that we may even run out of some. This, of course, was the basis for the famous bet between Paul Ehrlich and Julian Simon over whether the price of a basket of commodities would increase from 1980 to 1990, which the latter won.

However, in the last decade nominal (i.e., current) dollar prices for most commodities – food, energy, minerals and metals – have surged, due to increased demand and expansion of the money supply. In this section I will examine whether and to what extent recent increases have made these commodities less affordable. I will focus on metals, gasoline, and food in a variety of settings.

My preferred index of affordability is the ratio of price to an individual's wages or disposable personal income – the lower the ratio, the less affordable the commodity. However, where data on wages and disposable income are not available readily, I will use GDP or GNP per capita.

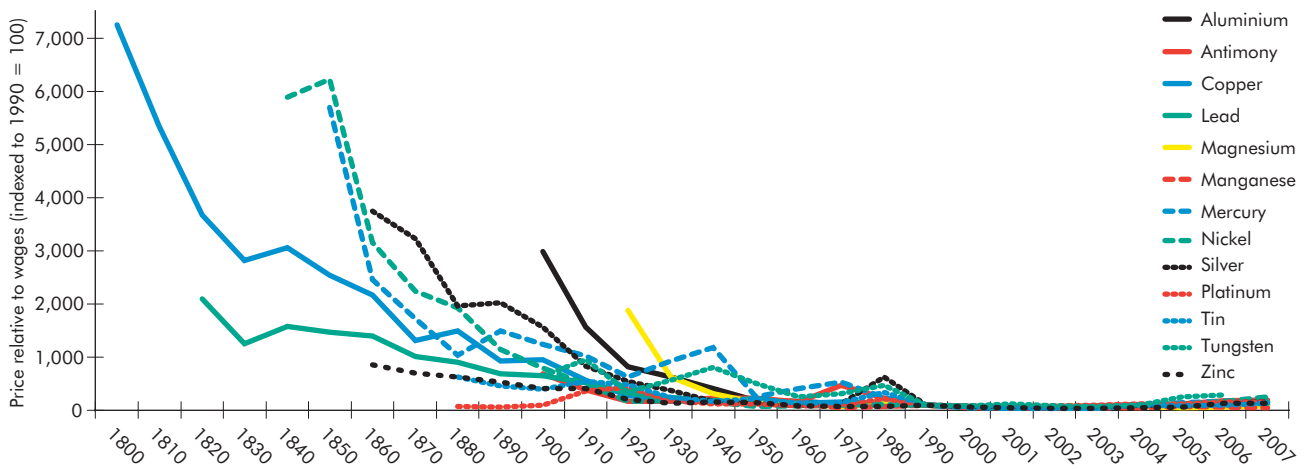
#### Metals

Figure 5 shows trends from 1800 to 2007 in the price of thirteen metals for the U.S. relative to wages, indexed to the 1990 level (=100). This indicates that these metals are generally priced higher today than in the 1990s, but not as high as they were in the 1970s and 1980s (except possibly for zinc and nickel). Perhaps more importantly, they are more affordable today than for most of history. Of course, we have no idea whether the current blips will become a long term trend or recede like previous blips in the long slide in prices-relative-to-wages.

Figure 6 shows indices for the nominal and real price of metals from 1900 to 2008. The nominal price index is patched together from Pfaffenzeller's (2007) index for six metals (aluminum, copper, lead, silver, tin, and zinc) for 1900–2000, and World Bank's (2008c, 2009) metals and minerals price index for the remainder of the period. The real price index is derived from the nominal price index using the BEA (2009) GDP deflator for 1929–2008, and the implicit price index published in U.S. Bureau of the Census (1975: 224) from 1900–1928. Although the indices are patched together using different data sources, there is no escaping the surge in prices since 2001–2002. Even in real terms, the metals price index hasn't been higher since World War I. However, in terms of affordability, estimated as the real GDP per capita divided by the real price, the picture is a little different.

Figure 7 shows that affordability peaked in 2002. It

Figure 5 **Metal prices relative to wages, U.S., 1800–2007**



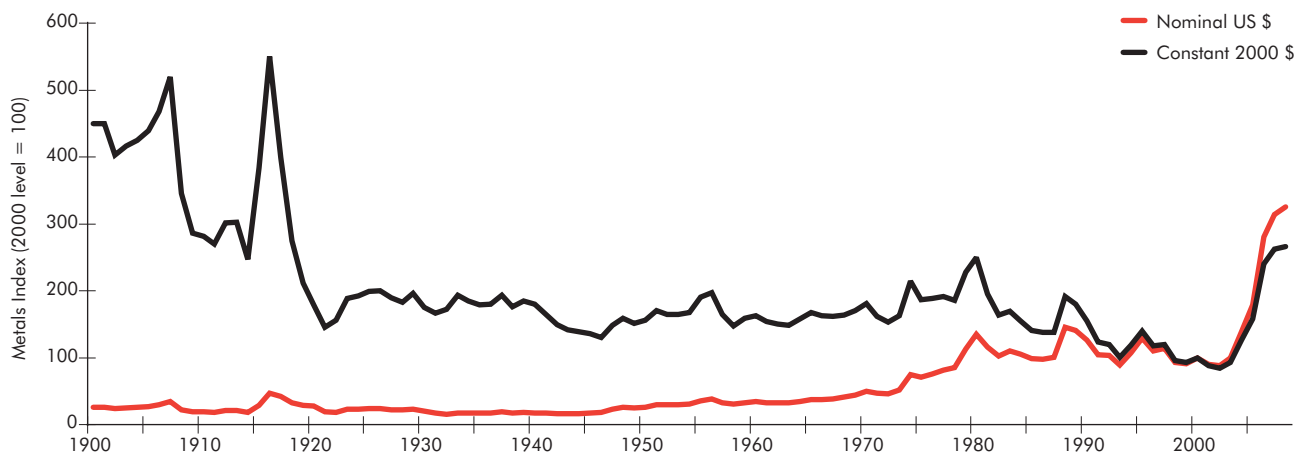
Sources: (1) Data for 1800–1990 are from Moore (1995). (2) Price data from 1990–2007 are from various issues of USGS, *Mineral Commodities Summaries and Minerals Year Books*, available at <http://minerals.usgs.gov/minerals/pubs/commodity/>, visited on July 7, 2008. (3) Wage data for 1990–2007 are from Bureau of Labor Statistics, *Establishment Data: Historical Hours and Earnings*, available at <ftp://ftp.bls.gov/pub/suppl/empsit.ceseeb2.txt>, visited June 27, 2008

is presently at the 1983–1984 level for the United States, and the 1991–1992 level for India. So, despite recent price run ups due to unprecedented demand, metals are more affordable today than they have been for much of history. For the average Indian, metals are eight times more affordable today than in 1900, and for the average American, they are thirteen times more affordable.

*Food*

Essentially similar patterns as that for metals are evident for food affordability (see Figure 8, which has been developed using the same sources and methods as that used for the previous figure). Food affordability peaked in 2001 for both the U.S. and India; food is 13 times more affordable today for the average American than it

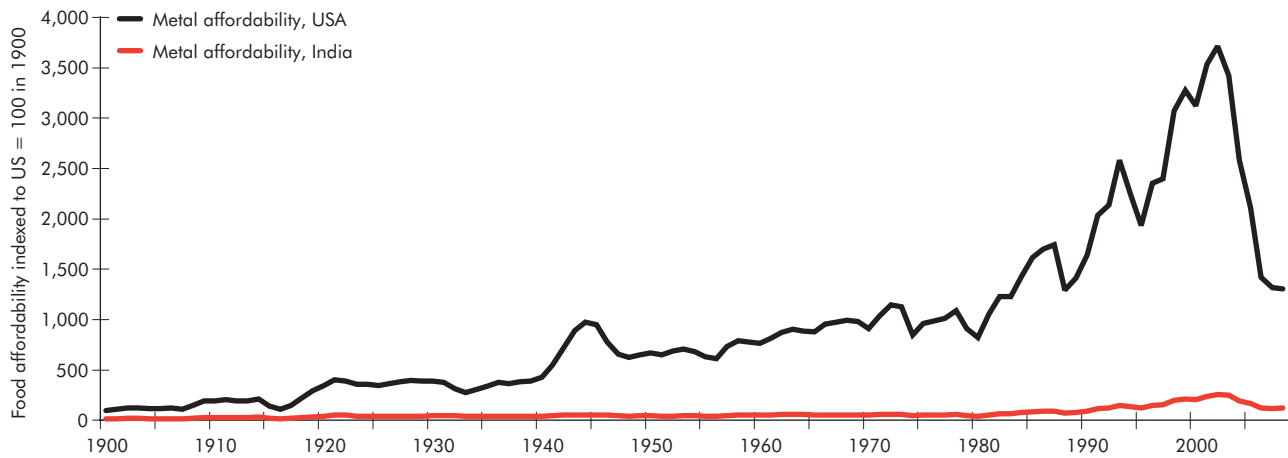
Figure 6 **Metals commodity indices, 1900–2008**



Sources: (1) Commodity price in nominal dollars is indexed to 100 in 2000. Data are from Pfaffenzeller’s (2007) index for metals for 1900–2000, and the World Bank index for minerals and metals for 2001–2008, courtesy of Betty Dow (World Bank 2008c) and World Bank (2009). (2) Constant dollars are based on GDP deflator for the U.S. from 1929–2008 using BEA (2009), and GNP deflator from USBC (1975:224), for 1900–1928



Figure 7 **Metals affordability index, India and U.S., 1900–2008**



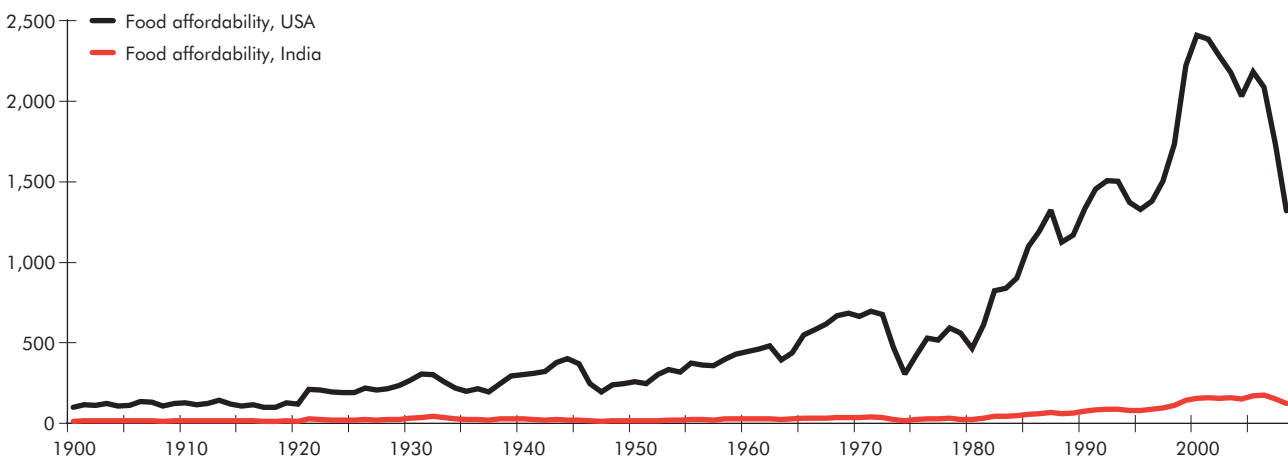
Sources: (1) See Figure 5. (2) U.S. and Indian GDP per capita are based on Maddison (2003) for 1900–1980, and GGDC (2008) for 1981–2007. For 2008, U.S. GDP per capita is based on the 2007–2008 growth in GDP per capita from BEA (2009), while Indian GDP per capita is based on a 5 percent growth in GDP per capita from 2007 to 2008 per EIU (2008)

was in 1900, whereas for the average Indian it is 8 times more affordable. This is one factor in the increased availability of food supplies per capita in India, and the long term decline in the proportion of the Indian population suffering from hunger and malnutrition (see Goklany 2007a, p. 22).

#### *Gasoline in the U.S.*

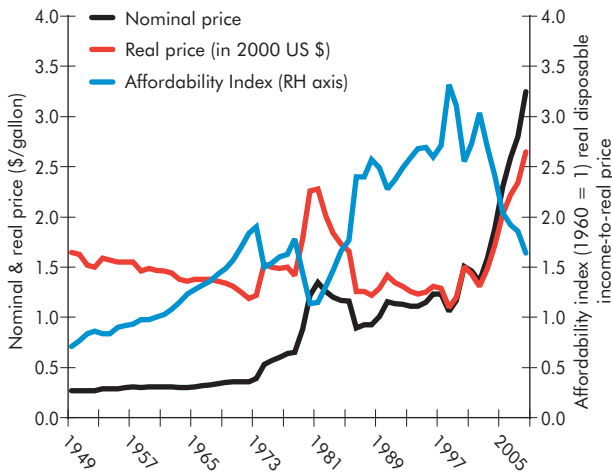
Figure 9 shows from 1949 to mid-2008, the nominal and real price indices for gasoline, and a gasoline affordability index for the U.S., the last calculated as the ratio of the average person's disposable income to the price of gasoline.<sup>5</sup> This figure, which uses a nominal price of regular gasoline of \$3.25 a gallon in 2008, shows that both the real inflation-adjusted price and the nominal

Figure 8 **Food affordability index, India and U.S., 1900–June 2008**



Sources: (1) Commodity price in nominal dollars is indexed to 100 in 2000. Data are from Pfaffenzeller's (2007) index for metals for 1900–2000, and the World Bank index for minerals and metals for 2001–2008, courtesy of Betty Dow (World Bank 2008c) and World Bank (2009). (2) Constant dollars are based on GDP deflator for the U.S. from 1929–2008 using BEA (2009), and GNP deflator from USBC (1975:224), for 1900–1928

Figure 9 **Gasoline affordability index, 1949–2008, (1960=1)**



The affordability index is calculated as the ratio of per capita disposable income to the price per U.S. gallon of regular gasoline (see text).  
Sources: DOE (2009), BEA (2009)

price in 2008 were at the highest they had been since at least 1949.<sup>6</sup> The gasoline affordability index (indexed to the 1960 level = 1) peaked in 1998 at 3.32. During 2008, averaged over the year, it was at 1.64, a level first reached in 1971 and last seen in 1984.<sup>7</sup>

### 5. Trends in environmental well-being

In this section I will examine long term trends in various key environmental indicators to establish whether they are consistent with Neo-Malthusian or other views regarding the effect of economic growth and technological change on the environment. I will use the IPAT equation to determine how well changes in impacts (I) track with changes in population (P), affluence (A), and technology (T).

#### *Estimating technological change*

In applying the IPAT equation, affluence will be measured by GDP per capita or, if that's unavailable, gross national product (GNP) per capita. For the U.S. the difference between these two measures in any year is slight – on average, within 0.54 percent (with a range from +1.21 to -0.05 percent) for 1929–1997 (Goklany 2007a).

Since A is represented by GDP per capita, the IPAT equation may be rewritten as:

$$I \equiv \text{population} \times (\text{GDP}/\text{population}) \times T \quad \dots (1)$$

Since total consumption – the product of P and A – is equivalent to GDP, the technology-factor (T) can be estimated using:

$$T = I/\text{GDP} \quad \dots (2)$$

Thus, T is equivalent to impact per unit of GDP. Notably, a decline in T would reduce I and denotes an improvement in technology.

The technological change ( $\Delta T$ ) from an initial time ( $t_i$ ) to final time ( $t_f$ ) can then be estimated by:

$$\Delta T = \Delta(I/\text{GDP}) \quad \dots (3)$$

If population, affluence, their product (GDP), and the technology-factor are all normalized to unity at  $t_i$ , then

$$\Delta T = (I_f/\text{GDP}_f) - 1, \quad \dots (4)$$

where subscript f denotes the value at the end of the period.

Where emissions (E) are used to characterize the environmental impact, technological change is the change in emissions per GDP, that is,

$$\Delta T = \Delta(\text{emissions}/\text{GDP}) = (E_f/\text{GDP}_f) - 1 \quad \dots (5)$$

I will, except where noted, use Equation 4 (or 5) to estimate technological change, and whether that has made matters better or, consistent with the Neo-Malthusian view, worse over the period of analysis. For some indicators, e.g., mortality from extreme weather events (a purported indicator of global warming) or water related diseases, I will substitute  $P_f$  for  $\text{GDP}_f$  ( $= P_f \times A_f$ ) in the above equations on the basis that, *ceteris paribus*, as a first order approximation, mortality increases linearly with P but is relatively insensitive to affluence.

#### *5.1 Cropland or terrestrial habitat conversion*

Because cropland is critical for producing the food and nutrition necessary to ward off hunger and malnutrition – still among the largest contributors to global mortality (Goklany 2007a, pp. 355–356) – the first Malthusian concern was that humanity may run out of cropland. Now many are concerned that there may be too much

cropland. In fact, the single largest threat to terrestrial ecosystems and biodiversity is the diversion of habitat to agricultural uses, particularly cropland (Goklany 1998; MEA 2005: 117).

Figure 10 shows trends for the U.S. from 1910 to 2006 in the amount of cropland planted, population (P), affluence (A), GDP (= P x A), as well as two measures of technology, namely, T (calculated as I/GDP) and T' (calculated as I/P). All variables are normalized to 1910.

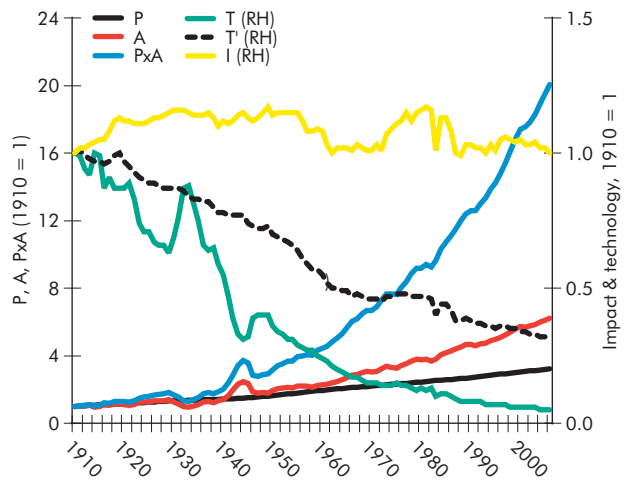
This figure shows that despite a more-than-tripling of the population and a 19-fold increase in consumption (GDP), cropland was unchanged at 330 million acres. That is, the impact as measured by this indicator has not increased, contrary to naïve interpretations of the IPAT equation. This is because the decline in the T-factor has compensated for these increases. T' was at 0.31 in 2006 relative to 1910, i.e., technology reduced the impact by 69 percent over what it would otherwise have been.

Arguably, however, it is more appropriate to use GDP (= P x A) to estimate technology because affluence increases the demand for meat and milk, and the propensity for wastage. Using this measure, T (= I/GDP) stands at 0.05 in 2006 relative to 1910, that is technology reduced impact by 95 percent. Perhaps, the correct measure would be to use the product of population and the logarithm of affluence. Regardless, T and T' bracket the range for technology.

Note that cropland was higher (387 million acres) in both 1949 and 1981 than in 1910 and 2006. The current area of cropland might have been lower still but for subsidies which have partially negated the improvements that technological change might otherwise have achieved. Note, however, that some of the increase in yield that has helped halt land conversion could be due to higher carbon dioxide concentrations (e.g., IPCC 2001, p.254). This is included in the technology term by default.

Figure 11, which shows global trends in cropland from 1700 to 2005, also offers no support for the proposition that increases in population and affluence necessarily increase impacts. In fact, this figure indicates that technological change since 1961 "saved" about 1,300 million hectares from conversion to cropland and that, like in the U.S., cropland may be peaking globally (that is, going through an environmental transition; Goklany 2007a). Whether it actually stabilizes and/or declines consistent with the environmental transition hypothesis depends on the availability, and barriers to, technological change. In this regard, European attitudes toward genetically modified crops, and the diffusion of those attitudes to developing countries, particularly in Africa, retards technological change and are counterproductive, as are

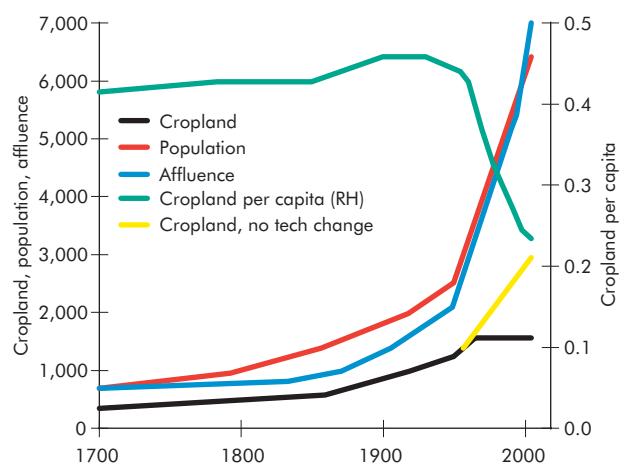
Figure 10 **IPAT for U.S. cropland, 1910–2006**



Sources: GDP and population data are from Maddison (2003), GGDC (2008), World Bank (2008a); cropland data is from ERS (2008)

subsidies in developed countries which keep more land under cultivation (Goklany 2007a).

Figure 11 **Global cropland (in billion hectares), population (in billion people), affluence (in thousands of 1990, PPP-adjusted International\$), and cropland per capita, 1700–2005**



Note that the difference between the dotted and solid blue lines equals the amount of habitat "saved" from conversion had technology been frozen at 1961 levels.

Sources: Goklany (2007a), Maddison (2003), GGDC (2008), FAOSTAT (2008); World Bank (2008a)

### 5.2 Water withdrawal and consumption

Just as the diversion of land to meet human needs is the single greatest threat to terrestrial biodiversity, so is diversion of water the greatest threat to freshwater biodiversity.

For the United States, over the 50-year period, 1950–2000, the split between surface and ground water withdrawals has stayed more or less constant at 80/20 percent, respectively (Hutton *et al.* 2004). The portion of surface-water withdrawals that was classified as saline increased from 7 to 20 percent between 1950 and 1975. It has since remained approximately constant.

Between 1950 and 1980, while U.S. population increased by 53 percent and, economic consumption by 191 percent, total water withdrawals increased by 144 percent. However, between 1980 and 2000, water withdrawals declined by 7 percent despite increases of 24 and 90 percent in population and economic consumption, respectively (Hutson *et al.* 2004). Moreover, the long term trend of declining total wetland area in the U.S. seems to have halted and even reversed, with 190,000 acres being added between 1998 and 2004 (Dahl 2006).

By contrast with the reduction in water withdrawals in the U.S., data from Shiklomanov (2000) indicates that while water withdrawals and use might be approaching saturation globally, they had not peaked as of 1995, although on a per capita basis, they began to decline in the 1980s. See Figure 12.

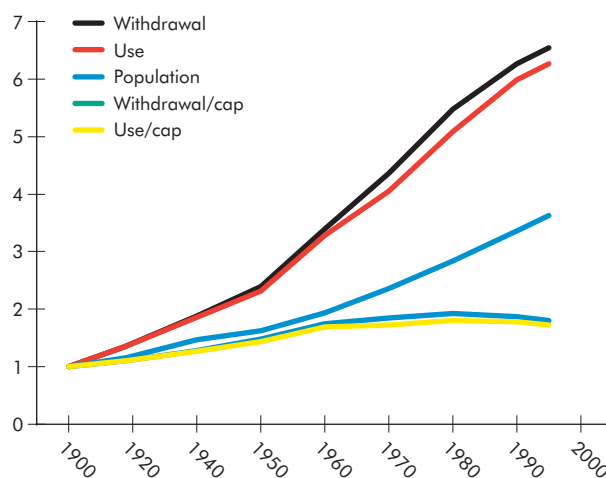
### 5.3 Water-related impacts

Water has traditionally been high on the list of environmental priorities because of the potential of death and disease from water related diseases. Figure 13 shows that from 1900–1970, U.S. death rates due to various water-related diseases – dysentery, typhoid, paratyphoid, other gastrointestinal disease, and malaria – declined by 99.6 to 100.0 percent (USBC, various years).

These reductions, which preceded the 1972 Clean Water Act, can be attributed to, among other things, greater knowledge of better hygiene, greater access to safe water and sanitation, and new and more effective therapies.

Analysis of cross country data indicates that with economic development and time, access to both safe water and sanitation generally increases in terms of absolute numbers and, more significantly, as a proportion of total population (Goklany 2007a, 2007b). Because of higher levels of economic development and technological

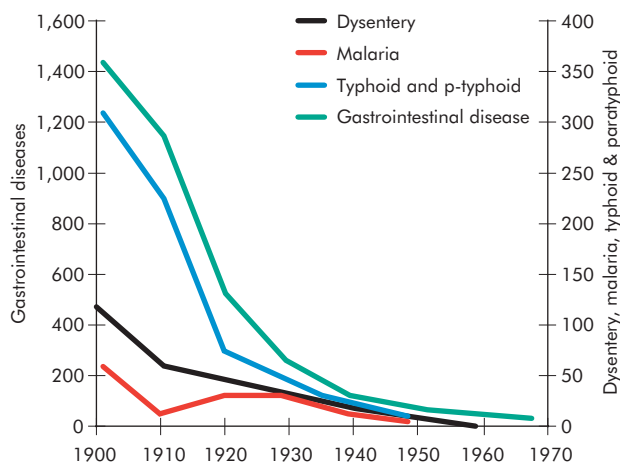
Figure 12 **Global water withdrawals and use, 1900–1995**



Source: Shiklomanov (2000)

diffusion, such access, although not yet universal, has never been higher. Between 1990 and the early 2000s, for example, the proportion of the population with access to safer water increased from 70 to 84 percent in South Asia and 49 to 53 percent in Sub-Saharan Africa, while with regard to sanitation, it increased from 16 to 35 percent in South Asia, and 32 to 36 percent in Sub-Saharan Africa (World Bank 2008b).

Figure 13 **Death rates for various water related diseases, 1900–1970**



Source: Goklany (2007a), based on USBC (various years, 1975)

#### 5.4 Traditional air pollution

Concern over traditional air pollutants – soot, other forms of particulate matter, sulfur dioxide, carbon monoxide and, in some places, ozone – was instrumental in raising environmental consciousness in the U.S. and today's richer countries. Long term data indicates that air quality for these traditional pollutants has generally improved, particularly for the substances – and in the areas – that were of the greatest public health concern (Goklany 2007a). For these countries, long term air quality trends show pronounced peaks that are generally consistent with the environmental transition hypothesis rather than with Neo-Malthusian theories that affluence and technological change make matters worse.

With respect to the U.S., probably a harbinger for other countries, the earliest environmental transitions apparently occurred for indoor air quality (by the 1940s), followed later by improvements in outdoor air quality. This is especially significant because the vast majority of people spend the majority of their time indoors, generally at home. Therefore indoor exposure is perhaps the single most critical determinant of the potential public health impact of air pollution. Remarkably, these improvements in indoor air quality, which were enabled by improvements in technology and greater affluence, occurred voluntarily as households moved away from solid fuels such as coal and wood to cleaner energy sources within the home – oil, gas, electricity.

With respect to U.S. national outdoor air quality as well, the transitions seem to have occurred earlier for pollutants and locations that were of the earliest and greatest concern. They occurred first for total suspended particulate matter (around 1957), followed by sulfur dioxide (early-to-mid 1960s), carbon monoxide (mid-to-late 1960s), lead (mid-to-late 1970s), ozone (mid-to-late 1970s nationally but mid-1950s in California, where it was a major early concern), and finally nitrogen oxides (in the late-1970s). Perhaps surprisingly, many of these transitions also preceded the U.S. Clean Air Act Amendments of 1970.

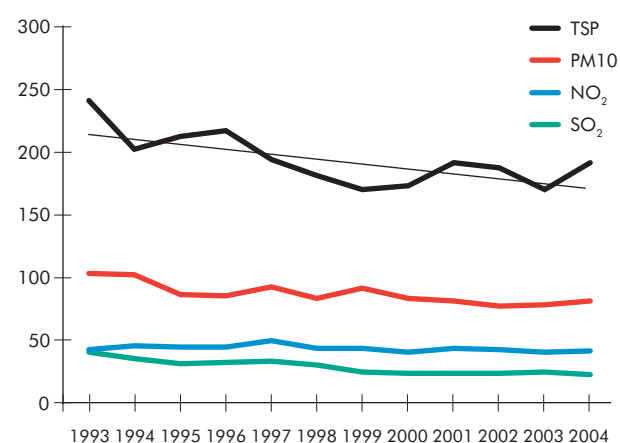
For the traditional air pollutants, trends in emissions (an indicator of less relevance to public health and welfare than either indoor or outdoor air quality), indicate that they too have gone through their environmental transitions in the US.

Notably, air quality in the currently industrializing (or developing) countries is substantially worse than in developed countries. Beijing, Mexico City, New Delhi and Cairo, for instance, are among the most polluted cities in the world. Nevertheless, developing countries

seem to have learnt from the experience of developed countries. In fact, in many respects, they are ahead of where industrialized countries were when they were at the same level of economic development. For example, the U.S. first introduced unleaded gasoline in 1975 when its GDP per capita was \$16,300, whereas India and China instituted some controls for lead-in-gasoline by 1997, when their GDPs per capita were \$1,600 and \$3,000, respectively (Maddison 2003; Goklany 2007a). By 2006, only about 25 countries out of about 200 were using leaded gasoline (Dumitrescu 2005) although the global GDP per capita was about \$7,300. This, of course, is due to the diffusion of knowledge and technology from industrialized to developing countries.

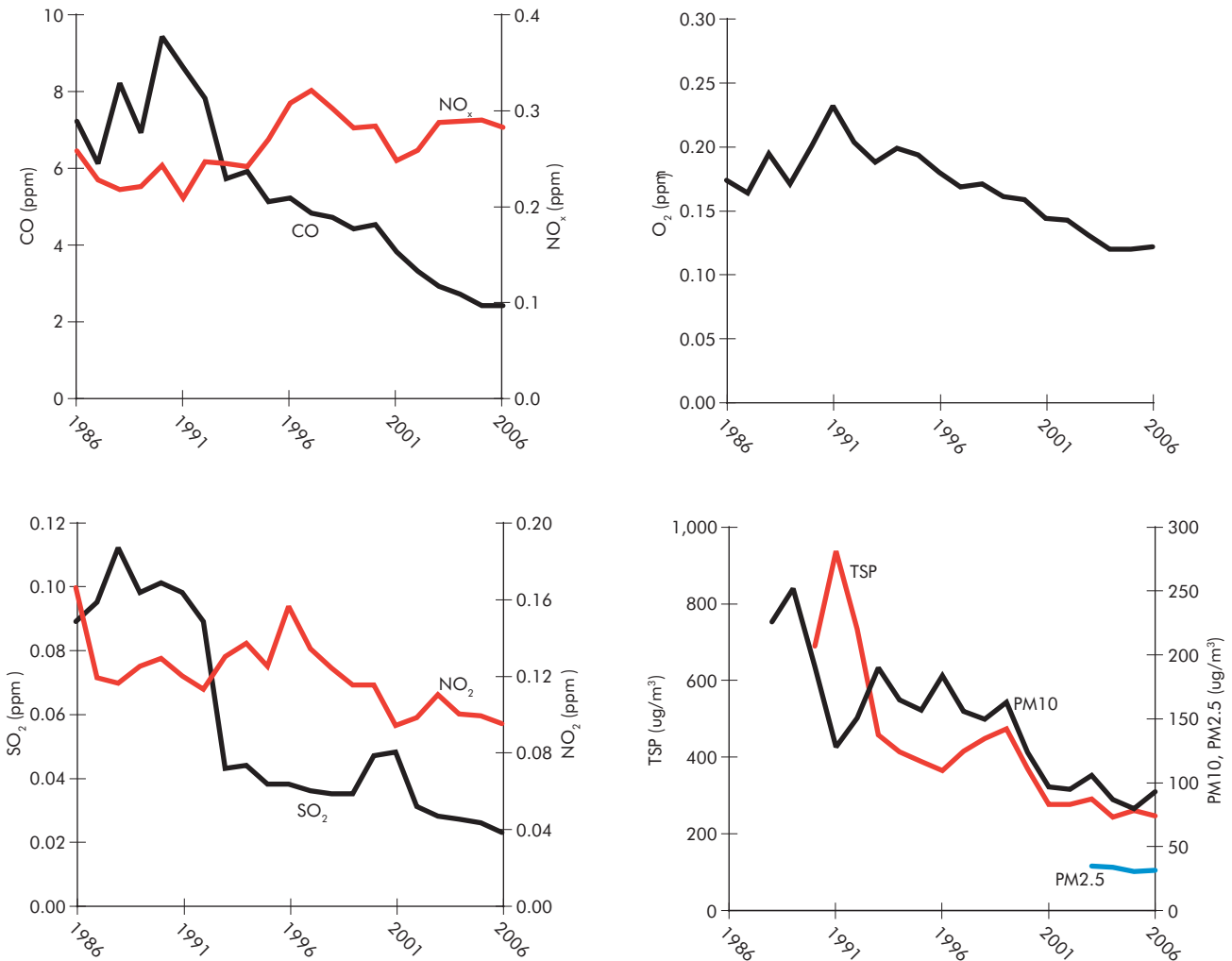
Analysis of air pollution trends from 1993–2004 in twenty Asian cities – Bangkok, Beijing, Busan, Colombo, Dhaka, Delhi, Hanoi, Ho Chi Minh, Hong Kong, Jakarta, Kathmandu, Kolkata, Mumbai, Manila, Seoul, Shanghai, Singapore, Surabaya, Taipei and Tokyo – showed that, in general, TSP and PM-10 decreased between 1993 and 2004, although ambient levels were above limits set by the World Health Organization (Figure 14; CAI-Asia 2006). [Sixteen of the 20 cities are in developing Asia.] For SO<sub>2</sub>, levels had been improved to within WHO guidelines. For NO<sub>x</sub>, the levels had been stabilized around WHO guidelines. These results are consistent with Hao and Wang's (2005) analysis indicating that despite substantial emission increases, average concentrations in Chinese cities for total suspended particulates, PM-10, and SO<sub>2</sub> declined by 25, 10 and 44 percent, respectively, between 1990 and 2002.<sup>8</sup>

Figure 14 **Air quality trends in 20 major Asian cities, 1993–2004**



Source: CAI-Asia (2006)

Figure 15 Air quality trends in the Mexico City metropolitan area, 1986–2006



Source: Molina et al. (2008)

In other words, some areas in Asia have apparently gone through their environmental transitions for a variety of air pollutants, and at lower levels of economic development than in the U.S.

There have been improvements in Latin America as well. Figure 15 shows improvements in Mexico City, legendary for its air pollution, from 1986–2006 (Molina et al. 2008). Similarly, PM-10 concentrations in Brazil’s industrial region of Cubatao – among the world’s fastest growing industrial areas – declined from 180 to about 80 micrograms per cubic meter from 1984–1998 (Wheeler 2001). Fine particulate matter (PM-2.5) concentrations dropped 52 percent in Santiago, Chile between 1989 and 2001 (Koutrakis et al. 2005).

The major air pollution problems in developing countries are, however, indoors. Half of the world’s population continues to use solid fuels such as coal, dung and

wood. The World Health Organization’s *Global Burden of Disease 2000 (Version 2)* study estimates that in 2000 air pollution was responsible for 2.4 million premature deaths (or 4.3 percent of all deaths). Two-thirds of these deaths were attributed to indoor pollution from particulate matter in developing countries – from cooking and heating with coal, dung and wood – and the remainder to outdoor air pollution (WHO 2002a, 2002b; Bruce et al. 2000). On the basis of disability-adjusted life years (DALYs), a measure which discounts every year of life lived under a disability by the severity of that disability, indoor air pollution accounts for 2.7 percent of annual lost DALYs worldwide, and outdoor air for 0.5 percent.

If the currently poor inhabitants of less developed countries were to grow richer, they would have the means to switch out of dirty solid fuels and into cleaner established technologies such as natural gas, oil or even

electricity, which would help reduce the disease burden in these countries significantly. It would essentially allow today's developing countries to follow the same path so successfully taken by the rich nations in reducing population exposure to air pollutants. This is essentially the opposite of the claim made by opponents of affluence.

### 5.5 Global warming

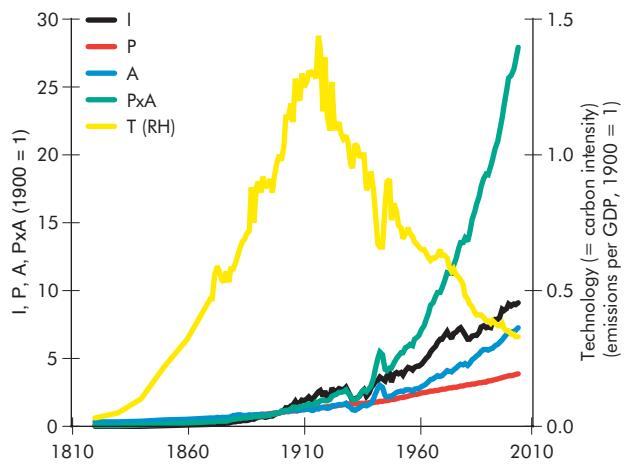
#### Carbon dioxide

Unlike the other environmental indicators examined thus far, carbon dioxide has only recently been elevated in the popular mind as a significant environmental problem. Arguably, this elevation did not occur until around the late 1990s with the passage of the Kyoto Protocol or even the first decade of the 21st century, with the publication of the IPCC's Third and Fourth Assessment Reports. Even now, some would dispute this characterization, while others would dispute its importance (e.g., Lomborg 2004; Goklany 2005). Efforts to reduce CO<sub>2</sub>, therefore, are still immature. This task is further complicated by the socioeconomic consequences of reducing CO<sub>2</sub> emissions (Nordhaus 2008) and the fact that it will necessarily take time, technology and capital to modify existing energy infrastructure. Accordingly, it is no surprise that empirical trends do not indicate that CO<sub>2</sub> has peaked. However, in many places emissions per GDP (or the carbon intensity) have peaked and are falling steeply. Indeed, CO<sub>2</sub> per unit of GDP is a *leading* environmental indicator (because absent a long term sustained reduction in it, a growing economy will be unable to bring about a transition with respect to total emissions; Goklany 2007a).

Figures 16 and 17 show U.S. and global trends from 1820 to 2004 in each of the terms of the IPAT equation and PxA (=GDP), all normalized to 1900 for CO<sub>2</sub>. I (i.e., CO<sub>2</sub> emissions), P, A, and PxA are plotted on the left hand axis, and technology (=I/PxA) on the right hand axis.

They show that for the U.S., despite a 27-fold increase in GDP since 1900, CO<sub>2</sub> emissions increased 8-fold. This translates into a 67 percent reduction in impact per unit of consumption (i.e., the T-factor, which is also the carbon intensity of the economy) during this period, or a 1.1 percent reduction per year in the carbon intensity between 1900 and 2004. Since 1950, however, U.S. carbon intensity has declined at an annual rate of 1.7 percent. (Arguably, CO<sub>2</sub> emissions might have been lower, but for the hurdles faced by nuclear power.)

Figure 16 **U.S. IPAT trends for CO<sub>2</sub>, 1820–2004**

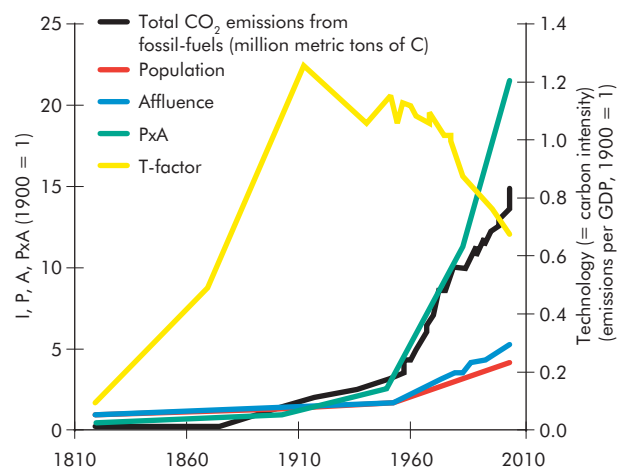


Sources: Marland et al. (2007), Maddison (2003), GGDC (2008)

Globally, output increased 21-fold since 1900, while CO<sub>2</sub> increased 13-fold because technology reduced the impact cumulatively by 32 percent or 0.4 percent per year. Both U.S. and global carbon intensity increased until the early decades of the 20th century. Since 1950, global carbon intensity has declined at the rate of 0.9 percent per year.

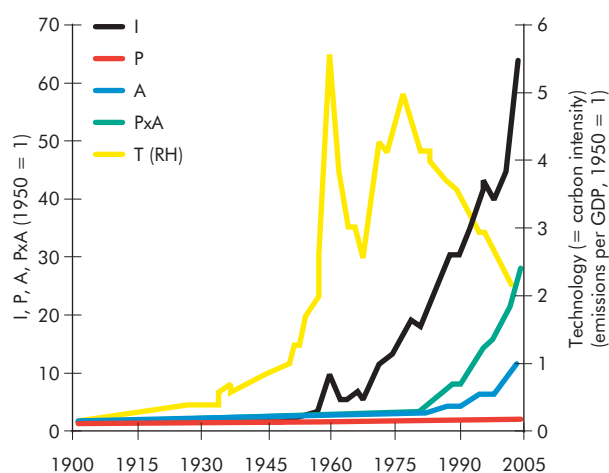
Figure 18 shows the components of IPAT and PxA for China from 1900–2004, each normalized to 1950 levels. Chinese output increased by a factor of 27 since 1950,

Figure 17 **Global IPAT trends for CO<sub>2</sub>, 1820–2004**



Sources: Marland et al. (2007), Maddison (2003), GGDC (2008), World Bank (2008a)

Figure 18 **China IPAT trends for CO<sub>2</sub>, 1900–2004**



Sources: Marland *et al.* (2007), Maddison (2003), GGDC (2008)

while CO<sub>2</sub> emissions increased by more than twice as much (a factor of 63), reflecting its rapid transition from a rural agrarian society to the world’s manufactory. From 1950 to 2004, improvements in carbon intensity failed

to keep pace with the cumulative output increase. Since 1979, the first year of China’s economic reforms, carbon intensity has dropped at an annual rate of 1.3 percent, in part because of the reforms. Nevertheless, this drop has not been large enough to compensate for the tremendous increase in consumption.

Since improvements in technology mostly preceded general recognition of CO<sub>2</sub> as an environmental issue, they can mainly be attributed to “business as usual” where all economic participants seek to maximize private welfare (including profits) via minimization of costs (including energy costs).

### *Deaths due to extreme events*

To the extent that extreme weather events are exacerbated by global warming, deaths due to such events could be an indicator of the impacts of global warming.

Globally, both cumulative mortality and cumulative mortality rate<sup>9</sup> for all extreme weather events (namely, drought, extreme temperatures, floods, slides, waves and surges, wildfires, and wind storms) have been declining since the 1920s [Goklany (2007c), based on data from

Table 1: **The effects of technological change on declining U.S. and global mortality and mortality rate for extreme weather events during the 20th century**

	Deaths, earliest 10-year period	Deaths, final 10-year period	Death rates, earliest 10-year period (per million)	Death rates, final 10-year period (per million)	Technological change (%), based on mortality rate	Rate of technological change (%/year), based on mortality rate
World all extreme events 1900/09–1997/2006	1,280,000	258,000	78.8	4.17	–95.3	–3.1
U.S. Hurricanes 1900/09–1997/2006	8,730	1,760	11.3	0.60	–94.7	–4.6
U.S. floods 1903/12–1997/2006	260	740	0.31	0.26	–15.8	–0.3
U.S. tornados 1917/26–1997/2006	3,160	620	2.90	0.22	–92.5	–4.1
U.S. Lightning 1959/68–1997/2006	1,180	440	0.63	0.16	–75.4	–2.2

Source: Goklany (2007c), based on EM-DAT (2007) for global mortality data; McEvedy and Jones (1978) for global population; Blake *et al.* (2007) for U.S. hurricanes; NCDC (2005, 2007) and NWS (2007) for U.S. lightning and tornados; HIC (2007) for U.S. floods; USBC (2007) for U.S. population. NOTE: A negative sign indicates that technological change reduces impacts.



EM-DAT (2007)). While older data are necessarily suspect, between 1900–1909 to 1997–2006, mortality apparently dropped by 80 percent and mortality rate by 95 percent, the latter at an annual rate of 4.6 percent (see Table 1). The drops after the 1920s (not shown below) are even steeper (Goklany 2007c).

Table 1 also shows that with regard to the U.S., a similar comparison of the earliest 10-year period to the latest 10-year period (1997–2006) for which data were available at the time of analysis, mortality due to hurricanes, tornados and lightning was reduced by 80, 80 and 63 percent, and mortality *rate* by an annual rate of 4.6, 4.1 and 2.2 percent per year, respectively. However, for floods, mortality increased by 85 percent, but mortality rate declined 16 percent (an annual rate of 0.3 percent).

Note that for each of these U.S. indicators in Table 1, except hurricanes, mortality and mortality rates peaked during the 20th century. For hurricanes the peak occurred in 1900–1909, and was dominated by the 8,000 fatalities due to the 1900 Galveston hurricane, and there was a subsidiary peak during the last period because of the 2005 hurricane season, for which I used a death tally of 1,525 per Blake (2007).

## 6. Effects of long term technological change on impacts

Table 2 shows for the environmental indicators and areas examined in Section 4, long term changes in environmental impact (I), population (P), affluence (A), their product ( $GDP = P \times A$ ), the technology factor (T), and technological change ( $\Delta T$ ). T and  $\Delta T$  are calculated using Equations 4 or 5, except for mortality, where population is substituted for GDP.

The entries for each of the components of the IPAT equation are their values at the end of the period of analysis normalized to unity at the beginning of the period. Thus, the first row indicates that in 2006, U.S. population was 3.22-times its 1910 level; affluence, 6.24-times; GDP, 20.08-times. Nevertheless, the environmental impact of U.S. agriculture, measured by the amount of cropland, was essentially unchanged. T, measured by cropland per GDP, was 0.05 times its 1910 level. Hence, the amount of technological change ( $\Delta T$ ) during the intervening period – the percent change in impact per unit of GDP – is minus 95.0 percent (in the second last column). [The *minus* sign indicates that the environmental impact per unit of GDP *declined*, i.e., matters *improved*.] Finally, the last column provides an estimate of the annual rate

of technological change, assuming exponential change (minus 3.1 percent per year).

As with all trends, results displayed in Table 2 can be sensitive to the starting and ending years used for compiling the data, particularly for episodic events, e.g., extreme weather events. To avoid bias, in these cases I used the longest readily available record.

This table indicates that since 1900 affluence has increased faster than population worldwide, and in the U.S., China and India.

Second, but for technological change, impacts would generally have been much higher, in many instances by an order of magnitude or more. For instance, per unit of GDP, technological change reduced the global environmental impact of agriculture by 84 percent from 1950 to 2005. In fact, it has stabilized the amount of habitat converted to cropland in the U.S. and almost stabilized it globally (Figures 10 and 11). During the 20th century, it reduced death rates from various water related diseases in the U.S. by 99.6–100 percent. It also reduced the cumulative global death rate from extreme weather events by 95 percent, while reducing U.S. death rates from hurricanes, lightning, floods and tornados by 16–95 percent. Because of technology, U.S. indoor air pollution levels are currently 96 to 99 (+) percent lower than they otherwise would be. However, while technology reduced the rate of increase, CO<sub>2</sub> emissions, nevertheless, grew substantially.

Third, improvements are apparently more pronounced for indicators most directly related to human well-being. Specifically, for each pollutant, indoor air quality improved earlier and faster than outdoor emissions (which comprise the bulk of emissions), and mortality rates were reduced more than indicators whose relationship to public health is more indirect. With respect to global warming related indicators, mortality rates from total extreme weather events declined substantially, although carbon dioxide emissions increased despite reductions in the carbon intensities of economies. The latter is true even in India and China, where recent improvements in carbon intensities coincide with the initiation of economic liberalization, despite generous fuel subsidies to consumers.

For the environmental indicators used to characterize the impacts on land, air, and water – cropland, indoor air quality, traditional air pollutant emissions, and mortality from water-related diseases – technological change generally more than compensated for any long term increase that might have occurred in impact due to increases in either population or affluence, but not always for the combined effect of the two (i.e.,  $P \times A$ ). The exceptions

to this are: (a) U.S. NO<sub>x</sub> emissions where technology compensated for population increase between 1900 and 2003, but not for affluence, (b) water withdrawals for the U.S. from 1950–2000, where technology compensated for population but not for affluence, and (c) global water withdrawals and consumption from 1900–1995, where technology failed to keep pace with either population or affluence.

What the table does not show is that even where technology was unable fully to compensate for the increase in aggregate output over the entire period – water withdrawals and national air emissions are cases in point – it moderated impacts so that, by the end of the period, in most cases impacts had peaked and were substantially lower than in previous decades (Goklany 2007a, p. 133).

In general, long term environmental trends have not conformed to the notion that, sooner or later, technology will necessarily increase environmental impacts. Moreover, if one goes sufficiently far back into the historical record, e.g., for habitat converted to cropland, air pollution emissions or water related diseases, the initial trends will show environmental deterioration, seemingly validating the Neo-Malthusian view. But over time this interpretation fails, as the environmental impact is more or less halted (e.g., cropland) or even reversed (air and water pollution) (Goklany 2007a). Such declines lend credence to the environmental transition hypothesis and indicate that, in effect, sooner or later technology no longer acts as a multiplier, but as a divisor for the environmental impact.

## 7. Discussion

Long term empirical trends offer little support for Neo-Malthusian worldviews. Yes, global population has continued to rise, as has affluence, output and consumption. But metals, food and energy are more affordable today than they have been for much of history. More importantly, human well-being has never been higher. Moreover, population is no longer increasing exponentially. In fact, there are signs that it could plateau, and possibly even decline in the coming decades.

Initially in the arc of development, environmental quality indeed suffered, but by virtually every critical measure – hunger, malnutrition, mortality, education, income, liberty, leisure, material goods, mobility, life expectancy – human well-being advanced. In the U.S., for instance, this advance has been more or less continuous since the 1850s, despite the waxing and waning of a variety of environmental problems in the interim. And

this is also true for the world as a whole, at least since the 1950s (Goklany 2007a).

The improvements in human well-being despite increased population suggest that contrary to Neo-Malthusian claims e.g., Diamond (2005, p. 505), affluence and technology have solved more problems than they have created.

Historically, in the richer countries hunger and water related diseases were conquered first, then indoor air pollution, and finally outdoor air pollution. Once richer countries learned to cope with water related diseases such as cholera and dysentery (through knowledge of basic hygiene, a better understanding of the causes of these diseases, better access to safe water and sanitation, draining of swamps, and so forth), there was little *public* emphasis on other environmental problems. Despite that, *private* actions for the most part cleaned up indoor air pollution. These actions, including voluntary switching to cleaner fuels and installation of more efficient combustion appliances, were enabled by greater prosperity and technological change, and driven by each household's natural desire to advance its own quality of life (Goklany 2007a, pp. 79–100).

Similar economic and behavioral forces were also at work for outdoor air pollution, and the pollution intensity of the economy declined, but not rapidly enough even though, in retrospect, many of the traditional air pollutants were in the midst of, or had even gone through, their environmental transitions (Goklany 2007a, pp. 130–139, 146–151, 191–201). In the U.S., in the wake of the prosperity of the 1960s and early 1970s and once the privations of the Great Depression and World War II had become distant, the clamor for governmental intervention grew. The resulting regulations helped maintain the momentum, although they do not seem to have accelerated, the underlying rate of improvement driven by the imperative of economic efficiency in a relatively free market system, and compounded by the transition from a manufacturing economy to a service and knowledge based economy (Goklany 2007a, pp. 232–234).<sup>10</sup> Consequently, environmental quality is much better now than in previous decades. Carbon dioxide emissions, however, continue to grow. But this is due to the fact that it is a late arrival to society's list of environmental problems – in fact, its importance, given other global problems, is still contested – and, in any case, there's been insufficient time to address it economically (Lomborg 2004; Goklany 2005, 2007a; Nordhaus 2008).

Today's developing countries have been following the path laid down by the early developers. Many of them have lower environmental quality than previously, but

because of the diffusion of technology (which includes knowledge) from developed countries, they are farther along than early trailblazers such as the U.S. at the same level of economic development. For instance, in 2006 when GDP per capita for low income countries was \$1,327, their life expectancy was 60.4 years, a level that the U.S. first reached in 1921, when its GDP per capita was \$5,300. Even Sub-Saharan Africa, the world's developmental laggard, is today ahead of where the U.S. used to be! In 2006, its per capita GDP was at the same level as the U.S. in 1820 but the U.S. did not reach Sub-Saharan Africa's current infant mortality level until 1917, and life expectancy until 1902 (estimated from World Bank 2008a; Maddison 2003, GGDC 2008; USBC 2008).

It can not be overemphasized that despite any environmental deterioration that may have occurred, the well-being of the vast majority of the world's human population has been improving continually over the past several decades, as indicated not only by life expectancy, but by other critical measures of well-being, including poverty, mortality rates, food supplies, education, child labor, and so forth (Goklany 2007a).

Why does reality not mirror Neo-Malthusian concerns?

First, much of the environmental and Neo-Malthusian narrative implicitly or explicitly equates human well-being with environmental well-being. While the latter may be a component of the former, the two aren't the same. Few inside and even fewer outside rich countries would rank environmental indicators among the most important indicators of human well-being,<sup>11</sup> except perhaps for access to safe water and sanitation.<sup>12</sup> In fact, the most critical indicators of human well-being – life expectancy, mortality rates, prevalence of hunger and malnutrition, literacy, education, child labor, or poverty – generally improved even during periods when other environmental indicators were deteriorating (e.g., Figure 3), indicating a lack of correlation between the two over the long term. In fact, long term trends are consistent with the environmental transition hypothesis in that in its early stages, economic and technological development is negatively correlated with environmental quality, whereas at high levels of development the correlation is positive (Goklany 2007a).

Second, as already emphasized, population growth has slowed. It is no longer growing exponentially. And affluence and technology have much to do with that (Figure 2).

Neo-Malthusians also overlook the fact that in many respects affluence, technology and human well-being reinforce each other in what has been called the cycle of

progress (Goklany 2007a, pp. 79–97). If existing technologies are not up to the task of reducing impacts or otherwise improving the quality of life, it is possible with wealth and human capital to improve existing technologies or create new ones that will. HIV/AIDS is a case in point.

When HIV/AIDS appeared on the scene, it was totally unanticipated. It was, for practical purposes, a death sentence for those who contracted it. It took the wealth and human capital of the most developed countries to launch a response. Out of this came an understanding of the disease and the development of various therapies. Once among the top ten killers in the U.S., today HIV ranks nineteenth (counting all cancers and cardiovascular diseases as individual categories). From 1995 to 2004, age-adjusted death rates due to HIV declined by over 70 percent (USBC 2008). The rich countries have figured out how to cope with it, and developing countries are benefiting from the technologies that the former were able to develop because they had the necessary economic and human resources, and institutions at their disposal.

Third, both technology and affluence are necessary because while technology provides the methods to reduce environmental problems, affluence provides the means to afford them. In fact, access to HIV therapies in many developing countries is much higher because of wealthy charities and governments of the developed countries (Goklany 2007a, pp. 79–97).

Fourth, there is a secular component to technological change (see Figures 2 and 4), so that it ought to advance even if affluence does not, provided we are open to scientific and technological inquiry. Thus, with secular technological change and the mutually reinforcing advances in economic development, the ability to reduce untoward impacts and enhance the quality of life has also grown rapidly.

These factors acting in concert over the long haul, have enabled technology for the most part to improve faster than either population or affluence and helped keep environmental damage in check (e.g., for cropland) or even reverse it (e.g., for water pollution, and indoor and traditional outdoor air pollution), particularly in the richer countries (see Table 2).

Table 2 also shows that in the long run, technology has often reduced impacts by an order of magnitude or more. Thus, notwithstanding plausible arguments that technological change would eventually increase environmental impacts, historical data suggest that, in fact, technological change *ultimately* reduces impacts, provided technology is not rejected or compromised via subsidies

Table 2: **Changes in population, affluence and technology for various indicators**

Indicator	Area	Period	Population (P)	Affluence(A = GDP/P)	P x A = GDP	Impact (I)	Technology factor (T)	Technological change Total ΔT in %   ΔT, in %/year	
<b>LAND (habitat converted to cropland)</b>									
cropland planted	U.S.	1910–2006	3.22	6.24	20.08	1.00	0.050	–95.0	–3.1
cropland	World	1950–2005	2.56	3.32	8.49	1.34	0.157	–84.3	–3.3
cropland	India	1961–2005	2.43	3.19	7.77	1.05	0.136	–86.4	–4.4
cropland	China	1961–2005	1.97	10.44	20.57	1.49	0.072	–92.8	–5.8
<b>WATER WITHDRAWAL &amp; USE</b>									
Water withdrawal	U.S.	1950–2000	1.86	2.97	5.52	2.26	0.403	–59.7	–1.8
Water withdrawal	World	1900–1995	3.16	6.27	19.8	6.54	2.07	107	0.08
Water consumption	World	1900–1995	3.16	6.27	19.8	6.27	1.98	98.5	0.07
<b>WATER (deaths due to water related diseases)*</b>									
Malaria	U.S.	1900–1970	2.68			0.000	0.000	–100	
typhoid and paratyphoid	U.S.	1900–1997	3.73			0.000	0.000	–100	
GI diseases	U.S.	1900–1970	2.68			0.004	0.002	–99.8	–8.6
dysentery	U.S.	1900–1998	3.78			0.014	0.004	–99.6	–5.5
<b>AIR (indoor air pollution; residential emissions per occupied household)</b>									
SO <sub>2</sub>	U.S.	1940–2002	2.17	4.07	8.83	0.02	0.002	–99.8	–9.5
VOC	U.S.	1940–2002	2.17	4.07	8.83	0.14	0.015	–98.5	–6.5
NO <sub>x</sub>	U.S.	1940–2002	2.17	4.07	8.83	0.39	0.044	–95.6	–4.9
PM-10	U.S.	1940–2002	2.17	4.07	8.83	0.05	0.006	–99.4	–8.0
CO	U.S.	1940–2002	2.17	4.07	8.83	0.05	0.006	–99.4	–7.9
<b>AIR (national annual emissions)</b>									
SO <sub>2</sub>	U.S.	1900–2003	3.80	7.08	26.93	1.60	0.059	–94.1	–2.7
VOC	U.S.	1900–2003	3.80	7.08	26.93	1.89	0.070	–93.0	–2.5
NO <sub>x</sub>	U.S.	1900–2003	3.80	7.08	26.93	7.94	0.295	–70.5	–1.2
PM-10	U.S.	1940–2002	2.17	4.07	8.83	0.29	0.033	–96.7	–5.4
CO	U.S.	1940–2003	2.17	4.07	8.83	1.14	0.127	–87.3	–3.2
Lead	U.S.	1970–2000	1.38	1.89	2.60	0.02	0.007	–99.3	–15.1
<b>GLOBAL WARMING (extreme weather events, deaths, based on 10–year averages)*</b>									
Deaths due to climate-related disasters	World	1900/09– 1997/2006	3.67			0.17	0.047	–95.3	–3.1
Deaths from hurricanes	U.S.	1900/09– 1997/2006	3.44			0.20	0.053	–94.7	–4.6

Indicator	Area	Period	Population (P)	Affluence(A = GDP/P)	P x A = GDP	Impact (I)	Technology factor (T)	Technological change	
								Total $\Delta T$ in %	$\Delta T$ , in %/year
Deaths from floods	U.S.	1903/12–1997/2006	3.25			2.85	0.842	–15.8	–0.3
Deaths from tornados	U.S.	1917/26–1997/2006	2.65			0.02	0.075	–92.5	–4.1
Deaths from lightning	U.S.	1959/68–1997/2006	1.51			0.37	0.246	–75.4	–2.2

#### GLOBAL WARMING (carbon dioxide emissions from combustion and industrial sources)

CO <sub>2</sub>	U.S.	1900–2004	3.84	7.28	27.91	9.12	0.327	–67.3	–1.1
CO <sub>2</sub>	U.S.	1950–2004	1.92	3.11	5.99	2.38	0.398	–60.2	–1.7
CO <sub>2</sub>	World	1900–2004	4.06	5.37	21.80	14.81	0.680	–32.0	–0.4
CO <sub>2</sub>	World	1950–2004	2.51	3.21	8.06	4.85	0.602	–39.8	–0.9
CO <sub>2</sub>	China	1950–2004	2.37	11.74	27.81	63.66	2.29	128.9	1.5
CO <sub>2</sub>	China	Since economic liberalization 1979–2004	1.34	5.06	6.76	3.31	0.49	–51.1	–1.3
CO <sub>2</sub>	India	1950–2004	2.97	3.63	10.77	20.16	1.87	87.1	1.2
CO <sub>2</sub>	India	Since economic liberalization 1991–2004	1.24	1.73	2.16	1.84	0.85	–14.8	–1.1

\*Death associated with these indicators are expected to increase with population but not with affluence (except through its effect on technology, which is captured in the T-factor). Therefore, the values of A and P x A are not relevant in these cases, and )T = percent reduction in death rates over this period. Deaths due to malaria are from USBC (1954) and Newman et al. (2004).

(which usually flow from the general public to politically favored elements of society).

To summarize, population, affluence and technology are not independent of each other. Moreover, technology is a function of time. Therefore, in the IPAT equation, the dependence of the I term on the P, A and T terms is not fixed. It evolves over time. And the Neo-Malthusian mistake has been to assume that the relationship is fixed, or if it is not, then it changes for the worse.

A corollary to this is that projections of future impacts spanning a few decades but which do not account for technological change as a function of time and affluence, more likely than not, will overestimate impacts, perhaps by orders of magnitude. In fact, this is one reason why many estimates of the future impacts of climate change are suspect, because most do not account for changes in adaptive capacity either due to secular technological change or increases in economic development (IPCC 2007, Figure SPM.2; Goklany 2007d; Reiter 2007; Southgate and Sohngen 2007)).

## 8. Conclusion

Contrary to Neo-Malthusian fears, population is no longer growing exponentially. Second, from a historical perspective, food, energy and materials are more affordable today than they have been for much of human history. Third, despite unprecedented growth in population, affluence, consumption and technological change, human well-being has never been higher, and in the last century it advanced whether trends in environmental quality were up or down.

These outcomes were all possible because of greater economic and technological development, and, more importantly, the institutions that undergird such development (Goklany 2007a). Together, they steadily improved human well-being over the last century. With respect to the environment, however, their record is mixed. Initially, in the rich countries, they exacerbated environmental problems, but eventually they provided the methods and means for cleaning up the environment.

That is, they went from being part of the problem to becoming part of the solution.

Developing countries, on the other hand, have yet to make that transition for many environmental indicators in many places, although technological diffusion, combined with a little bit of affluence, has allowed them to move ahead of developed countries at equivalent levels of development.

In general, the world seems to have made the environmental transitions for access to safe water and sanitation, and lead in gasoline, and seems to be on the verge of a transition for cropland and water withdrawals.

So much for the past and present; what about the future?

Humanity needs to improve the well-being of the billions in developing countries that still suffer from poverty and poverty-related problems such as hunger, malnutrition, contaminated water, malaria, and other diseases, while, over the next half century, also accommodating an additional three billion people and containing environmental impacts.

However, just as today's population couldn't be sustained and well-being improved with yesterday's technology (Table 2), tomorrow's population cannot be sustained or its well-being advanced with today's technology. Economic and technological development have brought us this far, and they are also necessary to move us forward.

Without them, poverty, and all its consequences, cannot be reduced; the world will have to postpone the transition for cropland; more land and water habitat will be diverted to meet human needs; and we will be in a poorer position to cope with new and unanticipated challenges that the rest of nature may throw our way, including novel or resurgent diseases (such as another AIDS, or worse) or climatic changes.

But neither economic nor technological development is guaranteed. Many policy preferences of some environmentalists and Neo-Malthusians, founded on their skepticism of affluence and technology, would only make progress toward a better quality of life and a more sustainable environment harder. Their fears could become self-fulfilling prophecies. Inklings of this can be seen in their antipathy toward genetically modified crops which delays progress in reducing worldwide hunger and malnutrition even as it postpones an environmental transition for cropland and the development of a more environmentally benign agriculture; in the (fortunately) largely unsuccessful efforts to subordinate human well-being to environmental quality that were used to justify restrictions on the use of DDT for public

health purposes; in their opposition to the development of natural resources even under strict environmental supervision, which reduces supplies and increases prices; in the hostility to energy development whether it is fossil fuels or nuclear, and which legitimizes dubious alternatives such as land and water hungry biofuels, solar farms, and dams; and at their dismay at the development of China and India as they finally raise themselves from a poverty that the richer nations escaped from a century ago (Goklany 2007a; Boqiang 2007).

## Acknowledgments

I am grateful to Nicholas Eberstadt for bringing Pfaffen-zeller (2007) to my attention. I also thank two anonymous referees, Julian Morris, and Caroline Boin, whose comments and criticisms have vastly improved this paper. Any remaining errors and shortcomings, however, are my responsibility.

I would also like to thank Luisa Molina for kindly sharing with me the data used in Figure 15, and CAI-Asia for doing the same for the data used in Figure 14.

## Notes

1. The other two indicators are affluence (as measured by GDP per capita), and literacy (or some combined measure for literacy and schooling of education).
2. Goklany (2007b) shows that a similar relationship holds for cross country TFR data for 1960 and 2000 using GDP in constant dollars per market exchange rates (MXR), whereas Figure 1 uses PPP-adjusted GDP.
3. Time series analysis frequently uses time as a crude proxy for technology. See, e.g., Bhattarai and Hammig (2001: 1000), Shafik (1994: 759), Grossman and Krueger (1995: 361), and Goklany (2007b). The broader the definition of technology, the better time serves as a proxy and, as noted in the Introduction, technology is indeed defined broadly in this paper because it includes both hardware and software (including knowledge, institutions and rules of behavior).
4. Time series from these sources were linearly extrapolated to 2008.
5. Figure 8 uses the price of regular leaded gasoline from 1949–1975, the arithmetical average of regular leaded and regular unleaded gasoline for 1976–1990, and regular unleaded for 1991–2008. Nominal gasoline prices are from DOE (2008, 2009). All other economic data are from BEA (2009). Specifically, the real price of gasoline is calculated using the implicit GDP price

deflator from Tables 1.1.9 for 1949- 2008. Real disposable income per capita is from BEA (2009), Table 2.1.

6. However, it should be noted that the price deflator used in calculating the 'real' price may not adequately take into account the expansion of the money supply in the past decade.
7. 2008 saw a very rapid increase in regular unleaded gasoline prices during the first half of the year (from \$3.11 per (U.S.) gallon for the week ending 7 January to \$4.11 for the week ending on 7 July) followed by an unprecedented drop during the remainder of the year. During the week ending 5 January 2009, the price was \$1.68. At its peak (during the week ending July 7, 2008), the U.S. unleaded gasoline price was \$4.11 per gallon, and the affordability index was at 1.35.
8. Generally the impacts of an air pollutant are more directly related to its concentration in the ambient air rather than the total mass of its emissions. Thus, the pollutant's outdoor (ambient) concentration, which is measured in terms of the volume or mass of the pollutant in a given volume of air (specified in terms of parts per million, ppm, or micrograms per cubic metre of air, respectively) is a much better indicator of its public health impact than its gross emissions. In recognition of this, the "ambient *air quality* standard" for any pollutant is almost universally specified in terms of ppm or micrograms per cubic metre rather than in terms of the mass of emissions. Consequently, it is possible to improve air quality without reducing overall emissions. This could be achieved, for example, through better dispersal of the pollutant in the air through, for instance, discharging exhaust gases containing emissions into the air via higher chimneys or at high velocities or high temperatures.
9. Mortality rate is the number of people dying due to extreme weather events divided by the total population exposed to the events.
10. The improvements due to increasing economic efficiency and the shift from manufacturing to service and knowledge based economies are also reflected in Figures 15 through 17.
11. The UNDP's Human Development Index, for instance, is based on three indicators: life expectancy, per capita income and some combined measure of education and literacy (UNDP 2008).
12. This also helps explain why these environmental problems are among the first to be solved, and why lack of such access trends downwards with economic development (Shafik 2004), indicating that virtually every country has gone past its environmental transition for these indicators (Goklany 2007a).

## References

- Ausubel, J.H. 1991. "Does Climate Still Matter?" *Nature* 350: 649–652.
- Ausubel, J.H. 1998. "Resources and Environment in the 21st Century: Seeing Past the Phantoms," *World Energy Council Journal* (July): 8–16.
- [BEA]. Bureau of Economic Affairs. 2009. *National Economic Accounts*. Available at <http://www.bea.gov/bea/dn/nipaweb/SelectTable.asp>. Visited 30 January 2009.
- Blake, E.S., Rappaport, E.N., Landsea, C.W., and Miami NHC 2007. *The Deadliest, Costliest, and Most Intense United States Hurricanes from 1851 to 2006 (and other Frequently Requested Hurricane Facts)*. NOAA Technical Memorandum NWS TPC-5.
- Boqiang, L. 2007. "We can't afford to pollute first, improve later." *China View*: 8 June 2007. Available at [http://news.xinhuanet.com/english/2007-08/06/content\\_6480387.htm](http://news.xinhuanet.com/english/2007-08/06/content_6480387.htm). Visited on 31 July 2008.
- Bruce, N., Perez-Padilla, R. and Albalak, R. 2000. "Indoor air pollution in developing countries: a major environmental and public health challenge," *Bulletin of the World Health Organization* 78: 1078–1092.
- [CAI-Asia] Clean Air Initiative for Asian Cities. 2006. *Air Quality in Asian Cities*. On file with author.
- Commoner, B. "The environmental cost of economic growth," *Chemistry in Britain* 8: 52–65.
- Dahl, R. 2005. "The Population Equation: balancing what we have with what we need." *Environmental Health Perspective*: 113: A599-A605.
- Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. [http://wetlandfws.er.usgs.gov/status\\_trends/](http://wetlandfws.er.usgs.gov/status_trends/).
- Diamond, J. 2005. *Collapse: How Societies Choose to Fail or Succeed* (New York: Viking).
- Department of Energy. 2008. *Motor Gasoline Retail Prices, U.S. City Average*. Available at <http://www.eia.doe.gov/emeu/mer/prices.html>.
- Department of Energy. 2009. *Weekly Retail Gasoline and Diesel Prices*. Available at [http://tonto.eia.doe.gov/dnav/pet/pet\\_pri\\_gnd\\_a\\_epmr\\_pte\\_cpgal\\_a.htm](http://tonto.eia.doe.gov/dnav/pet/pet_pri_gnd_a_epmr_pte_cpgal_a.htm). Visited 30 January 2009.
- Dumitrescu, E. 2005. *Global Phaseout of Leaded Gasoline*. United Nations Environment Program.
- Economic Research Service. 2008. *Major Land Uses, 1910–2006*. Available at <http://www.ers.usda.gov/Data/MajorLandUses/spreadsheets/croplandusedforcrops.xls>, visited 11 July 2008.
- Economist Intelligence Unit. 2008. *Country Briefings: India, Economic Data*, 19 December 2008. Available at <http://www.economist.com/countries/india/profile.cfm?folder=Profile%2DEconomic%20Data>. Visited 12 January 2009.

- Ehrlich, A.H. and Ehrlich, P.R. 1987. *Earth* (New York, NY: Franklin Watts).
- Ehrlich, P.R. 2008. "Demography and Policy: A View from Outside the Discipline." *Population and Development Review* 34: 103–113.
- Ehrlich, P.R., and Ehrlich, A.H. 1990. *The Population Explosion* (New York, NY: Simon and Schuster).
- Ehrlich, P.R., and Ehrlich, A.H. 1991. *Healing the Planet* (Reading, MA: Addison-Wesley).
- Ehrlich, P.R., and Goulder, L.H. 2007. Is Current Consumption Excessive? A General Framework and Some Indications for the United States. *Conservation Biology* 21: 1145–1154.
- Ehrlich, P.R., and Holdren, J.P. 1971. "Impact of Population Growth," *Science* 171: 1212–1217.
- Ehrlich, P.R., Wolff, G., Daily, Hughes, J.B., Daily, S., Dalton, M., and Goulder, L. 1999. "Knowledge and the Environment," *Ecological Economics* 30 (2): 267–284.
- EM-DAT: *The OFDA/CRED International Disaster Database*. 2007. Available at [www.em-dat.net](http://www.em-dat.net), Université Catholique de Louvain, Brussels, Belgium, visited 20 September 2007.
- EPA. 2007. Report on the Environment: Science Report (SAB Review Draft). Available at <http://cfpub.epa.gov/ncea/cfm/recorddisplay.cfm?deid=140917#Download>.
- [FAO] Food and Agricultural Organization. 2006. *The State of Food Insecurity 2006* (Rome: FAO).
- FAOSTAT. 2008. *FAO Database* available at <http://faostat.fao.org/default.aspx>, visited 26 July 2008.
- Fogel, R. W. 2003. "Changes in the Process of Aging during the Twentieth Century: Findings and Procedures of the Early Indicators Project." *Working Paper 9941* (Cambridge, MA: National Bureau of Economic Research).
- [GGDC]. Groeningen Global Data Center. 2008. *Total Economy Database*. Available at <http://www.conference-board.org/economics/database.cfm>. visited 12 July 2008.
- Goklany, I.M. 1995. "Strategies to Enhance Adaptability: Technological Change, Economic Growth and Free Trade," *Climatic Change* 30: 427–449.
- Goklany. 1996. "Factors Affecting Environmental Impacts: The Effects of Technology on Long Term Trends in Cropland, Air Pollution and Water-related Diseases." *Ambio* 25: 497–503.
- Goklany, I.M. 1998. "Saving Habitat and Conserving Biodiversity on a Crowded Planet," *BioScience* 48: 941–953.
- Goklany, I.M. 2005. "A climate policy for the short and medium term: stabilization or adaptation?" *Energy & Environment* 16: 667–680.
- Goklany, I.M. 2007a. *The Improving State of the World: Why We're Living Longer, Healthier, More Comfortable Lives on a Cleaner Planet* (Cato Institute, Washington, DC).
- Goklany, I.M. 2007b. "Integrated strategies to reduce vulnerability and advance adaptation, mitigation, and sustainable development," *Mitigation and Adaptation Strategies for Global Change*, DOI 10.1007/s11027-007-9098-1
- Goklany, I.M. 2007c. "Death and Death Rates Due to Extreme Weather Events: Global and U.S. Trends, 1900–2006." In: *The Civil Society Report on Climate Change*, International Policy Press, London, pp. 47–59.
- Goklany, I.M. 2007d. "Is a Richer-but-warmer World Better than Poorer-but-cooler Worlds?" *Energy & Environment* 18 (7–8): 1023–1048.
- Graedel, T. and B. Allenby (1995). *Industrial Ecology*. Englewood Cliffs, NJ: Prentice Hall.
- Grossman, G.E., and Krueger, A.B. 1995. "Economic growth and the environment," *The Quarterly Journal of Economics* 110 (2): 353–377.
- Hutson, S.S. et al. 2004. Estimated Use of Water in the United States in 2000, USGS Circular 1268 (released March 2004, revised April 2004, May 2004, February 2005). Available at <http://pubs.usgs.gov/circ/2004/circ1268/>.
- Hydrologic Information Center. 2007. *Flood Fatalities*. Available at [http://www.nws.noaa.gov/oh/hic/flood\\_stats/recent\\_individual\\_deaths.shtml](http://www.nws.noaa.gov/oh/hic/flood_stats/recent_individual_deaths.shtml).
- IUCN. 1999. The Freshwater Biodiversity Crisis. *World Conservation* 2/99. <http://www.iucn.org/bookstore/bulletin/1999/wc2/content/freshwaterbio.pdf>. 7 November 2001.
- IUCN. 2000. *Confirming the Global Extinction Crisis*. IUCN Press Release, 28 September 2000. <<http://www.iucn.org/redlist/2000/news.html>>. Visited 7 November 2001.
- IPCC (2000). *Emissions Scenarios*. Cambridge University Press, Cambridge.
- IPCC (2007). *Climate Change 2007: Impacts, Adaptation and Vulnerability*, [www.ipcc.ch/SPM13apr07.pdf](http://www.ipcc.ch/SPM13apr07.pdf).
- Koutrakis, P. et al. 2005. "Analysis of PM<sub>10</sub>, PM<sub>2.5</sub>, and PM<sub>2.5-10</sub> concentrations in Santiago, Chile, from 1989 to 2001." *Journal of the Air & Waste Management Association* 55(3): 342–51.
- Landes, D.S. 1998. *The Wealth and Poverty of Nations: Why Some Are So Rich and Some So Poor* (New York: W.W. Norton).
- Lomborg, B. 2004. *Global Crises, Global Solutions*. Cambridge: Cambridge University Press.
- Lutz, W., Sanderson, W., and Scherbov, S. 2008. *IIASA's 2007 Probabilistic World Population Projections, IIASA World Population Program Online Data Base of Results 2008*, <http://www.iiasa.ac.at/Research/POP/proj07/index.html?sb=5>
- Maddison, A. 2003. *Historical Statistics for the World Economy: 1–2003 AD*. Available at <http://www.ggdc.net/maddison/>, visited 12 July 2008.
- Manton, K. G., Gu, X.L. and Lamb, V.L. 2006. "Change in chronic disability from 1982 to 2004/2005 as measured by long-term changes in function and health in the U.S.



- elderly population," *Proceedings of the National Academy of Sciences*, 103: 18374–18379.
- Marland, G., Boden, T., Andres, R.J. 2007. *National Co<sub>2</sub> Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751–2004*. Available at [http://cdiac.esd.ornl.gov/trends/emis/em\\_cont.htm](http://cdiac.esd.ornl.gov/trends/emis/em_cont.htm), visited 11 July 2008.
- McEvedy, C., and Jones, R. 1978. *Atlas of World Population History* (New York: Penguin).
- Millennium Ecosystem Assessment [MEA]. 2005. *Millennium Ecosystem Assessment Synthesis Report*. Pre-publication Final Draft, approved by MA Board on March 23, 2005. On file with author.
- Molina, L.T., Madronich, S., Gaffney, J.S., Singh, H.B. 2008. Overview of MILAGRO/INTEX-B Campaign. IGACtivities Newsletter, no. 38, pp. 2–15.
- Mulder, M. B., and Coppolillo, P. 2004. *Conservation: Linking Ecology, Economics, and Culture*, Princeton University Press, pp. 163–165.
- Myers, N. 1997. "Consumption: Challenge to Sustainable Development," *Science* 276: 53–55.
- National Climatic Data Center. 2005. *2004 Annual Summaries*. Available at [http://www.nws.noaa.gov/om/severe\\_weather/sum04.pdf](http://www.nws.noaa.gov/om/severe_weather/sum04.pdf).
- National Climatic Data Center. 2007. *2005 Annual Summaries*. Available at [http://www.nws.noaa.gov/om/severe\\_weather/sum05.pdf](http://www.nws.noaa.gov/om/severe_weather/sum05.pdf).
- National Weather Service. 2007. *Summary of U.S. Natural Hazard Statistics*. Available at [http://www.nws.noaa.gov/om/severe\\_weather/sum04.pdf](http://www.nws.noaa.gov/om/severe_weather/sum04.pdf).
- Newman, R.D., Parise, M.E., Barber, A.M., and Steketee, R.W. 2004. Malaria-Related Deaths among U.S. Travelers, 1963–2001. *Annals of Internal Medicine* 141(7): 547–555.
- Nordhaus, W. 2008. *A Question of Balance: Weighing the Options on Global Warming Policies* (Yale: Yale University Press), forthcoming.
- Pfaffenzeller, S., Newbold, P., and Rayner, A. 2007. "A Short Note on Updating the Grilli and Yang Commodity Price Index." *World Bank Economic Review* 21 (1): 151–163.
- Raffensperger, C. and Tickner, J. (eds.) 1999. *Protecting Public Health & the Environment: Implementing the Precautionary Principle* (Washington, D.C.: Island Press).
- Reiter, P. 2007. Human Ecology and Human Behavior: Climate change and health in perspective. In: *The Civil Society Report on Climate Change*, International Policy Press, London, pp. 21–46.
- Revkin, A.C.. 2008. *How Much Nature is Enough?* Available at <http://dotearth.blogs.nytimes.com/2008/06/04/how-much-nature-is-enough/#more-282>, visited 26 July 2008.
- Ryan, C. 1999. "Information Technology and DfE: From Support Tool to Design Principle," *Journal of Industrial Ecology* 3(1): 5–8.
- Shafik, N. (1994). "Economic development and environmental quality: an econometric analysis," *Oxford Economic Papers* 46: 757–773.
- Shiklomanov, I.A. 2000. "Appraisal and Assessment of World Water Resources," *Water International* 25: 11–32.
- Simon, J. (1995) *The State of Humanity*. (Cambridge, MA: Blackwell Publishers).
- Southgate, D. and Sohngen, B. 2007. Human Ecology and Human Behavior: Climate change and health in perspective. In: *The Civil Society Report on Climate Change*, International Policy Press, London, pp. 61–75.
- United Nations Development Program [UNDP]. 2008. *Human Development Report 2007/2008: Statistical Update 2008*. Available at <http://hdr.undp.org/en/statistics/data/>, visited 3 February 2009.
- United Nations Population Division. *World Population Prospects: The 2006 Revision, Population Database*. Available at <http://esa.un.org/unpp/>, visited 20 July 2008.
- [USBC]. U.S. Bureau of the Census. Various years. *Statistical Abstract of the United States*. Available at <http://www.census.gov/compendia/statab/>.
- USBC. 1975. *Historical Statistics of the United States: Colonial Times to 1970*. Available at [http://www.census.gov/compendia/statab/past\\_years.html](http://www.census.gov/compendia/statab/past_years.html).
- USBC. 2008. *Statistical Abstract: Historical Statistics*. Available at [http://www.census.gov/compendia/statab/hist\\_stats.html](http://www.census.gov/compendia/statab/hist_stats.html), visited 29 July 2008.
- Wheeler, D. 2001. *Racing to the Bottom? Foreign Investment and Air Pollution in Developing Countries* (Washington, DC: World Bank), available at <[netec.mcc.ac.uk/WoPEc/data/Papers/wopwoaed2524.html](http://netec.mcc.ac.uk/WoPEc/data/Papers/wopwoaed2524.html)>, visited 10 November 2002: 4–5.
- [WHO] World Health Organization. 2002a. *World Health Report 2002*. Available at <http://www.who.int/entity/whr/2002/en/index.html>.
- WHO. 2002b. *Global Burden of Disease 2000, Version 2 Estimates*, available at <[www3.who.int/whosis/menu.cfm?path=evidence,burden,burden\\_estimates,burden\\_estimates\\_2000V2,burden\\_estimates\\_2000V2\\_region&language=english](http://www3.who.int/whosis/menu.cfm?path=evidence,burden,burden_estimates,burden_estimates_2000V2,burden_estimates_2000V2_region&language=english)>, visited 14 November 2002.
- Wilson, E.O. 1992. *The Diversity of Life*. Cambridge, Massachusetts, USA: Belknap.
- World Bank. 1984. *World Development Report 1984*. Oxford University Press, New York, N Y.
- World Bank. 2001. *World Development Indicators*.
- World Bank. 2005. *World Development Indicators*.
- World Bank. 2007. *Global Economic Prospects*.
- World Bank. 2008a. *World Development Indicators*, Available at <http://go.worldbank.org/IW6ZUUHUZO>. Visited July 2008.
- World Bank. 2008b. *Millennium Development Goals: Ensure Environmental Sustainability*. Available at <http://devdata.worldbank.org/gmis/mdg/environment10.htm>. Visited on 25 July 2008.
- World Bank. 2008c. *Commodity Price Index*. Courtesy of Betty Dow, 8 July 2008.

World Bank. 2009. *Commodity Price Data (Pink Sheets)*.

Available at <http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTDECPROSPECTS/0,,contentMDK:21148472~menuPK:556802~pagePK:64165401~piPK:64165026~theSitePK:476883,00.html>. Visited 7 January 2009.

[WRI] World Resources Institute. 2008. *Earth Trends*, available at <http://earthtrends.wri.org/index.php>. Visited 28 July 2008.