

# Overpopulation and sustainability



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Achieving future sustainability not only depends on the land, water, energy, and biological resources that support human life, but also on the number of humans who have to share these vital resources. The world population is projected to double its current number of 6.5 billion in about 58 years, based on the current growth rate of 1.2% per year (Population Reference Bureau 2005). Even if a worldwide policy of two children per couple, instead of the current 2.8 children, was agreed upon tomorrow, the world population will continue to expand for about 70 years, before stabilizing at about 13 billion people. Population momentum, which depends on the age structure of the current world population, will influence this growth. For example, even China, with a policy of one child per couple, will add about 8 million to its population this year because of its young age structure.

The World Health Organization reports that more than 3.7 billion people are malnourished (WHO 2004) – the largest number and proportion ever reported. Malnutrition occurs when food is scarce, costly, and/or when political unrest interferes with its production. Malnutrition causes human suffering and death and also significantly increases susceptibility to diseases such as malaria, HIV/AIDS, and tuberculosis.

The United Nations Food and Agriculture Organization indicates that per capita availability of cereal grains, the mainstay of human diets, has been decreasing for the past 20 years (UNFAO 2002). Despite advances in biotechnology and agricultural technologies, per capita grain production also continues to decline.

Because of the increasing world population, more food, water, energy, shelter, and jobs will be required to maintain human life and health at levels that we all feel are just. Accompanying overpopulation is the movement of humans and their activities onto vital crop- and forestlands. Consider that more than 99.9% of human food (calories) comes from the land, and less than 0.01% from oceans and other aquatic ecosystems (UNFAO 2001–02). Just when food production should be increasing dramatically to meet population needs, per capita world cropland has declined 20% over the past decade. More than 10 million ha of cropland are degraded and lost each year because of soil erosion (Preiser 2005). Erosion is intensifying worldwide, especially in developing countries where the rural poor remove soil-protecting crop residues for cooking fuel.

Furthermore, valued forests are being cleared to replace lost cropland. On average, only 0.23 ha of cropland per capita are available worldwide, while a minimum of 0.5 ha is available for a diverse food system like that of the US and Europe. At present, cropland occupies 17% of the total US land area.

Adequate supplies of freshwater are essential for all plant and animal life, and much is used in agricultural production. For instance, corn requires 5 million liters of water per ha (more than 500 000 gallons per acre). Worldwide, more than 70% of all freshwater is used in agriculture (UNESCO 2001). Fossil energy is also essential for food production and to supply fresh, clean water. Modern agriculture uses enormous quantities of fossil energy for such inputs as fertilizers, farm machinery, pesticides, and powering irrigation. To produce a hectare of corn or rice requires the use of approximately 1000 liters of oil equivalents (Pimentel *et al.* 2002a).

Over the past century, cheap, available fossil energy has fostered the major expansion in the world population. Yet oil and natural gas reserves are projected to last only about 40 years (Salameh 2005). The projections keep declining because human consumption increases as the population grows. Coal is expected to last 50 to 100 years, depending on how fast it is substituted for oil and gas. However, the conversion of coal into oil and gas will contribute greatly to air pollution and global climate change.

Obviously the development of new energy sources is urgently needed to replace the dwindling supply of fossil energy. However, wind power, photovoltaics, biomass, and other renewable energy technologies, when fully operational will, at best, provide only about half of the current 100 quads of the annual energy consumption in the US (Pimentel *et al.* 2002b). Furthermore, using the new energy sources will require the use of about 17% of US land area. Ethanol and biodiesel can be produced from biomass like corn for liquid fuel needs. However, abundant scientific evidence suggests that both require more fossil energy to produce than the net energy in fuels.

To further complicate plans for sustainability, global climate change will have negative impacts on agriculture, public health, and the environment (Patz *et al.* 2000). These changes are already apparent and will influence water resources, cropping seasons, and ultimately food production. Also anticipated are increases in crop pests and insect vectors of diseases such as malaria.

To halt the growing imbalance between human population numbers and their essential resources, humans must actively conserve cropland, freshwater, energy, and other basic environmental resources. Certainly, popula-

tions in developed countries could contribute by reducing their high consumption of all resources, especially fossil fuels. We need to focus on improving food crops, for instance by developing perennial grains and pest-resistant crops, and by improving their nutritional makeup.

Sustainability for future generations will not be ensured until overpopulation is substantially reduced and the resources essential for maintaining human life and environmental integrity are conserved.

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Despite our population's staggering annual growth (the United Nations estimates another 76 million individuals will be added in 2006; UN Population Division 2005), recent changes in fertility patterns represent arguably the most positive of all global trends of major influence on Earth's biosphere. Women on every continent are bearing children later in life, and having fewer children than their mothers. About a dozen developing countries, including South Korea, Tunisia, Trinidad, and Thailand, now report lower fertility rates than the United States (currently estimated at about 2.1 children per woman; US Census Bureau 2005). Brazil, Turkey, Mexico, Vietnam, and Iran are within a few years of also attaining the two-child average (UN Population Division 2005).

The global demographic transition – from large families and short lives to small families and longer lives – is,

however, incomplete. According to the UN, 55 countries (comprising about 1 billion people) still have fertility rates over 4 children per woman. Yet, even in countries that have recently achieved the two-child average, growth continues because of population momentum (the maturation of large cohorts who, despite having low fertility, will sustain population growth as they increase the number of reproductive-age adults and later fill out the older portions of the age structure).

New regional dynamics have also come into play. While most of the slowing in world population growth is the result of increased contraceptive use and later marriage in formerly high-fertility countries, a growing share is due to modern humanity's most recent public health failure: the AIDS epidemic, which has boosted death rates dramatically in eastern and southern Africa (UN Population Division 2004). Meanwhile, fertility levels have dipped far below replacement (1.1 to 1.6 children per woman) in 23 European countries, promoting a rapid increase in the median age and initiating population decline in some states (UN Population Division 2005).

While ecologists were among those few scientists who, as early as the 1960s, drew policy makers' attention to the potential impacts of rapid population growth, today defense policy makers are taking a hard look at a broader range of population dynamics. A recent study shows a robust association between a country's position in the demographic transition and its risk of civil conflict (Figure 1). The demographic factor presumed to be most critical in this relationship is the "youth bulge" – the large proportion of young adults that is characteristic of countries in the early phases of this transition. For example, in the 1990s, countries with more than 40% of their adult population under age 30 were about 2.3 times as likely to experience a new civil conflict as those with lower proportions (Cincotta *et al.* 2003).

The youth bulge hypothesis asserts that youthful age structures tend to exacerbate political tensions while facilitating recruitment of young men by state and non-state military organizations (Moller 1967–68; Fuller and Pitts 1990; Goldstone 1999; Mesquida and Weiner 1999; Cincotta 2004). In Africa, the Middle East, the Andes Region, the Pacific Islands, and south-central parts of Asia, where average family sizes are still large, boys grow up in youth-packed neighborhoods where adolescent behavioral development and the rules for social mobility are often structured by chronically underemployed young men. Here, parental authority in the home is easily overpowered by hierarchy on the streets. A youth bulge virtually guarantees that the number of school-leavers will outpace job growth, leaving even educated young men underemployed, frustrated, and resentful. The confluence of these conditions lowers recruitment costs for insurgents, terrorist networks, state-run militias, and legitimate security organizations – all of which have become employers of choice and avenues for social and political mobility.

Other demographic factors of concern to defense and

intelligence analysts are correlated with the youth bulge. Almost all countries with a large proportion of young adults are experiencing rapid rates of urban population growth (upwards of 3% per year). In many, per capita cropland and freshwater availability have declined to very low levels, undermining the rural sector's capacity to provide livelihood and sustenance and driving young people to the cities, where they are apt to find slum conditions and hardship (Xenos 2003).

If the youth bulge model is reasonably accurate, it follows that future risks of instability and civil conflict could be reduced by focusing international development efforts on those countries with young age structures. These efforts should promote job growth for young adults and encourage progress through the demographic transition – that is, work to further reduce fertility and mortality rates in early-transition countries and improve women's status. Lessons on how the latter is accomplished can be drawn from successful national policies and programs applied in East Asia and the Caribbean from the late 1960s onward. With local support, such efforts work to improve access to modern contraception and sexual health information, increase girls' educational attainment, and make it easier for women to enter and compete in the workforce.

Religious fundamentalists and their political allies are bent on reversing these effects. The mobilization of such increasingly powerful political opposition should be of concern to those of us who believe that continued progress of the global demographic transition is likely to positively influence global security and governance, as well as help efforts to change the course of potentially disastrous environmental, social, and economic trends.

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For more than a generation, most industrialized nations have been producing too few children to avoid long-term population loss, or to prevent the trend towards a rapidly aging population. Now the phenomenon has spread to the developing world, where many nations are growing old before they get rich. Iran, for example, even while under the tight rule of a militantly Islamic clerisy, has seen its fertility rate drop by two-thirds, to below replacement levels. It now faces very rapid population aging, as do most other countries in the region.

Total world population should continue to grow, albeit at a slower rate, for many decades to come. But a global decline in the number of children has already begun. The number of 0–4-year-olds has been declining since 1990. By 2050, according to United Nations (UN) projections, there will be 35 million fewer children under the age of 4 in the world than there are today. Meanwhile, the population of elders (60+) will have swollen by 1.2 billion. Over the next half century, therefore, all remaining population growth will likely be seen in people who have already been born, paradoxical as this might seem (UN 2004). In the second half of the century, if current trends continue, total world population will begin to fall. As the supply of women of reproductive age shrinks with each new generation, population momentum becomes negative, pushing population down with compounding force. After a certain point, even if fertility rises, the population will still shrink.

What are the causes and consequences of the worldwide fall in fertility? Today, nearly half the world's population live in urban areas, and the trend towards urbanization continues unabated. In an urban economy, the “cost” of children is much higher than in an agrarian setting, as children have no useful economic role. Moreover, the minimum standard of education required to secure a well paying job continuously increases as societies develop, thereby making the cost of children even greater. Indeed, in advanced economies, many people have not even finished school, much less become established in a career, before their fertility (or their partner's) begins to decline.

As women gain new economic opportunities, the cost of bearing children rises, often in the form of foregone wages and compromised careers. Meanwhile, although social security systems, as well as private pension plans, depend on the human capital created by parents, they offer the same pension benefits, and often more, to those who avoid the burdens of raising a family. Finally, with the widespread availability of safe and effective contraception, an ever-larger share of the world's population is equipped to take advantage of the higher living standards available to those who remain childless or limit their family size. For all these reasons, global fertility rates are likely to fall to well below replacement rates and stay there, in the absence of some

enormous cultural or economic transformation.

The first order effect of declining fertility is generally positive. Many economists believe, for example, that falling birth rates helped make possible the economic boom that occurred in many Asian nations, beginning in the 1960s. As the relative number of children declined, so did the burden of their dependency, thereby freeing up more resources for investment and adult consumption.

Yet, even if declining fertility at first brings a “demographic dividend”, that dividend eventually has to be repaid if the trend continues. At first there are fewer children to feed, clothe, and educate. However, soon there are fewer productive workers as well, while there are also more and more dependent elderly, each consuming far more resources, mostly in the form of healthcare, than children or young adults do. In the US, for example, total per capita consumption for households headed by a person over 65 is 39% higher than for households headed by a person under 25 (Bureau of Labor Affairs 2003). Meanwhile, per capita federal spending on persons 65 and over is seven times greater than per capita spending on children – a gap that continues to widen (Congressional Budget Office 2000).

A falling population might at first seem beneficial to the environment, but this is not necessarily so. As societies age, the ever-increasing cost of healthcare and pensions can easily consume resources that would otherwise be available for investment in cleaner energy, increased energy efficiency, and conservation. Falling population levels may also erode the market case for such investments by reducing the depletion rates for oil, coal, and other carbon-based forms of energy. A world of 3 billion persons living in sprawling McMansions and driving gas-guzzling SUVs will produce more pollution than a world of 9 billion persons who, because of depleted carbon-based energy supplies, have shunned sprawl, eliminated auto dependency, and developed alternative, cleaner forms of energy. Japan is a world leader in energy efficiency precisely because its high population density and dependence on foreign oil make investments in energy-saving systems like mass transit and high-speed rail not only economically feasible, but economically necessary.

A society in which the average family has few or no children also puts an over-sized “footprint” on the environment, because it requires a very large number of housing units per person. An aging society is also likely to be more risk averse, less entrepreneurial, and less committed to education, thereby making technological solutions to problems such as global warming less likely. Finally, with fewer workers to support each retiree, and with each retiree consuming more and more healthcare, economies will have to work harder to finance the burden. The greater threat to the world’s environment thus comes not from a surplus of children, but from a worldwide shortage.

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David Pimentel emphasizes that population growth, heavy resource consumption, and inappropriate land use threaten sustainability for future generations. The HIV/AIDS epidemic compounds the problem. AIDS is having devastating effects on families, societies, and economies, particularly in sub-Saharan Africa, where the disease is closely linked to rural livelihoods, agriculture, natural resource consumption, and land use. Although Africa is the most heavily impacted region, “next-wave” countries in Eastern Europe, Asia, and the Caribbean are also likely to experience major increases in AIDS cases in the near future.

In 2004, between 35.9 and 44.3 million people were infected with HIV globally, 24–28 million of them in sub-Saharan Africa (UNAIDS and WHO 2004). That same year, the global epidemic killed an estimated 3.1 million people. At first glance, AIDS might appear to reduce population growth, and hence lessen the problems Pimentel describes. In the 60 countries most affected by the virus, there will be 344 million fewer people than in a no-AIDS scenario by 2050; again, most of this difference will occur in sub-Saharan Africa. However, even with AIDS factored in, the global population is expected to rise from 6.5 billion in 2005 to 9.1 billion in 2050 (medium estimate). Only three countries are expected to experience negative population growth rates because of AIDS: Swaziland, Botswana, and Lesotho. In most other developing countries affected by the epidemic, populations will continue to grow because of their moderate or high fertility (UN 2005).

Behind these broad population figures, the impacts of AIDS on demographic structure are seriously worsening the imbalances between population and natural resource consumption/land use in sub-Saharan Africa. The most economically active age group (15–49 years old) is most impacted by AIDS (UNAIDS 2004). When individuals in this age group succumb to the disease, wages and agricultural labor are lost. Rural households are forced to change their livelihood strategies in an ever-deepening spiral of poverty. They often cultivate less labor-intensive but also less nutritious crops (Barnett and Whiteside 2002) and increase natural resource consumption. Activities such as hunting, fishing, wild food-plant collection, and fuel-wood extraction increase as families struggle to maintain diets

and generate alternative income (Barany *et al.* 2001; Africa Biodiversity Collaborative Group 2002). The subsequent increase in resource use is often unsustainable.

Indigenous knowledge of agriculture and resource management is often lost when parents die before passing it on to their children. For example, using fire for agricultural clearing can increase as indigenous knowledge of agricultural production disappears and less labor is available for farming. Uncontrolled fires destroy natural resources such as forest foods and building materials (M Jurvelius *pers comm*) and can accelerate erosion. As AIDS orphans grow up, they often have little indigenous knowledge and a weak attachment to land and resources. This could result in unsustainable mining of natural resources and future insecurity, both locally and nationally.

Compounding this, law enforcement capacity is being weakened by the epidemic, as is the ability of governments and non-governmental organizations to provide technical support for rural development and resource management. At a local level, AIDS can result in shifts in land and resource control, as traditional governance structures break down and power relations change. Inefficient and unsustainable use can increase, particularly if knowledge of sustainable practices is lost or there is less commitment to sound use. In addition, in some societies, widows and orphans cannot inherit land when the male head of a household dies, because of patriarchal laws and traditions. Even if there is a legal basis for inheritance, land-grabbing may occur (International Center for Research on Women 2004).

With its huge economic, social, and environmental impacts at multiple levels, HIV/AIDS cannot be tackled by the health sector alone. A multisectoral approach is needed, involving agriculture, education, and environmental management. On the conservation side, sustainable resource-based enterprises can provide low-labor economic and food security opportunities. Non-labor-intensive agricultural techniques can improve production and reduce unsustainable environmental pressure. Lessons and coping strategies from sub-Saharan Africa could help next-wave regions reduce the impacts.

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The world population is likely to start declining after reaching a peak somewhat below 9 billion around 2060–70 (Lutz *et al.* 2001). Based on recent data, this may even be an overestimation of population growth; it has become apparent that the fertility level in China has already declined to around 1.5 children per woman. In contrast to the fears of many ecologists, this expected population stabilization and decline will not be the consequence of increasing mortality due to famines and environmental disasters arising from the “population explosion”. Instead, it will result from historically unprecedented fertility declines which are already far advanced in most parts of the world and which are unlikely to stop at a level high enough to replace current population. At present, more than half of the world's population has sub-replacement fertility (Wilson 2004). Approximately 30 countries have fertility levels of below 1.5 and show no signs of recovery.

What is wrong with Pimentel's projection of a population of 13 billion people, assuming constant growth rates in the future? Constant growth rates are almost impossible to achieve: global annual population growth rates peaked around 2.05% in the early 1960s and have since declined to the current 1.3%. Further significant declines in the global growth rate are close to certain, as a result of the age structure in low fertility countries and partly as a consequence of the universal process of demographic transition. The demographic transition paradigm implies that after an initial decline in death rates, birth rates will decline, typically after a delay of several decades. This paradigm turns out to have amazing predictive power; in virtually every country in the world, a mortality decline was followed by a fertility decline, with only the length of the lag time and the speed of the fertility decline showing some variation between countries. There is broad scientific consensus about this among demographers. This is also reflected in the United Nations (UN) population projections, where even in the high variant the growth rate will decline to 0.85 by the middle of this century, whereas it will decline to only 0.33 and –0.22 in the medium and low variants, respectively (UN 2003). The UN medium variant projects a stabilization of the world population at around 9 billion for 2100 and thereafter (UN 2004).

In my view, the medium variant of the UN projections is too high for two reasons: China, which is home to more than 20% of the current world population, registered a total fertility rate (mean number of children per woman) of 1.22 in its 2000 census. Although this is likely to be an undercount, the rate of 1.8, as used by the UN, is clearly too high. Many studies have addressed the issue; the most plausible assessment is that fertility was around 1.5 (Retherford *et al.* 2004; Lutz *et al.* 2005). The tendency seems to be towards further decline rather than an

increase to 1.85, as the UN assumes. In South Korea, studies show that despite strong government efforts to increase the birth rate, it has continued to fall, to a current low of 1.19. This raises the more general point of the fertility level at the end of the demographic transition. Conventionally, it has been assumed that fertility stabilizes at 2.1 (replacement level = two surviving children per woman). More than half of the world population has fertility below this and many countries (mostly in Southern and Eastern Europe) are below 1.3 (PRB 2004). There is no good theory about the future of low fertility; the arguments that would suggest further fertility declines are equally numerous and convincing as those suggesting some recovery (Lutz in press).

Population momentum (as rightly stressed by David Pimentel) plays an important role in the demographic outlook. Much of the expected increase in world population occurs because more young women are entering their reproductive ages. However, the momentum also works in the other direction, if fertility has been low for some time. It has been shown (Lutz *et al.* 2003) that the European Union has already entered a period of negative momentum, with fewer potential mothers in the populations of European countries. This constitutes a new, independent force toward population aging and shrinking which will soon affect more countries.

We are currently seeing a demographically divided world, with some countries that are still in the process of a demographic transition showing high population growth, while concerns about an aging population dominate in other, demographically more advanced countries. I agree with David Pimentel that a world population of 13 billion would be reason for concern, but I do not see this as a realistic scenario. The global future will be one of population stabilization and decline. But there still is need for action in some parts of the world. In the countries that still have high growth rates, however, policies that enhance social development, improve reproductive health, and thereby lower unwanted fertility, will be to the benefit of the people immediately concerned, as well as to the global community as it strives for sustainable development.

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The optimum world population size has been debated since the time of the Greeks (see Cohen 1995), and debate continues about whether the world's population is too large or growing too fast to maintain the health and sustainability of the planet and its population. Nevertheless, there is clear evidence that human migratory processes can significantly impact the natural environment as they contribute to concentrations of population and their economic activities, notably in urban communities. Indeed, people have always been migratory; the earliest populations were hunter-gatherers who exploited the resources in their vicinity and then moved on. As human populations were small relative to land area, this way of life presented no major problems, as the natural resources of the origin areas could regenerate over time. But with the discovery of agriculture, it became possible for humans to live close together in urban settlements and meet their food needs without migrating. While agriculture also made population growth possible, mortality rates continued to be high, so the human population grew very slowly and only reached 1 billion for the first time around 1800. It has since grown faster as mortality declined, reaching 2 billion in 1927, 4 billion in 1974, 6 billion in 1999, and now 6.5 billion in early 2006. World population growth was highest in the 1960s, but has been declining since fertility rates have fallen to half the levels of 40 years ago. The United Nations (UN) thus projects the global population will reach 9.1 billion in 2050, growing at less than 1% per annum in the interim (UN 2005).

More relevant for the present topic is the continuing redistribution of the world's population from rural to urban areas, a process which has been going on since the beginning of civilization, but especially since the industrial revolution of two centuries ago. As recently as 1950, only 29% of the world's population lived in urban areas, a figure projected to reach 50% in 2007, following which the majority of the world's population will be living in urban areas. Even in the developing world, where according to the World Bank 1.1 billion people live in poverty, over half the population will be living in urban areas after 2017, according to UN projections (UN 2004). What are the implications of this for the natural environment? It is often thought that if people are concentrated in urban places, it should alleviate pressures on rural biomes and reduce impacts on the environment. Although urban

consumption can obviate this (ie the “ecological footprint” of cities), there can be some relief, as nature regenerates itself under certain conditions. Indeed, this is happening in many developed countries where aggregate forest cover has been increasing for some years (FAO 2005). But the gradual ongoing decline in rural population in most countries by no means guarantees such a halcyon result.

Governments, policy makers, and social scientists have been so focused on urbanization, the growth of cities, and the associated budgetary and infrastructural difficulties of meeting the needs of urban populations that in most countries the needs of rural populations and agricultural development have been neglected (Lipton 1977). Similarly, the focus of scholars has been on rural–urban migration, to the detriment of other forms, notably rural–migration, including to frontier regions. This migration is having substantial environmental impacts throughout Latin America, Asia, and Africa. Surprisingly, rural–rural migration flows were found to be larger than rural–urban flows in 11 of 14 countries with available data (Bilborrow 2002). This migration is increasingly to areas along the agricultural frontier, lands covered by previously inaccessible forests, or marginal in terms of water supply or topography. While these areas are often initially “opened up” by external forces and factors, such as logging or mining/oil operations, it is the subsequent rush of migrants eager to establish new farms that has been the major proximate cause of landscape change, including tropical deforestation. In the past three decades, hundreds of thousands of families have engaged in rural–rural migration in the developing world; satellite imagery vividly shows the resultant loss of forest cover. The depletion and destruction of rainforests in turn has very serious consequences for the environment, including the protection of biodiversity.

However, there is a need for research that goes beyond the simple view of migration to new natural environments leading to exploitation and depletion of resources. One question is: are migrants different from people who already live in those environments? Migrants may originate from very different environments and may not be familiar with the resources of their destination and appropriate methods of production, or even care about them. In many places where migrants move to the frontier, such as the Amazon basin, they encounter indigenous populations who have lived there for centuries and use the resources much more sustainably. However, I am not aware of quantitative studies measuring these differences, which should take into account the very different population densities.

There is a growing body of scientific knowledge on the impacts of human populations on ecosystems, particularly tropical forests. Most of this literature takes the existence of migrants as a given and assumes that they are the main proximate cause of most deforestation, discounting other forces as noted above. The literature is missing a careful assessment of those other forces, their underlying political and economic causes, and their linkages to migration (Pichon and Bilborrow 1999). In addition, there has been no serious quantitative study on the migrants themselves, regarding (a)

where they come from (beyond the basic administrative data, such as province of origin); (b) why they left their places of origin (which requires a full analysis of the individual and household characteristics of migrants, and of the local economic and environmental conditions that may have contributed to their leaving); and (c) why they chose the tropical forest frontier as their destination. Research is just beginning to tackle this topic, as top migration scholars have rarely made forays into the environmental field and vice versa. Understanding the answers to these questions will go a long way towards providing useful information to policy makers concerned about developing policies to reduce the impacts of migrants on natural ecosystems. In fact, this is a current priority of the major environmental organizations: to develop policy recommendations that can reduce the impacts on protected areas around the world.

Research on the impacts of migrants on the landscape has been carried out using multivariate statistical models to investigate the relative effects of human populations by age, gender, etc, compared to those of many other factors reflecting biophysical, economic, local, and infrastructural impacts (see survey in Geist and Lambin 2002). There are now a number of such high-quality studies that encompass tropical deforestation and land use change (summarized in Bilborrow 2002) on countries in Latin America, Asia, and Africa. Other notable studies exist on dryland areas, montane settings, and coastal environments, including coral reefs (see eg special issue of *Ambio* in 2002). We have learned much from these studies, but more research is needed on all these biomes to more precisely identify the human migration impacts on natural environments. This research will benefit from drawing upon data from both satellite imagery and household surveys, and should involve long-term data collection and monitoring of key sites, including protected areas.

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