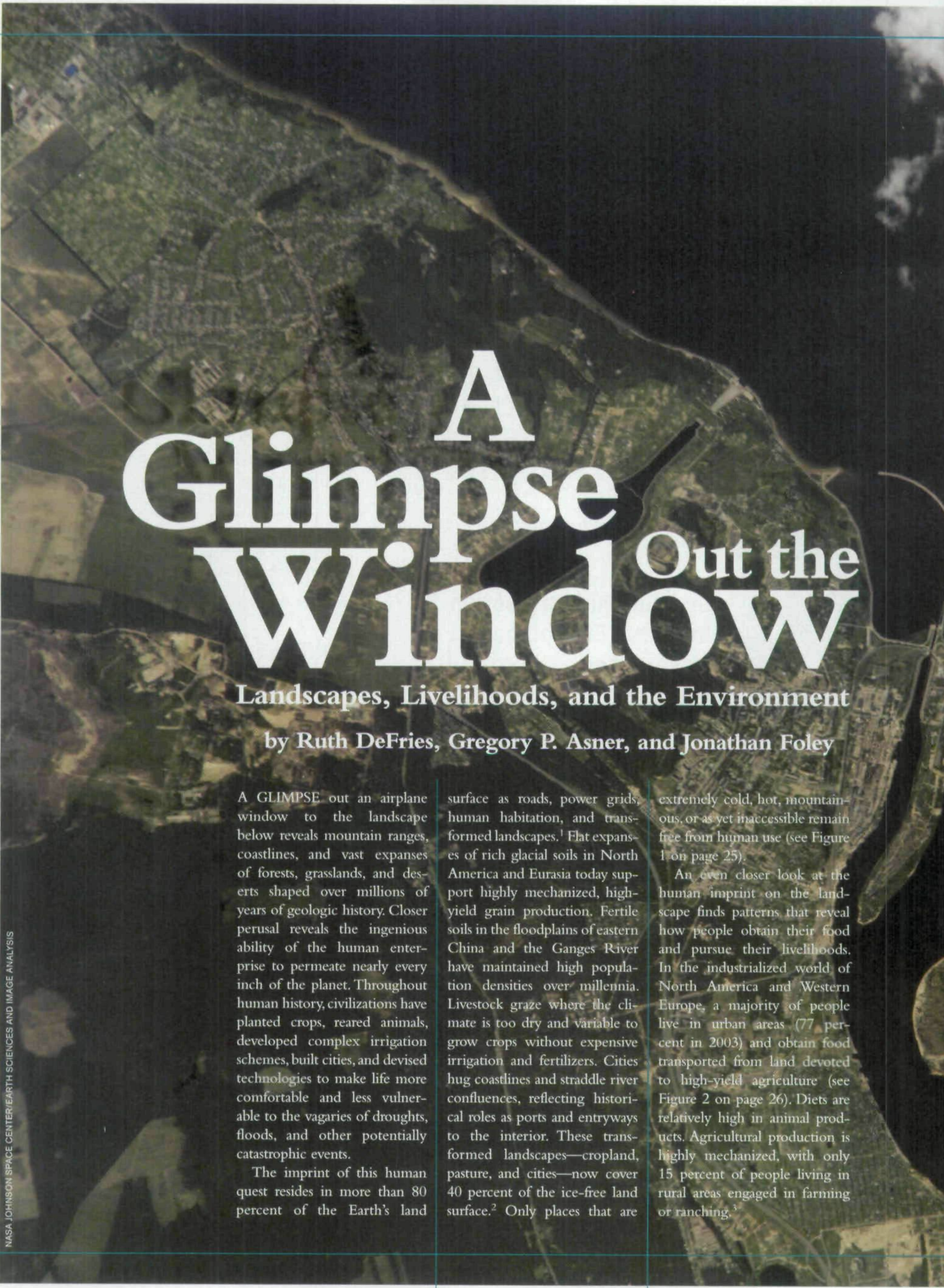


NASA JOHNSON SPACE CENTER/EARTH SCIENCES AND IMAGE ANALYSIS

A Glimpse Out the Window

Landscapes, Livelihoods, and the Environment

by Ruth DeFries, Gregory P. Asner, and Jonathan Foley

A GLIMPSE out an airplane window to the landscape below reveals mountain ranges, coastlines, and vast expanses of forests, grasslands, and deserts shaped over millions of years of geologic history. Closer perusal reveals the ingenious ability of the human enterprise to permeate nearly every inch of the planet. Throughout human history, civilizations have planted crops, reared animals, developed complex irrigation schemes, built cities, and devised technologies to make life more comfortable and less vulnerable to the vagaries of droughts, floods, and other potentially catastrophic events.

The imprint of this human quest resides in more than 80 percent of the Earth's land surface as roads, power grids, human habitation, and transformed landscapes.[1] Flat expanses of rich glacial soils in North America and Eurasia today support highly mechanized, high-yield grain production. Fertile soils in the floodplains of eastern China and the Ganges River have maintained high population densities over millennia. Livestock graze where the climate is too dry and variable to grow crops without expensive irrigation and fertilizers. Cities hug coastlines and straddle river confluences, reflecting historical roles as ports and entryways to the interior. These transformed landscapes—cropland, pasture, and cities—now cover 40 percent of the ice-free land surface.[2] Only places that are extremely cold, hot, mountainous, or as yet inaccessible remain free from human use (see Figure 1 on page 25).

An even closer look at the human imprint on the landscape finds patterns that reveal how people obtain their food and pursue their livelihoods. In the industrialized world of North America and Western Europe, a majority of people live in urban areas (77 percent in 2003) and obtain food transported from land devoted to high-yield agriculture (see Figure 2 on page 26). Diets are relatively high in animal products. Agricultural production is highly mechanized, with only 15 percent of people living in rural areas engaged in farming or ranching.[3]

This pattern is in stark contrast with patterns in parts of the world that are still in agrarian stages of development. Although overall global food production has increased 168 percent over approximately the past 40 years and is ample to feed all 6.5 billion people on the planet today, 13 percent of the world's population still suffered from malnutrition between 2000 and 2002 because they were too poor to purchase adequate food.[4] The imprint of this paradox is seen throughout the rural landscape of the developing world in crops grown on infertile soils and steep slopes, mosaics of shifting cultivation, forests scavenged for fuelwood, and seasonal migrations pursuing fodder for livestock. Most people in the developing world live in rural areas, with South Asia having the highest percentage at more than 70 percent. (The exception is the Latin American and Caribbean region, which is as urbanized as industrialized countries.) Of the rural population throughout all developing regions, the vast majority is engaged in agriculture, growing low-yield crops for their own households and local markets. Diets also contrast with those in the industrialized world, with consumption of animal products far less than half and per capita caloric intake at 65 to 80 percent of that in industrialized societies.[5]

The human imprint on the landscape emerges from millions of individual decisions in pursuit of food and livelihoods. Through time, as societies evolve from agrarian to industrial and information-based economies, the landscape mirrors accompanying shifts in how people obtain food, what they eat, and where they work. Historical examples in North America and Europe follow a general pattern, and similar patterns are emerging in some developing regions.[6]

Following initial conversion from wildlands, subsistence and small-scale farming dominate. Then, populations concentrate in urban centers and are supported by intensive agriculture in more distant locations (see Table 1 on page 28). Alexander Mather, a geographer at the University of Aberdeen, first empirically observed these trends in forest transition from historical studies of initial declines in forest cover followed by a slow increase with urbanization.[7] This forest transition has occurred in at least 20 countries, in some cases from forest regeneration as farmlands are abandoned and in other cases through replanting programs such as in China.[8]

© MICHAEL REYNOLDS–EPA/CORBIS

These terraced fields in Baishuitai, China, are just an example of the many ways that people have changed and shaped the land for agricultural purposes.

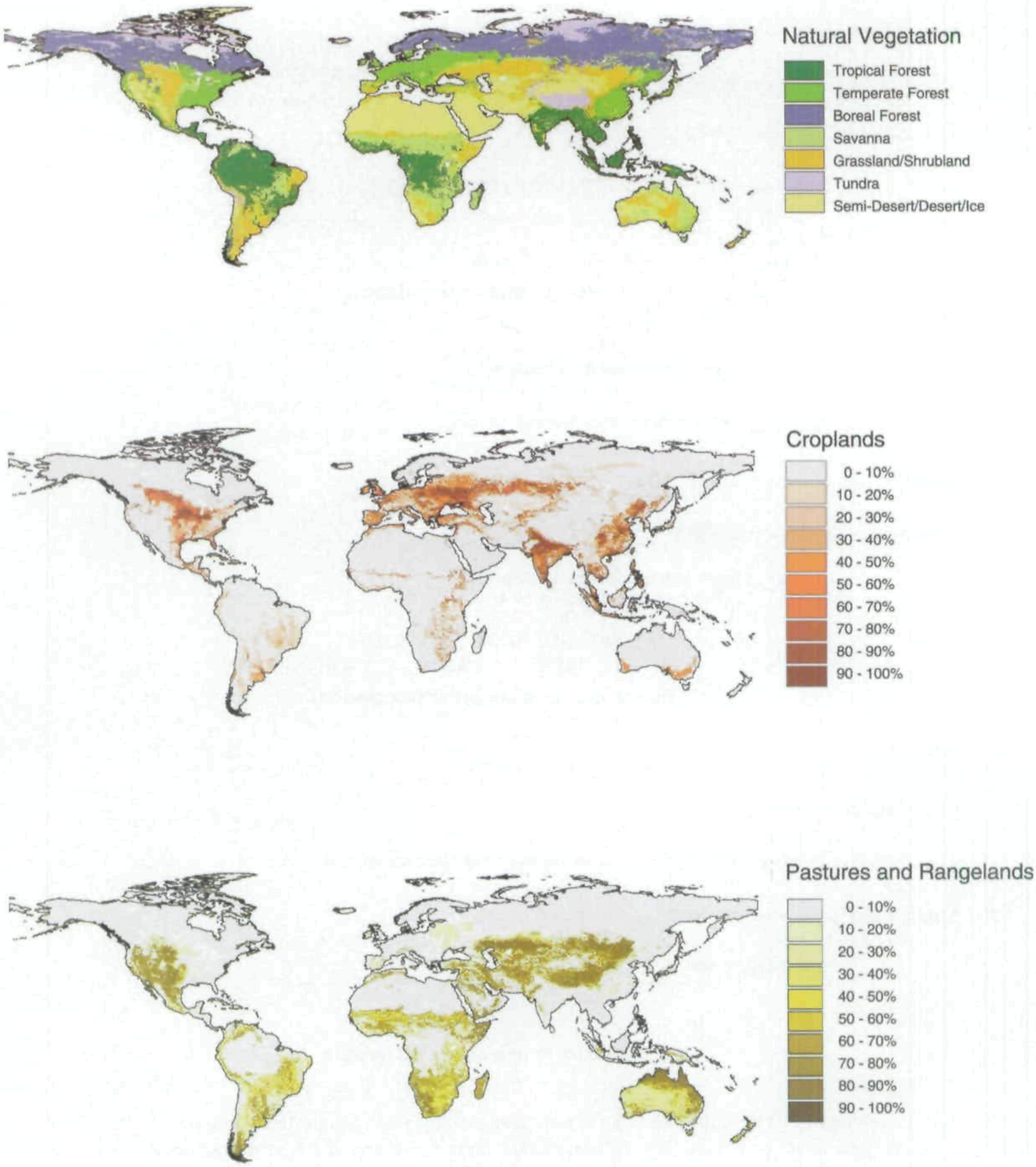
Not all places move through these transitions at an orderly pace. Some places remain in one stage indefinitely, such as remote forests and drylands that have been supporting populations living subsistence lifestyles for centuries. Other places speed rapidly through initial wildland clearing to intensive agriculture over the course of a few years, such as the rapid expansion of cropland for soybean exports in Latin America.[9] Other places bypass this transition entirely, such as countries that rely entirely on food imports.

The specific course of land use transitions vary with particular ecological conditions, demographic and consumption patterns, economic forces, and policies.[10] The combined result of these forces has increased the area undergoing transitions almost fourfold from the 1700s to the 1900s.[11] More recently, intensified production (rather than expansion of cropland into new areas) has been responsible for much of the increase in global food supply.[12] This trend toward intensification, along with urban growth as societies shift toward later stages of the land use transition, is likely to continue into the future. Other shifts occur in society's demographics, diet, and health parallel to these land use transitions. Assessing the benefits to society of land use transitions against negative environmental outcomes requires understanding the full suite of consequences in all of these domains.

Societal Transitions and Land Use Trends

Transitions in land use (Table 1) reflect changes in where people live, their livelihoods, and their sources for food as economies shift from agrarian to industrial to service oriented. The land use transitions also parallel other well-documented transitions in demography, diet, and health (see Figure 3 on page 29).

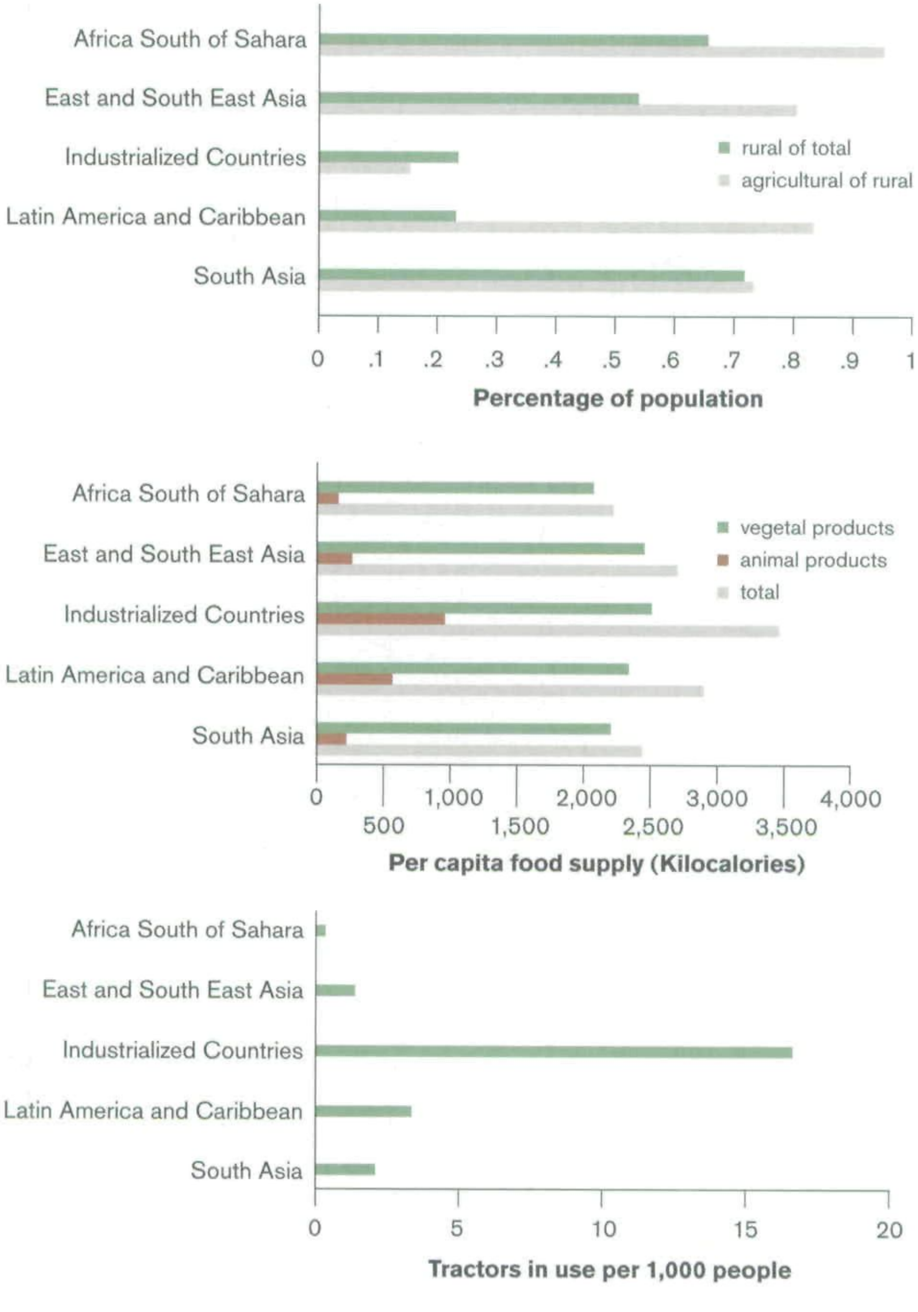
Figure 1. Geographical distribution of cropland and pasture in the 1990s



NOTE: The "potential vegetation" that would exist in the absence of human land use is estimated based on climate (top).

SOURCE: Adapted from J. Foley et al., "Global Consequences of Land Use," *Science*, 22 July 2005, 570–74.

Figure 2. Food production/consumption world comparison, 2003



NOTE: Top: Percentage of total population living in rural areas is highest in South Asia and lowest in industrialized countries, while agricultural populations (agricultural population is defined as all persons depending for their livelihood on agriculture, hunting, fishing, or forestry) comprise more than 70 percent of the rural population in all developing regions, but only 15 percent in industrialized countries; Middle: Per capita food supply per day and proportion of total in animal products is highest in industrialized countries; Bottom: Food production is more mechanized in industrial countries, as illustrated by the number of tractors in use.

SOURCE: Food and Agriculture Organization of the United Nations Statistical Databases (FAOSTAT), http://www.faostat.fao.org.

© RAINER HOLZ–ZEFA/CORBIS

Fast, convenient foods are usually the least healthy. Urban dwellers tend to reach for packaged foods first, creating nutritional deficits in the face of seeming abundance.

Demographic Transition

The demographic process of moving from small, slow-growing populations with high mortality and high fertility rates to large, slow-growing populations with low mortality and low fertility rates has occurred nearly everywhere over the past two centuries where economic growth has provided opportunities and where family planning options are available.[13] The transition has been completed in all industrialized countries, with a further stage in some countries of below-replacement fertility and declining population. In nearly all developing countries, reductions in fertility have declined more rapidly than expected in recent decades, except in sub-Saharan African countries, where fertility rates remain high. Reductions in fertility rates generally accompany urbanization, parallel to the land use transitions, although the relationship varies among regions (see Figure 4 on page 30). Asian countries generally have reached the replacement fertility rate of 2.1 at lower levels of urbanization compared with other regions. All regions, however, display inverse relationships between fertility rates and the percentage of urban dwellers in the total population.[14]

Land use transitions also parallel the documented diet transition. Public health research[15] identifies four broad nutritional patterns that have occurred through history in different places at different times:

- the hunting/gathering food stage, characterized by a diet high in carbohydrates and fiber and low in fat;
- the famine stage, in which the diet is less varied and subject to scarcity according to gender and social status, accompanying the subsistence/small-scale agriculture stage of the land use transition;
- the receding famine stage, when consumption of fruits, vegetables, and animal protein increases, and starchy staples become less important; and
- the nutrition-related noncommunicable disease stage, with a diet high in total fat, cholesterol, sugar and other refined carbohydrates, often accompanied by the sedentary lifestyle characteristic of most high-income societies. (This pattern is also becoming more prevalent in populations in low-income societies.)

Following Bennett's Law, which associates rising income with shifts in the primary sources of calories from starchy staples (rice, wheat, and root crops) to more diverse diets that include more fat, meat, fish, and fruits and vegetables, meat consumption has been growing dramatically in China and to a lesser extent elsewhere in the developing world[16] (see Figure 5 on page 31). The reflection on the landscape is seen, for example, in the diversification of crops surrounding urban areas in India[17] and cities such as Hanoi[18] and in large-scale conversion in the Amazon to export soybeans to China for livestock feed.[19]

Health and Energy Transitions

Disease specialists have documented a third major societal trend, the epidemiological transition: a shift from acute infectious and deficiency diseases characteristic of underdevelopment to chronic noncommunicable diseases such as coronary disease and obesity.[20] The transition is reflected in patterns of mortality, life expectancy, infant mortality, and causes of death and morbidity. As with the other transitions, the pattern follows the land use transitions as economic structures shift from agrarian to urban-based industrial.

Finally, as land use moves through the transition toward urbanization, societies climb the energy ladder. The vast majority of poor rural households depend on biomass energy, including wood, dung, and agricultural residue.[21] The extent to which rural fuelwood collection leads to loss or degradation of forests is not known, although projections in the 1970s of major forest loss and fuelwood shortages have not materialized. Analysis of household energy use in urban areas throughout the developing world reveals that, with rising income and development, consumption shifts from traditional biofuels to kerosene or coal and ultimately to modern fuels (such as liquefied petroleum gas) and electricity.[22] Impacts of urban woodfuel demand are seen in a case study around Hyderabad, India, where the forest area shrank by nearly half and the scrubland decreased by 60 percent within a 50 mile radius from 1928 to 1963. The speed at which societies climb the energy ladder has major ramifications for forests as well as indoor air pollution and greenhouse gas emissions.[23]

Whether land use responds to or drives these major societal trends cannot be easily disentangled, and it most likely plays both roles in different circumstances. Forest regrowth from farm abandonment, for example, resulted from economic forces that consolidated jobs in urban areas. Land use can also drive societal trends through unintended environmental consequences. On short time scales, land use consequences such as eutrophication in coastal areas from nutrient runoff, urban growth that increases population densities in places vulnerable to storm damage, or loss of soil fertility by unsustainable agricultural practices can inhibit positive societal trends toward reduced birth rates and improved health and nutrition. On longer time scales, greenhouse gas emissions and biodiversity loss from land cover conversion potentially undermine ecosystem services on which societies ultimately depend.[24]

The challenge for society is to promote land uses associated with improved diet and health, reduced poverty, and long-term sustainability of ecosystems while avoiding those with negative consequences. By understanding potential environmental repercussions at different stages, it becomes feasible to anticipate consequences and develop policies that promote land uses conducive to positive societal change.

Land Use Trade-offs

Land use change has allowed civilizations to grow crops, feed livestock, obtain energy, build cities, and carry out myriad other activities that underlie mate-

Table 1. Land uses and food production/consumption systerms

Stage in land use transition	Land use[a]	Food production/ consumption system	Examples
Wildlands	Hunter-gatherer Small-scale horticulture	Foods collected or grown locally	Remaining wildlands in boreal forests, desert regions of Africa and central Australia, Arctic tundra, and Amazon Basin
Frontier clearing	Logging Commercial deforestation Small-scale deforestation	Commercial products for commercial clearings; Locally grown or collected for small-scale clearing	Current frontier clearing mainly in humid forests of South America and Southeast Asia
Subsistence/ small-scale farming	Shifting cultivation Nomadic pastoralism Mixed crop and livestock Small-scale rainfed agriculture	Crops grown in household plots or exchanged in local markets[b]	Throughout developing world where ~50 percent of the total population engage in subsistence agriculture
Urban/intensive agriculture	Irrigated agriculture Confined livestock Aquaculture Urban	Commercial products from intensive agriculture transported to urban areas	Industrialized societies

[a] Typologies for agricultural systems are adapted from the source material.
[b] In many places, small-scale commercial production, remittances, and off-farm income sources enhance household consumption beyond products derived from subsistence farming.

SOURCE: K. Cassman and S. Wood, "Cultivated Systems" in R. Hassan, R. Schole, and N. Ash, eds., *Ecosystems and Human Well-being: Current Status and Trends*, Volume 1 (Washington, DC: Island Press, 2005); E. W. Sanderson et al., "The Human Footprint and the Last of the Wild," BioScience 52, no. 10 (October 2002): 891-904; J. Dixon, A Gulliver, and D. Gibbon, *Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World*, (Rome and Washington, DC: Food and Agriculture Organization of the United Nations, and World Bank, 2001).

rial advancement of any society and progression through the other major societal transitions. Land use change also profoundly alters ecosystems as vegetation is cleared and biomass is diverted for human consumption. Unintended environmental consequences potentially undermine future land use options.

Concern about the unintended environmental consequences from land use change dates back at least as far as Plato in his writings about Attica in the fourth century BC (see the box on page B1). Scholarship over the centuries has evolved from descriptive accounts of land use change and its consequences to more quantitative analysis for projecting change and forecasting ecological feedback. In the 1860s, George Perkins Marsh, a pioneer of environmental scholarship, observed landscape change from human activities in his book *Man and Nature*.[25] Similar books from other scholars followed, such as *Man's Role in Changing the Face of the Earth* (which came out in the 1950s) and *The Earth as Transformed by Human Action* (published in 1990).[26] From the titles alone, it is possible to see how the perception of society's relationship to the environment has changed.

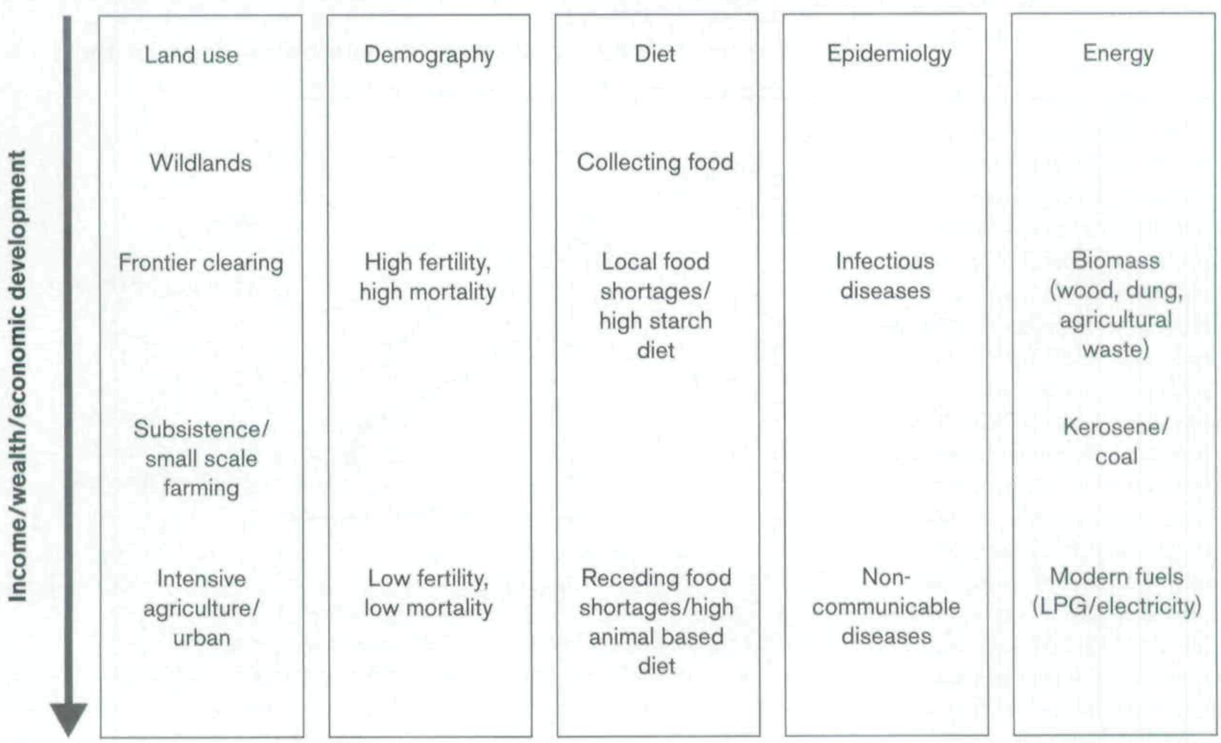
Peter Vitousek, an ecologist at Stanford University, and his colleagues estimated that humans co-opt approximately 40 percent of the Earth's net primary production.[27] In the scientific community, the past two decades have witnessed a surge of investigations into the causes and consequences of land use change and the development of quantitative tools to address these issues.[28]

Over the past decade, the approach in the scientific community has evolved to view land use change as a trade-off: essential for human survival but potentially detrimental to the environment.[29] Ultimately, societal values on appropriate trade-offs between short-term gains and longer-term environmental consequences come into play in land use decisions. Many consequences of land use change occur over multiple scales of time and space, are difficult to quantify, and do not have direct economic costs that can easily be assessed against the benefits. Environmental repercussions of land use change are consequently not commonly considered in land use decisions.

The consequences of land use change fall into a few general categories:[30]

• *Greenhouse gas emissions*. Several different greenhouse gases are emitted from different types of land use change. Carbon dioxide is released when vegetation is burned or cleared. Tropical deforestation in the last few decades emitted approximately one-quarter of all anthropogenic emissions of carbon dioxide to the atmosphere. Regrowing vegetation on abandoned farmland acts as a tem-

Figure 3. Schematic relationship among major societal transitions



SOURCE: Compiled by R. DeFries, 2006.

porary sink for carbon dioxide from the atmosphere. Other greenhouse gas emissions include methane from rice paddies and grazing ruminants and nitrous oxide from fertilizers. Intensive land uses for agriculture or urban settlements use fossil fuels for machinery and vehicles, resulting in the currently most dominant flux of greenhouse gases to the atmosphere.

• *Climate regulation.* Changes in vegetation alter exchanges of water, energy, and momentum between the land and atmosphere. Large-scale clearing of tropical forests generally leads to warmer, drier climates due to decreased evapotranspiration. In contrast, clearing temperate and boreal forests typically has a cooling effect through increased albedo (reflection of incoming solar radiation), especially in winter when fields that replaced darker forest landscapes are covered in snow. Some studies suggest that land cover change can alter atmospheric circulation and affect climate long distances from the location of the land cover change. On more local scales, urban expansion generates heat islands from concrete surfaces and reduces evapotranspiration.

• *Hydrology and water quality.* Land cover change alters streamflows through increasing precipitation runoff from exposed soil and impervious surfaces. Increased runoff exacerbates floods, reduces low flow, and increases sediment loads in streams. As excess nutrients are rinsed away from fertilized fields, streams and lakes experience eutrophication.

• *Human health.* Impacts of land use change on human health include changes in habitats for mosquitoes and other disease vectors, emergence of disease through contact with wildlife, mortality and morbidity from heat waves induced by urban heat islands, and exposure to dust and associated diseases from wind erosion.

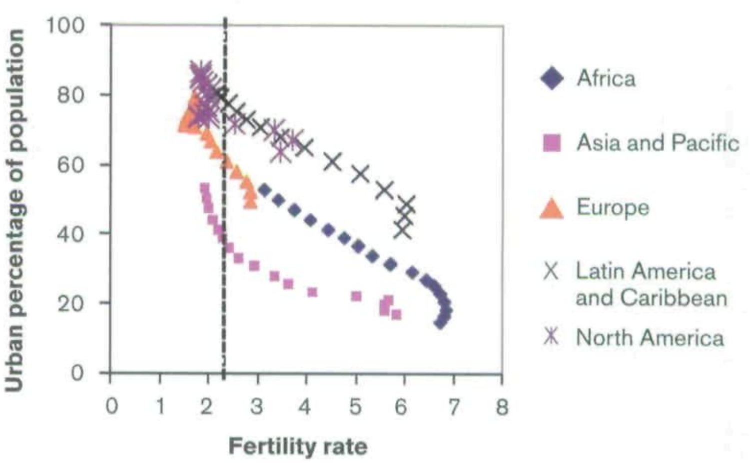
• *Biodiversity.* Land use change directly alters the diversity of ecosystems by way of habitat loss and fragmentation. Indirect impacts of land use change on biodiversity occur through altered microclimate and disturbance (such as fire) frequency. One of the most insidious forms of indirect land use impacts is the widespread proliferation of species to new environments, which can readily result in degradation of local ecosystems and the proliferation of exotic species.

• *Soil fertility.* Soil erosion through wind and water reduces available soil nutrients. Harvesting without nutrient replacement has led to depletion of soil fertility in many parts of Africa and Latin America. Heavy grazing of arid ecosystems and/or infertile soils results in organic matter losses and compaction that decrease fertility. Soil degradation remains challenging to quantify and attribute to specific land uses, but current estimates state that soil degradation affects 10 to 20 percent of the world's drylands.

These multiple consequences operate over different scales in space and

Swaths of deforested land are visible from the air over Mato Grosso, Brazil. The Amazon rainforest is home to up to 30 percent of the world's plant and animal species.

Figure 4. Fertility rates and urban percentage of total population, 1950 projected to 2030



NOTE: Replacement fertility rate of 2.1 occurs at varying levels of urbanization in different regions. Each point represents consecutive five-year averages between 1950 and 2030.

SOURCE: United Nations Environment Programme, GEO data portal, http://geodata.grid.unep.ch/ (accessed 14 August 2006).

time (see Figure 6 on page 33). Climate consequences from the release of greenhouse gases, for example, are distant in space and time from the actual land cover change. At the other end of the spectrum, nutrient runoff from excess fertilizer application occurs quickly over more local scales. The temporal scales required to recover from environmental consequences also vary. Recovery from species extinction or regeneration of eroded soil substrates is virtually impossible on human time scales. On the other hand, water quality can improve in a matter of years if runoff is controlled.

A major challenge in accounting for these myriad consequences in land use decisions rests in projecting which suite of consequences are relevant for different types of land use in different biophysical settings. Climate, ecological, and topographic settings mediate the ecosystem responses to land use change.

Environmental Consequences

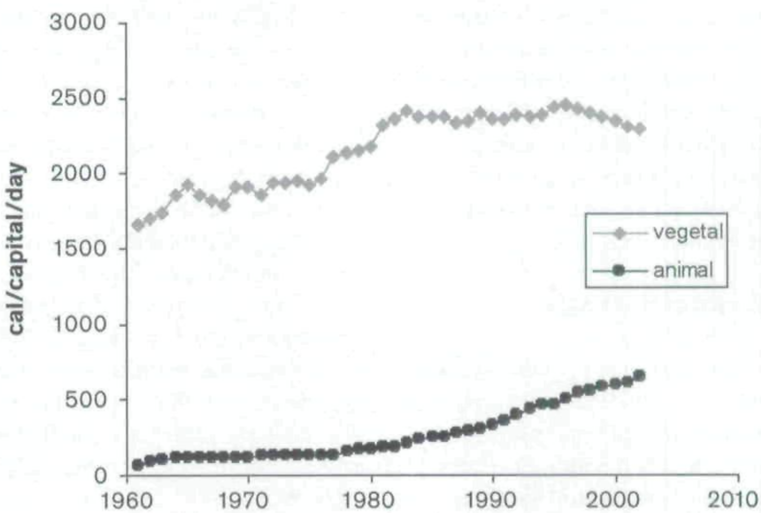
Identifying the suite of environmental consequences associated with various stages in land use transitions highlights the trade-offs that societies need to consider at any particular stage. As the demographic and epidemiologic transitions provide a context for projecting future trajectories and developing policies that respond to the expected changes, land use transitions may provide a similar framework for land use decisions. The particular course of transitions and the environmental consequences vary within this broad framework depending on particular ecological and socioeconomic circumstances. The scientific ability to identify and quantify the suite of consequences resulting from a particular land use decision or policy is only beginning to emerge.

A particular suite of consequences occurs with the frontier stage of the land use transition framework—namely carbon dioxide emissions as vegetation burns or decays and loss of biodiversity with habitat fragmentation. In the stage of subsistence and small-scale farming, methane emissions from ruminants, loss of large mammal species from hunting, and loss of soil fertility from shortened fallow cycles and erosion might become important. With the shifts towards intensive agriculture and expanded urban settlement, nutrient runoff from fertilizer use, salinization on irrigated soils, urban heat islands, and flooding from increased impervious surface area become the dominant environmental consequences (See Table 2 on page 34).

Michael Huston, a biologist at Texas State University at San Marcos, identified consequences of land use transitions for biodiversity based on environmental constraints on land use.[31] Initial locations for agriculture preferentially occur in high-productivity environments, eliminating those components of biodiversity that depend on these environments (large vertebrates and carnivores) and preserving those components that survive on marginal lands (plant diversity). This pattern is amplified with industrialization as high productivity locations are selectively used for intensive production. The transition to an information-based economy breaks this linkage between productivity and land-use intensity and allows loss of remaining reservoirs of biodiversity on marginal lands to be developed for recreational and residential use. This pattern is seen in the western United States.[32]

Human health consequences also vary with stages in land use transition.[33] In frontier clearings, people come into contact with animals and are exposed to new zoonotic diseases. Deforestation can also increase breeding sites for vector-borne diseases, such as occurred with mosquito habitat and malaria in the Peruvian Amazon.[34] In the subsistence stage, living in close proximity to domestic animals constantly exposes people to zoonotic diseases. Dams, irrigation, and agricultural development in the intensification stage of land use transitions lead to shifts in vector populations and have been associated with diseases such as snail-borne schisto-

Figure 5. Growth in per capita consumption of vegetal and animal products in China from 1960 to 2006



SOURCE: Food and Agriculture Organization of the United Nations Statistical Databases (FAOSTAT), Food Balance Sheets 2006, http://faostat.fao.org/site/554/default.aspx (accessed 15 August 2006).

Overgrazing allows no margin for error when drought occurs. These cows in Conyers, Georgia, are hoping to find some edible grass in the drought-ravaged pasture on the other side of the fence.

somiasis. Urbanization is associated with a range of health problems (including respiratory diseases), many of which are exacerbated by urban heat island effects. Finally, as land use in temperate areas has shifted from agriculture and toward regenerating forests in the United States, infection rates of Lyme disease rose with increases in contact between humans and ticks. While these examples illustrate the broad-scale variations in land use consequences during different stages of the transition, details vary from place to place in response to particular ecological and socioeconomic conditions.

Biophysical Settings

The bioclimatic and edaphic (soil-related) setting strongly control environmental consequences of land use.[35] Mesic (moist) regions of the world with well-developed soil substrates—the central United States, central Europe, India, and East Asia—are biophysically suited to agricultural and timber harvesting activities. These areas serve as the breadbaskets of the world and have undergone massive conversions in the course of human civilization (see Figure 1). Arid systems are predisposed to degradation from agricultural and ranching activities.[36] Many humid tropical ecosystems with low fertility soils are also often predisposed to degradation following forest clear-cutting, a process that drives further deforestation[37] and cascading losses from fire.[38]

The biophysical setting of a particular place sets the general range of possible land uses but does not preclude a full spectrum of land use options with input of technology, capital, and management. As an example, the vast *cerrado* (savanna) of Brazil has become a globally important source of soybeans and pastureland over the last four decades. This land use was only possible with relatively recent development of technologies that enable farmers to overcome limitations of nutrient-poor, acidic soils through fertilizers, new crop varieties, heavy use of herbicides and pesticides, and modern machinery.[39]

The biophysical setting also mediates the severity of environmental consequences of land use change. Forest clearing, for example, releases more carbon dioxide to the atmosphere in the tropics than in temperate forests merely because standing biomass is far greater in the former. Overgrazing and expansion of cropped areas have led to soil salinization, erosion, and other forms of degradation on more than 10 to 20 percent of the world's drylands, with sensitivity increasing with aridity.[40] The biophysical constraint on the severity of environmental consequences from land use transitions adds yet another dimension to land use decisions and constrains the capital and management required for productive use and for minimizing negative environmental consequences.

Uncertainty in the Tropics

Land use transitions reflect the general pattern that has historically occurred in most temperate areas. The urbanization process was completed last century when intensive cropland replaced less productive farms. Today, land use transitions in temperate areas include mainly forest regrowth on abandoned farmland and urban sprawl.

Much of the major changes in land use are likely to occur in tropical regions over the foreseeable future. Several forces underlie this trend. First, the major growth in urban areas and almost all of the world's total population growth is occurring in developing regions of the tropics (see Figure 7 on page 35). Between 1975 and 2000, the number of urban agglomerations in megacities (greater than 10 million inhabitants) grew from 2 to 3 in developed regions and 5 to 13 in developing regions. By 2015, these numbers are expected to grow to 6 and 15 respectively.[41]

While megacities have major environmental impacts and large ecological footprints, most of the urban population lives in smaller towns and cities. The number of urban agglomerations in smaller cities (500,000 to 1 million inhabitants) is expected to increase only slightly from 99 to 119 between 1975 and 2015 for developed regions, compared with an increase from 153 to 388 for developing regions. This massive growth in the number of urban agglomerations will likely have major impacts on surrounding areas with increased demands for food, water, and energy. As a second force underlying major land use changes in the tropics, land available for future conversion for agriculture within current technological capabilities is mainly in the tropical regions of South America and Africa. Suitable land elsewhere in temperate regions and Asia has already been converted. Finally, as a third force, growing global economic demands for agricultural products is generating land cover conversions in continents distant from its ultimate consumption, making land use conversion profitable at locations far away from where the products are ultimately consumed.[42]

The future path of these tropical land use transitions is what underlies many environmental issues of the future. Will deforestation trends accelerate in remaining tropical forests and release increasing quantities of greenhouse gases? Will expansion of urban areas lead to sedentary lifestyles and chronic noncommunicable diseases? Will the rural poor continue to grow crops on marginal agricultural lands, with resulting losses in soil fertility? Or will off-farm employment opportunities result in a "win-win" benefit for local people and natural regeneration of landscapes? Will negative consequences from land use undermine the positive benefits from demographic, nutritional, and epidemiologic transitions? As scientific understanding of the consequences of land use change moves forward, policies to promote land uses that mitigate negative consequences are emerging.

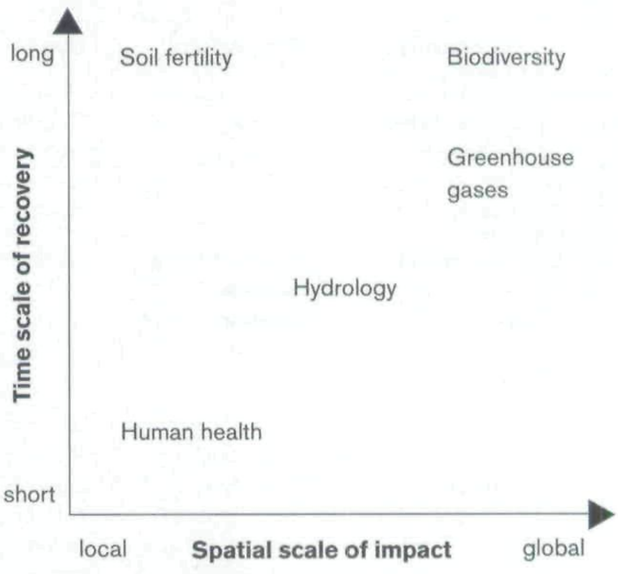
A HISTORICAL PERSPECTIVE ON LANDSCAPE CHANGE

Concerns about soil degradation and increased runoff from loss of tree cover data as far back as Plato writing about Attica in the fourth century BC:

...there are remaining only the bones of the wasted body, as they may be called, as in the case of small islands, all the richer and softer parts of the soil having fallen away, and the mere skeleton of the land being left. But in the primitive state of the country, its mountains were high hills covered with soil, and the plains, as they are termed by us, of Phelleus were full of rich earth, and there was abundance of wood in the mountains. Of this last the traces still remain, for although some of the mountains now only afford sustenance to bees, not so very long ago there were still to be seen roofs of timber cut from trees growing there, which were of a size sufficient to cover the largest houses; and there were many other high trees, cultivated by man and bearing abundance of food for cattle. Moreover, the land reaped the benefit of the annual rainfall, not as now losing the water which flows off the bare earth into the sea, but, having an abundant supply in all places, and receiving it into herself and treasuring it up in the close clay soil, it let off into the hollows the streams which it absorbed from the heights, providing everywhere abundant fountains and rivers, of which there may still be observed sacred memorials in places where fountains once existed; and this proves the truth of what I am saying.

SOURCE: Plato, *The Timaeus and Critias of Plato* (Whitefish, MT: Kessinger Publishing, 2003).

Figure 6. Environmental consequences of land use change on spatial and temporal scales



SOURCE: Compiled by R. DeFries, 2006.

Land Use Decisionmaking

Negative consequences of land use potentially stifle other major societal shifts toward improved health, diet, and demographics. In the absence of prices that reflect the value of ecosystem services, several approaches are developing that potentially address the need to consider the trade-offs in land use decisions.

One such approach is payment for ecosystem services, which attempts to remedy the market failure that occurs when the environmental value of ecosystems is excluded from the market analysis.[43] For example, clearing land in a watershed has a cost to downstream landowners if the clearing results in downstream flooding. Payment to the upstream landholders to maintain the vegetative cover rather than clear it avoids the cost to the downstream landowners. Hundreds of initiatives on payment for ecosystem services have been undertaken in the last decade to induce farmers to protect land.[44] Costa Rica, in particular, established an environmental services payments scheme in 1996 in which small-scale landholders of natural forests and forest plantations receive direct payments for the environmental services these forests provide to society. The experience to date suggests a role for such a market-oriented approach, although questions remain about how feasible such schemes are in the long-term, who benefits from them, and what their roles are in poverty alleviation.

International treaties such as the Convention on Biological Diversity and Ramsar Convention on Wetlands have not adopted binding agreements on land use change. However, evolving discussion within the United Nations Framework Convention on Climate Change (UNFCCC) addresses the trade-offs between the economic gains from tropical deforestation and greenhouse gas emissions.[45] The Conference of Parties held in December 2005 agreed to consider the technical feasibility of providing carbon credits to developing


© CORBIS

Silt erodes into the South China Sea from the Borneo coastline. Roads to the palm oil plantations and the fields themselves are visible from outer space.

Table 2. Examples of environmental consequences associated with stages in land use transitions

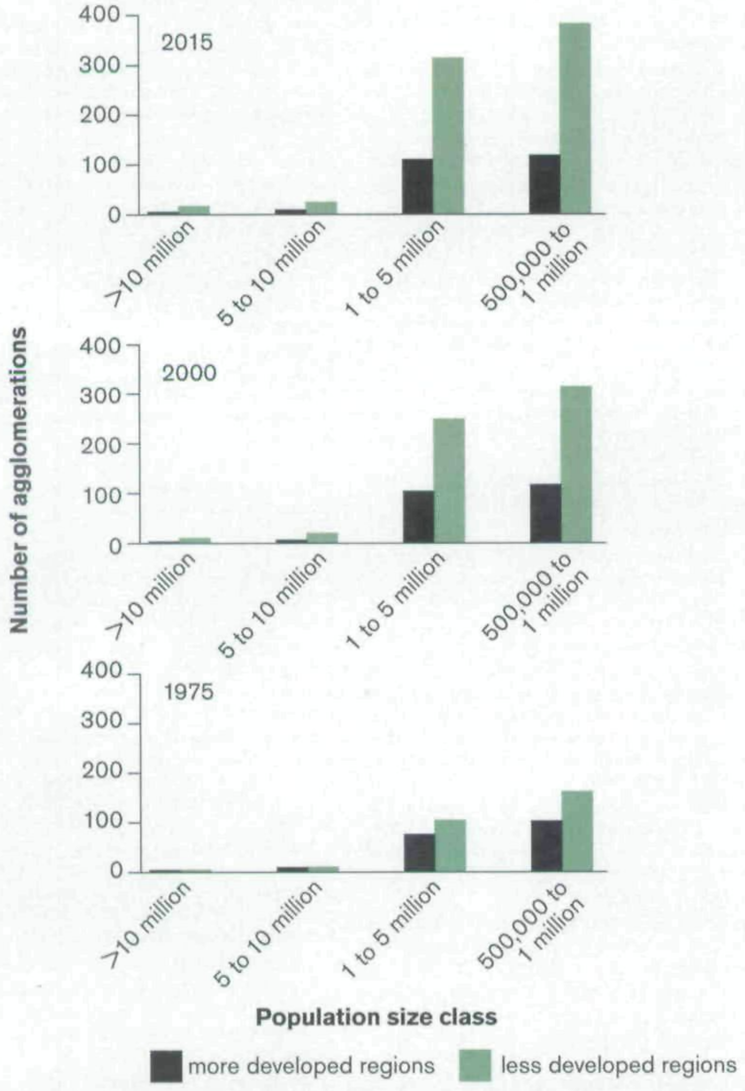
Stage in land use transition	Environmental consequences				
	Greenhouse gases	Biodiversity	Hydrology	Human health	Soil fertility
Frontier clearing	Carbon dioxide, methane from burning and decay of vegetation	Habitat fragmentation	Flooding and sedimentation from loss of vegetative cover	Zoonotic diseases from wild animals; habitats for disease vectors	Erosion of exposed surfaces
Subsistence agriculture/ small-scale clearing	Methane from livestock and rice paddies	Decline in large mammal populations from hunting	Sediment loads	Zoonotic disease from domestic animals; indoor air pollution from biomass burning for energy	Soil nutrient depletion if insufficient fallow or over-grazing
Urban/intensive agriculture	Nitrous oxide from fertilizer	Loss of microbial diversity in monocultures	Runoff from urban impervious surfaces; nutrient runoff from excess fertilizer	Heat waves; obesity	Wind erosion; salinization

SOURCE: Compiled by R. DeFries.

countries for averted deforestation in the next commitment period of the UNFCCC. As this article goes to press, it remains to be seen whether the Conference of Parties adopts this policy.

The emerging policies to influence land use through market mechanisms, whether through direct payments for ecosystem services or carbon credits, show that environmental consequences of land use change are not currently considered in land use decisions. Simultaneous to the policy developments, a scientific community is developing to disentangle the patterns of land use in different parts of the world, quantify the environmental consequences, and project future land use and its consequences. This base of understanding is fundamental for society as people's livelihoods and landscapes co-evolve into the future.

Figure 7. Number of urban agglomerations by population size class of urban development for 1975, 2000, and 2015 (projected)



NOTE: Small towns and cities with fewer than 500,000 inhabitants have been and will continue to be the size class of urban settlement in which the largest share of the world's urban population resides.

SOURCE: United Nations, *World Urbanization Prospects: The 2003 Revision* (New York: Department of Economic and Social Affairs, Population Division, 2004).

Conclusions

Each time a hoe breaks the soil, a crane puts a building beam in place, or a chain saw cuts a tree's branch, at that time and place someone decides—usually unconsciously—that the advantage for individual livelihood or economic gain outweighs any adverse consequences. Biophysical characteristics of climate, soils, and topography and economic characteristics of access to land, capital, machinery, infrastructure, and markets intertwine within the individual's decision. In some cases the advantage is clear—a poor rural farmer with limited access to technology and capital and few means to purchase food has no choice but to farm available land. In other cases the advantage accrues to populations far away, such as the urban dweller purchasing goods in a completely different place from where they were produced. Landscape patterns revealed through a glimpse out the window emerge from millions of such individual decisions, each decision in turn reflecting society's demographics, diet, health, and degree of urbanization at that time and place.

While land use patterns reflect advantages in a particular situation, the full spectrum of environmental consequences from individual land use decisions are difficult to predict and rarely considered. Fundamental questions about the environmental ramifications over time and space, detrimental consequences to livelihoods for different segments of the population, and effectiveness of policy options to mitigate negative consequences are ripe for research. The suite of consequences that occur as societies move through transitions from wildlands to intensive production and consumption (see Table 2) sketches out a broad framework. But the ability to forecast consequences within particular biophysical and economic settings is only beginning to emerge. As much of the world's population becomes urbanized, and much of the remaining rural population continues to suffer from chronic poverty, the long-recognized need to understand the positive and negative consequences of land use change for development has never been greater.

Ruth DeFries is a professor at the University of Maryland, College Park, with joint appointments in the Department of Geography and Earth System Science Interdisciplinary Center. Her research covers land use change and its interactions with climate, biodiversity, and other ecosystem services. She co-edited (with G. Asner and R. Houghton) the volume *Ecosystems and Land Use Change*, published in 2004 by the American Geophysical Union. She was elected in 2006 to the U.S. National Academy of Sciences and can be reached at rdefries@mail.umd.edu. Gregory P. Asner is a faculty member of the Department of Global Ecology at the Carnegie Institution of Washington. He also holds a faculty position in the Department of Geological and Environmental Sciences at Stanford University. His work studies how human activities alter the composition and functioning of ecosystems at regional scales. Asner combines field work, airborne and satellite mapping, and computer modeling to understand the response of ecosystems to land use and climate change. He can be reached at gasner@globalecology.stanford.edu. Jonathan Foley is the Director of the Center for Sustainability and the Global Environment (SAGE) at the University of Wisconsin, where he is also the Gaylord Nelson Distinguished Professor of Environmental Studies and Atmospheric & Oceanic Sciences. Foley's work focuses on the behavior of complex global environmental systems and their interactions with human societies. He can be reached at jfoley@wisc.edu.

NOTES

1. E. W. Sanderson et al., "The Human Footprint and the Last of the Wild," *BioScience* 52, no. 10 (October 2002): 891–904.

2. J. Foley, et al., "Global Consequences of Land Use," *Science*, 22 July 2005, 570–74.

3. Food and Agriculture Organization of the United Nations Statistical Databases (FAOSTAT), *Population Data 2006*, http://www.faostat.fao.org (accessed 15 August 2006).

4. S. Wood and S. Ehui, "Food," Chapter 8 in R. Hassan, R. J. Scholes, and N. Ash, eds., *Ecosystems and Human Well-Being: Current State and Trends, Volume 1* (Washington, DC: Island Press, 2005).

5. FAOSTAT, Food Balance Sheets 2006, http://faostat.fao.org/site/554/default.aspx (accessed 15 August 2006).

6. J. Mustard, R. DeFries, T. Fisher, and E. F. Moran, "Land Use and Land Cover Change Pathways and Impacts" in G. Gutman et al., eds., *Land Change Science: Observing, Monitoring, and Understanding Trajectories of Change on the Earth's Surface* (Dordrecht, The Netherlands: Springer 2004); M. A. Huston, "The Three Phases of Land-use Change: Implications For Biodiversity," *Ecological Applications* 15, no. 6 (2004): 1864–78; and R. DeFries, G. P. Asner, and R. A. Houghton, "Trade-offs in Land-use Decisions: Towards a Framework for Assessing Multiple Ecosystem Responses to Land Use Change," in R. DeFries, G. P. Asner, and R. A. Houghton, eds., *Ecosystems and Land Use Change* (Washington, DC: American Geophysical Union, 2004), 1–12.

7. A. S. Mather, *Global Forest Resources*, (London: Belhaven Press, 1990).

8. T. K. Rudel, et al., "Forest Transitions: Towards a Global Understanding of Land Use Change," *Global Environmental Change* 15, no. 1 (2005): 23–31.

9. R. Naylor et al., "Losing the Link Between Livestock and Land," *Science*, 9 December 2005, 1621–22.

10. E. Lambin, H. J. Geist, and E. Lepers, "Dynamics of Land-use and Land-cover Change in Tropical Regions," *Annual Review of Environment and Resources*, 28 (2003): 205–41.

11. G. C. Hurtt et al., "The Underpinning of Land-use History: Three Centuries of Global Gridded Land-use Transitions, Wood Harvest Activity, and Resulting Secondary Lands," *Global Change Biology* 12, no. 7 (2006): 1208–29.

12. H. A. Mooney, A. Cropper, and W. V. Reid, "Confronting the Human Dilemma: How Can Ecosystems Provide Sustainable Services to Benefit Society?" *Nature*, 31 March 2005, 561–62.

13. J. E. Cohen, "Human Population: The Next Half Century," *Science*, 14 November 2003, 1172–75.

14. FAOSTAT, note 3 above.

15. B. Popkin, "The Nutrition Transition and its Public Health Implications in Lower Income Countries," *Public Health Nutrition* 1, no. 1 (1998): 5–21; and S. Wood and S. Ehui, note 4 above.

16. FAOSTAT, note 3 above.

17. P. Rao, P. S. Birthal, P. K. Joshi, and D. Kar, "Agricultural Diversification in India and Role of Urbanization," International Food Policy Research Institute, Markets, Trade, and Institutions Division discussion paper 77, http://www.ifpri.org/divs/mtid/dp/mtidp77.htm (accessed 11 August 2006).

18. L. M. van der Berg, M. S. van Wijk, and P. Van Hoi, "The Transformation of Agriculture and Rural Life Downstream of Hanoi," *Environment and Urbanization* 15, no. 1 (2003): 35–52.

19. Naylor, note 9 above.

20. A. R. Omran, "The Epidemiologic Transition: A Theory of the Epidemiology of Population Change," *The Milbank Quarterly* 83, no. 4 (2005): 731–57.

21. J. Arnold, G. Kohlin, and R. Persson, "Woodfuels, Livelihoods, and Policy Interventions: Changing Perspectives," *World Development* 34, no. 3 (2006): 596–611.

22. D. Barnes, K. Krutilla, and W. Hyde, *The Urban Household Energy Transition: Social and Environmental Impacts in the Developing World* (Washington, DC: Resources for the Future, 2005).

23. R. Bailis, M. Ezzati, and D. Kammen, "Mortality and Greenhouse Gas Impacts of Biomass and Petroleum Energy Futures in Africa," *Science* 1 April 2005, 98–103.

24. Millennium Ecosystem Assessment, *Ecosystems and Human Well-Being: Our Human Planet* (Washington, DC: Island Press, 2005).

25. G. P. Marsh, *Man and Nature, or Physical Geography as Modified by Human Action* (Cambridge, MA: Harvard University Press, 1864).

26. W. L. Thomas Jr., *Man's Role in Changing the Face of the Earth* (Chicago: University of Chicago Press, 1956); and B. L. Turner II, et al., eds., *The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years* (Cambridge, UK: Cambridge University Press, 1990).

27. P. Vitousek, P. R. Ehrlich, A. H. Ehrlich, and P. A. Matson, "Human Appropriation of the Products of Photosynthesis," *BioScience* 36, no. 6 (1986): 368–73.

28. E. F. Lambin and H. J. Geist, eds. *Land-Use and Land-Cover Change: Local Processes and Global Impacts* (Berlin: Springer, 2006); DeFries, Asner, and Houghton, note 6 above; and G. Gutman, et al., eds., *Land Change Science: Observing, Monitoring, and Understanding Trajectories of Change on the Earth's Surface* (New York: Springer, 2004).

29. R. DeFries, J. Foley, and G. P. Asner, "Land Use Choices: Balancing Human Needs and Ecosystem Function," *Frontiers in Ecology and the Environment* 2, no. 5 (2004): 249–257; J. Foley, note 2 above; and Millennium Ecosystem Assessment, note 24 above.

30. For more detailed discussion of these consequences and further references, see R. DeFries, G. P. Asner, and R. A. Houghton, eds., note 6 above; and J. Foley et al., note 2 above.

31. M. Huston, note 6 above.

32. ibid.

33. J. Patz and D. Norris, "Land Use Change and Human Health," in DeFries, Asner, and Houghton, note 6 above, 159–67.

34. A. Vittor, et al., "The Effect of Deforestation on the Human-biting Rate of *Anopheles Darlingi*, the Primary Vector of *falciparum malaria* in the Peruvian Amazon," *American Journal of Tropical Medicine and Hygiene* 74, no. 1 (2006): 3–11.

35. G. P. Asner, R. DeFries, and R. A. Houghton, "Typological Responses of Ecosystems to Land Use Change," in DeFries, Asner, and Houghton, note 6 above.

36. U. Safriel and Z. Adeel, "Dryland Systems," in R. Hassan, R. Scholes, and N. Ash, eds., *Ecosystems and Human Well-Being: Current State and Trends, Volume 1* (Washington, DC: Island Press, 2005), 623–62.

37. G. P. Asner, J. Elmore, L. Olander, R. E. Martin, and A. T. Harris, "Grazing Systems, Ecosystem Responses, and Global Change," *Annual Review of Environmental Resources* 29 (2004): 261–99.

38. D. C. Nepstad, et al., "Large-scale Impoverishment of Amazonian Forests by Logging and Fire," *Nature*, 8 April 1999, 505–8; and M. A. Cochrane, "Fire Science for Rainforests," *Nature*, 27 February 2003, 913–19.

39. C. A. Klink and A. Moreira, "Past and Current Human Occupation and Land Use," in P. Oliviera and R. Marquis, eds., *The Cerrados of Brazil: Ecology and Natural Hisotry of a Neotropical Savanna* (New York: Columbia University Press, 2002), 69–88.

40. U. Safriel and Z. Adeel, note 36 above.

41. United Nations, *World Urbanization Prospects: The 2003 Revision*, http://www.un.org/esa/population/publications/wup2003/WUP2003.htm (accessed 11 August 2006).

42. R. Naylor, note 9 above.

43. S. Pagiola, J. Bishop, and N. Landell-Mills, eds., *Selling Forest Environmental Services: Market-Based Mechanisms for Conservation* (London: Earthscan Publications Ltd., 2002).

44. S. Wunder, *Payments for Environmental Services: Some Nuts and Bolts*, http://www.earthscape.org/p1/ES16955/nuts_bolts.pdf (accessed 11 August 2006).

45. M. Santilli, et al., "Tropical Deforestation and the Kyoto Protocol: An Editorial Essay," *Climatic Change* 71, no. 3 (2005): 267–76.