Human Population Growth and Tradeoffs in Land Use

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Key questions addressed in this chapter

- ♦ *Population growth and spatial distribution for the whole world and for the United States*
- ♦ *Forest and woodland cover and agricultural extensification and intensification for the whole world and for the United States*
- ♦ *Theoretical perspectives on the relations among population change, land-cover change, and human carrying capacity*
- ♦ *Tradeoffs in land use and forest use that arise from the combination of population growth, increasing consumption, increasing non-timber values in forest use, and increasing interactions between the U.S. and the rest of the world*

Keywords: Demographics, technology, culture, economics, consumption, human carrying capacity

1 INTRODUCTION

This chapter focuses on population in relation to land use, and especially on tradeoffs in land use that affect forests. Globally, a growing population is likely to increase the material demands people place on land, including demand for forest products. However, in the past century, changes in prices, technologies, institutions, values and the spatial distribution of the population changed the demands Americans placed on their forests more than the changes in the size of the U.S. population changed these demands.

Human use of land, water and other natural and human-made resources is influenced by four major factors: population, economics, the environment, and culture. A population is described by its size (the numbers of people by categories of age, gender and other characteristics), rate of growth or decline, spatial distribution (for example, urban versus rural, and the distribution of population density) and migration. Economics includes institutions for ownership or common use of land, incentives for land exploitation or conservation, markets or other institutions for dealing in land as well as the products of and inputs to land, labor force availability, and sources and conditions of capital and credit. The environment includes the physical, chemical and biological quality of land, air and water, including climate. Culture includes political institutions; governmental, commercial, and individual policies toward land use; styles of life; expected roles of women, men, children and elderly in paid work and family life; levels of education; and religious and traditional views of relations between humans and their land and water.

American planners, managers, and citizens must consider the global perspective, even if they are concerned only to protect American resources and interests, because the United States is intimately linked to the rest of the world. The United States is linked demographically to populations abroad through migration and competition for jobs (Burtless 1995); economically through international markets and international technologies that affect the demand for commodities and services derived from land; environmentally through atmospheric emissions, introduced forest pests, and global climatic changes; and culturally through the spread of free-market institutions, rising material expectations and consumerism, technologies, political movements, and other values that affect the supply of and demand for products and services derived from land.

In the last thousand years, forests have changed from being superabundant, essentially free and often viewed as an impediment to development (land "improvement" often meant removing the trees) to being priced in many economies. Forests have changed from being valued primarily as a source of land, timber and game to being valued for a host of goods and services. They have changed from being a subject of interest principally to the locality where they are found to a subject often of worldwide interest (for example, as objects of trade, sinks of carbon, reservoirs of biodiversity, or targets of ecotourism). The timber products extracted from forests have changed from primarily logs to lumber to plywood, veneer, composites, chips and pulp (Clawson 1995). If the trend continues toward reconstituting products from smaller components, forests may assume a role as incubators of complex organic molecules. Some of these molecules may replace some of those now derived from fossil fuels.

The innovations in institutions and policies that are developed to deal with problems in land use, particularly forestry, may provide useful models of policies helpful for other environmental concerns, because the state of the world's forests may be a leading indicator of the fate of other human-induced changes in the environment. Kates et al. (1990: 7) estimated human-induced changes in nine aspects of the environment between 10,000 B.C. and the mid-1980s, and tabulated the estimated dates by which half of the total change had been achieved. The environmental variables, and the year by which half the total change was achieved, were: deforested area (1850); number of vertebrate species that became extinct through human action since A.D. 1600 (1880); carbon releases (total mass mobilized by human activity) (1920); lead releases (1950); population size (1950); total annual water withdrawal for human use (1955); carbon tetrachloride production (1960); sulfur releases (1960); phosphorus releases (1975); and nitrogen releases (1975). These estimates suggest that changes in global forests preceded other major environmental changes.

Human population growth and land use interact with economics, the environment and culture. A full treatment of the interactions (Turner et al. 1990, Cohen 1995b) lies far beyond the reach of this chapter. Section 2 of this chapter is devoted to a global perspective, section 3 to a United States perspective, and section 4 to the future tradeoffs that U.S. citizens and managers will have to face in forestry and land use, especially as a result of interaction between domestic U.S. and international factors.

This chapter is intended for front-line land managers who seek a perspective on where daily decisions fit into a larger picture. It is also intended to give upper-level land-use policy-makers in government, business and philanthropy a richer picture of long-term trends and major issues. Finally, this chapter could introduce students of land use and forestry to some of the issues they can expect to confront in their future professional careers.

1.1 Historical Context: Theories of Population Change and the Environment

The relationship between human population growth and land use, especially land degradation, is addressed by four major theories or conceptual frameworks: (1) neoclassical economics, (2) classical economics and natural science, (3) dependency theory, and (4) combinations of these approaches that view population as an intermediate variable (Jolly 1994). Each of these approaches has strengths and weaknesses. Here I offer only a cartoon-like summary of each approach, relying largely on Jolly (1994). The purpose is to show the diversity of currently defended views of the relation between population growth and land use.

1.1.1 Neoclassical Economics

Neoclassical economics argues that, when markets function well, an economy can provide an increasing population with a steady or rising level of living, given a finite endowment of natural resources. In this view, technology can substitute human-made goods and services for those provided by nature and can make it possible to use the resources provided by nature more efficiently. Rising prices in the market for natural resources, including land and its products, will smoothly elicit technological innovation and shift consumer preferences away from scarce goods and services.

Neoclassical economists often acknowledge that, in many countries and sectors, markets do not function well — especially when governments interfere with markets — and that rapid population growth may make it more difficult for markets to be efficient. In their view, land degradation may be a temporary response to population growth while technology devises a more efficient use of land. Or land degradation may be a response to inefficiencies of markets, as when land resources are commonly owned (Hardin 1968). Or land degradation may be the result of exhausting land resources, a result that is perfectly acceptable to neoclassical economists because the market will call forth equivalent or superior alternatives to use of the land. Slowing population growth would only buy time to find substitutes for land and to correct inefficiencies in markets and institutions. In summary, economic inefficiencies lead to land degradation.

1.1.2 Classical Economics and Natural Science

Classical economists, based on an interpretation of the work of Thomas Robert Malthus (1766–1834), and many natural scientists argue that an economy cannot provide a rapidly growing population with a steady or rising level of living, given a finite endowment of natural resources. In this view, additional workers will eventually encounter diminishing returns from a fixed land area and additional consumers will eventually use up enough fixed resources to have a negative impact on the environment. If the population passes a certain level that may be called the carrying capacity of the land, then birth rates must fall or death rates must rise to lower the population to a level that the land can support. In summary, high population growth causes land degradation.

Some proponents of this view acknowledge that the adverse impact on land of rapid population growth is compounded by an unequal distribution of wealth, which may push the numerous poor to the most marginal and fragile lands. Long fallow periods and crop rotation may be abandoned in the face of growing numbers of people to feed. Degradation of land aggravates poverty, which leads to further land degradation. Some proponents also recognize that people's expectations play a crucial role: for a given density of population on land of a given quality, people with higher expectations of what they can extract from the land may degrade it more rapidly than people with lower expectations. Nevertheless, for most proponents of this view, reductions in human fertility are the key to avoiding environmental destruction, including land degradation, and to raising levels of living. Land reform and technological innovations at best buy time until limits are reached, because the human ability to substitute human-made capital for natural resources is limited.

1.1.3 Dependency Theory

Dependency theory argues that systems of production and social relations cause poverty, especially the exploitative relations between the now-rich industrialized countries and the now-poor developing countries; and it is poverty that causes both environmental degradation and rapid population growth. In this view, export-oriented production, cash crops to earn foreign currency, inappropriate technologies from industrialized countries, and the influence of multinational corporations all contribute to land degradation in the poor countries. The root problem is seen as the structure of society or political economy within developing countries as well as the international social, political and economic relations between poor and rich countries. Poverty leads to land degradation because the poor countries lack appropriate technology, capital, management skills and educational resources; poor farmers may know their practices are degrading their own land, but lack any resources to rectify the problem. Poverty also leads to rapid population growth because, compared to wealthy families, poor families desire more children as sources of labor (in their youth) and of social security (when parents are old).

For dependency theorists, the key to stopping land degradation is to alleviate poverty. Poverty is to be alleviated, first, by increasing productivity through economic development and, second, by distributing output more equitably through social change (both between rich and poor countries, and within poor countries). If technological innovation only amplifies the relative power of the already wealthy, it may have an adverse impact on both land degradation and population growth; if it is appropriate for the needs and environmental setting of the poor, it can foster greater equity and wealth and contribute to slowing population growth. The Malthusian limits that concern the classical economists and natural scientists lie so far beyond the constraints currently imposed by poverty and inequity as to be of little significance. In summary, poverty and inequity cause both land degradation and high fertility.

1.1.4 Population as an Intermediate Variable

"Intermediate variable" theorists argue that a variety of fundamental causes affect land use and land degradation, and that rapid population growth intensifies the environmental effects of these fundamental causes. The fundamental causes may vary from region to region. Examples of fundamental causes include warfare, movements of refugees, polluting technologies, subsidies for inappropriate human settlement, artificial controls on food prices, lack of employment opportunities, absence of rural credit, ineffective extension services, and low agricultural productivity. Higher numbers of people and more rapid population growth aggravate the adverse effects of all of these fundamental causes of land degradation.

For intermediate variable theorists, slowing rapid population growth buys time to address the fundamental causes of land degradation, even though the effects of population policies often take a very long time to appear. Economic, agricultural and silvicultural policies directed at land use are required to address land degradation (Shaw 1989).

1.1.5 The Roles of Population Growth and Spatial Distribution

For neoclassical economists, population growth is a neutral factor in land degradation. For classical economists and some natural scientists, population growth is the principal independent cause of land degradation. For dependency theorists, both population growth and land degradation are symptoms of poverty and inequity. For intermediate variable theorists, population growth exacerbates the adverse effects of other ultimate causes of land degradation. Each is a partial, and partially useful, view of the relation between human population growth and land use.

The intermediate variable theory alone allows for spatial variation in the factors that affect land use and land degradation. With that partial exception, none of these theories is situated in a real space of countries and continents with varying economies, environments, cultures, and histories. After reviewing the history that follows, I will describe (in Section 2.6) two other approaches that partially remedy this shortcoming of the theories just summarized.

2 GLOBAL HISTORY OF HUMAN POPULATION GROWTH AND LAND USE

Over the centuries, human populations have increased, shifted their distribution, and changed the way they have used natural resources to sustain themselves.

2.1 History of Global Population Size

In the last two millennia, global human population growth experienced two major phases (Cohen 1995b). In the first phase, which ended around 1965–70, the rate of increase of the human population steadily increased, not merely in absolute numbers of people added per year but also in the percentage increase per year. (Massive epidemics in the 14th century, and possibly earlier, briefly interrupted the steady increase.) During the interval A.D. 1–1650 the population doubled from roughly 0.25 billion (10^9) to 0.5 billion. The next doubling of global population (to 1 billion people) required less than two centuries (roughly 1650–1830), and the next (to 2 billion) about one century (roughly 1830–1930). During the interval 1930–1974, the population doubled from 2 to 4 billion (Fig. 1). Thus the doubling time dropped from roughly 1,650 years to roughly 44 years. These simple facts show that global human population growth cannot be described by an exponential curve or by a logistic curve. An exponentially growing population has a constant growth rate (if measured as percent increase per year) and hence a constant doubling time. In a population that grows according to the logistic curve, the growth rate (again, percent increase per year) always decreases as the population size increases.

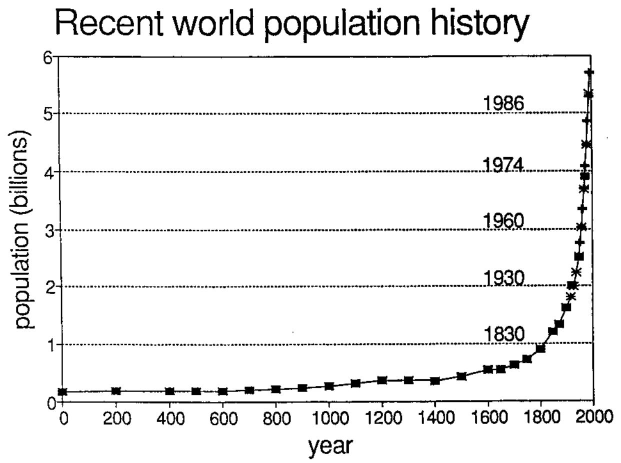

Fig. 1. Estimated global human population from A.D. 1 to 1997. Source: Cohen (1995b); Population Reference Bureau (1996). Copyright © 1995 by Joel E. Cohen.

The second phase began around 1965–70 and still continues. In this phase, the population growth rate erratically declined from its peak around 2.1% per year in the interval 1965–70 to an estimated 1.5% per year in 1997. A growth rate of 1.5% per year implies a doubling in 46 years, and is still extremely rapid compared to rates of global population growth experienced before 1945. Temporary dips in the global population growth rate in earlier centuries were due mainly to transient rises in death rates, as consequences of natural or human-induced catastrophes. By contrast, the decline in the global population growth rate since 1965 has been overwhelmingly due to a reduction in the numbers of children born per woman, while death rates mainly continued to decline. Based on the history of fertility in countries where fertility is now low, it seems reasonable to suppose that the global fall in fertility will continue without significant reversals. But the transient, dramatic rise in fertility called "the baby boom" which occurred in the United States and some other countries after 1945 shows that there is nothing inevitable about continuing local and global declines in fertility.

The absolute increase per year in the human population reached its all-time peak of around 90–95 million (10^6) additional people per year in the early 1990s. The absolute increase slowly began to decline in the mid-1990s to its present level around 85–90 million additional people per year. These absolute rates of increase are tremendous compared to historical experience. For example, the present absolute increase per year is roughly the same as the century's increase from A.D. 1600 to 1700. More than 90% of all the population increase that has ever occurred has taken place within the last three and a half centuries, and more than 70% within this century alone. While it took from the beginning of time until 1830 to add the first billion people, the most recent billion were added in 12 years.

Global statistics conceal very different stories in different parts of the world. About 1.2 billion people live in the economically more developed and richer regions, where average annual incomes are $18,100: Europe, the United States, Canada, Australia, New Zealand, and Japan. The remaining 4.6 billion live in the economically less developed and poorer regions, where average annual incomes are $1,100 (Population Reference Bureau 1996). In aggregate, the rich one-fifth of the world's population generates and spends about 80% of the world's income.

The population of the rich countries increases perhaps 0.1% per year. This growth, if continued, implies a doubling of population after more than 500 years. The population of the poor countries grows at 1.9% per year, a rate sufficient to double in 37 years if continued. The population of the least developed regions, where the world's poorest half-billion people live, increases by 2.8% per year, with a doubling time of less than 25 years (Population Reference Bureau 1996). Suppose (contrary to what is likely to happen) that the populations of the rich, poor and least developed countries continued to grow at their present rates for a typical lifetime of 74 years, and that no presently poor countries became rich. Then the population of the rich countries would increase roughly 8%, the population of the poor countries would grow 400% (the result of two doublings), and the population of the least developed regions would increase about 800% (about three doublings in 74 years).

2.2 Global Population Distribution

In 1994, the world had an average population density on ice-free land of 0.42 people per hectare (ha). In the rich countries, the population density was 0.22 people per ha; in the poor countries, 0.54 people per ha. The poor countries have more than twice the population density of the rich, on average, and their populations are increasing 10 to 20 times faster.

The last two centuries have witnessed a massive movement of people from the countryside to cities. Current statistics on urban populations follow each country's definitions, which vary from country to country. In spite of definitional fuzziness, the overall trend is clear. In A.D. 1800, about 2% of people lived in places with 20,000 or more people. By 1950, about 20% of people lived in places with 20,000 or more people (Cohen 1995b: 100). Today, about 45% of the world's population is urban (Population Reference Bureau 1996). The absolute number of city dwellers rose more than 140-fold from perhaps 18 million in 1800 to 2.5

billion today, while global population increased more than six-fold.

The move from the countryside to cities took place first in the countries that industrialized first; those are today's rich countries. By roughly 1915, more than half the population had left the farm in only one country, Great Britain. Today 75% of the 1.2 billion people in the rich countries (and 75% of people in the United States) live in cities.

Now people in the poor countries are moving to cities, in some cases even when their countries are not industrializing. During 1990–1995, the population of cities in poor countries grew by 3.5% per year, while the urban population of rich countries grew by 0.8% per year (United Nations 1995). In both rich and poor regions, the urban population grew far faster than the total population. But in absolute numbers of people, most of the shift to cities is yet to come: by 1996, in the poor countries, only 35% of people lived in cities (Population Reference Bureau 1996). Rapid urbanization in the poor countries seems likely to continue on a massive scale.

A striking aspect of urbanization has been the rise of megacities, especially in poor countries. A megacity is defined as an urban region with 10 million people or more. In 1950, there was one megacity in the world: New York. In 1994, there were 14 megacities in the world, and 10 of the 14 were in poor countries.

The form of the distribution of population density appears to be remarkably similar at the spatial scales of the whole earth, the United States, and an individual state (New York, in this example). Already, and perhaps increasingly in the future, a relatively small fraction of the land is occupied at a high human population density, while a very large fraction of the land is lightly or very sparsely occupied. As an increasing fraction of people moves into cities, the former direct presence on the land of a dispersed agricultural population is replaced by the remote demands of a city-dwelling populace. This shift may facilitate some aspects of land management and make others more difficult.

2.2.1 Self-similarity in the Distribution of Population Density

This subsection is devoted to showing the evidence for the claim in the previous paragraph that the distribution of population density appears to be remarkably similar in form at the spatial scales of the whole earth, the United States, and an individual state (New York, in this example).

I analyzed 1989 estimates of the population and area of 148 countries (World Resources Institute 1992). In 1989, the U.S.S.R. still existed as a political entity. The combined areas and populations of these 148 countries covered more than 13 billion ha, which include almost the entire ice-free land area and human population of the earth. I divided each country's population by its land area to get its population density, then ranked the countries from the least to the most densely populated (Cohen 1995b: 103).

The top left panel of Fig. 2 shows the cumulative area of all countries in which the population density was less than or equal to the population density shown. For example, nearly 13 billion ha had an average population density of 10 or fewer people per ha, and a very small area had a population density greater than 10 people per ha.

To see the cumulative distribution of area at low population densities, I replotted the same data with population density on a logarithmic scale in the second row of the first column of Fig. 2 (Cohen 1995b: 104). More than 11 billion ha (approximately 85% of the land) had one person per ha or fewer, and more than 10 billion ha (over 75% of the land) had on average less than half a person per ha.

To emphasize the distribution of population density among the countries with the lowest population densities, I replotted the same data with both population density and cumulative area on logarithmic scales in the bottom left panel of Fig. 2. Together these three panels give the global pattern of population density in relation to cumulative area on the scale of all nations.

To see the distribution of population density within a nation, I applied the identical treatment to the 1990 populations and areas of the states of the United States plus Washington, DC. The three plots in the middle column of Fig. 2 are remarkably similar to the corresponding plots for the countries of the world.

To see the distribution of population density within a single state of the United States, I applied the identical treatment to the 1990 populations and areas of the 62 counties of New York State. The plots of county population density as a function of cumulative area in the right column of Fig. 2 are similar to the plots for states and countries. The total area of New York State, somewhat less than 13 million ha, is about one-thousandth of the total ice-free land area of the world, roughly 13 billion ha.

For the world's countries, the states of the United States, and the counties of New York State, the distribution of human population density by area is self-similar over a thousandfold range of areas. That is, if the absolute scale is removed from the axis labels, it is not possible to determine the size of units being plotted from the shape of the plotted curves.

These questions remain to be addressed: Does the apparent self-similarity in the distribution of popu-

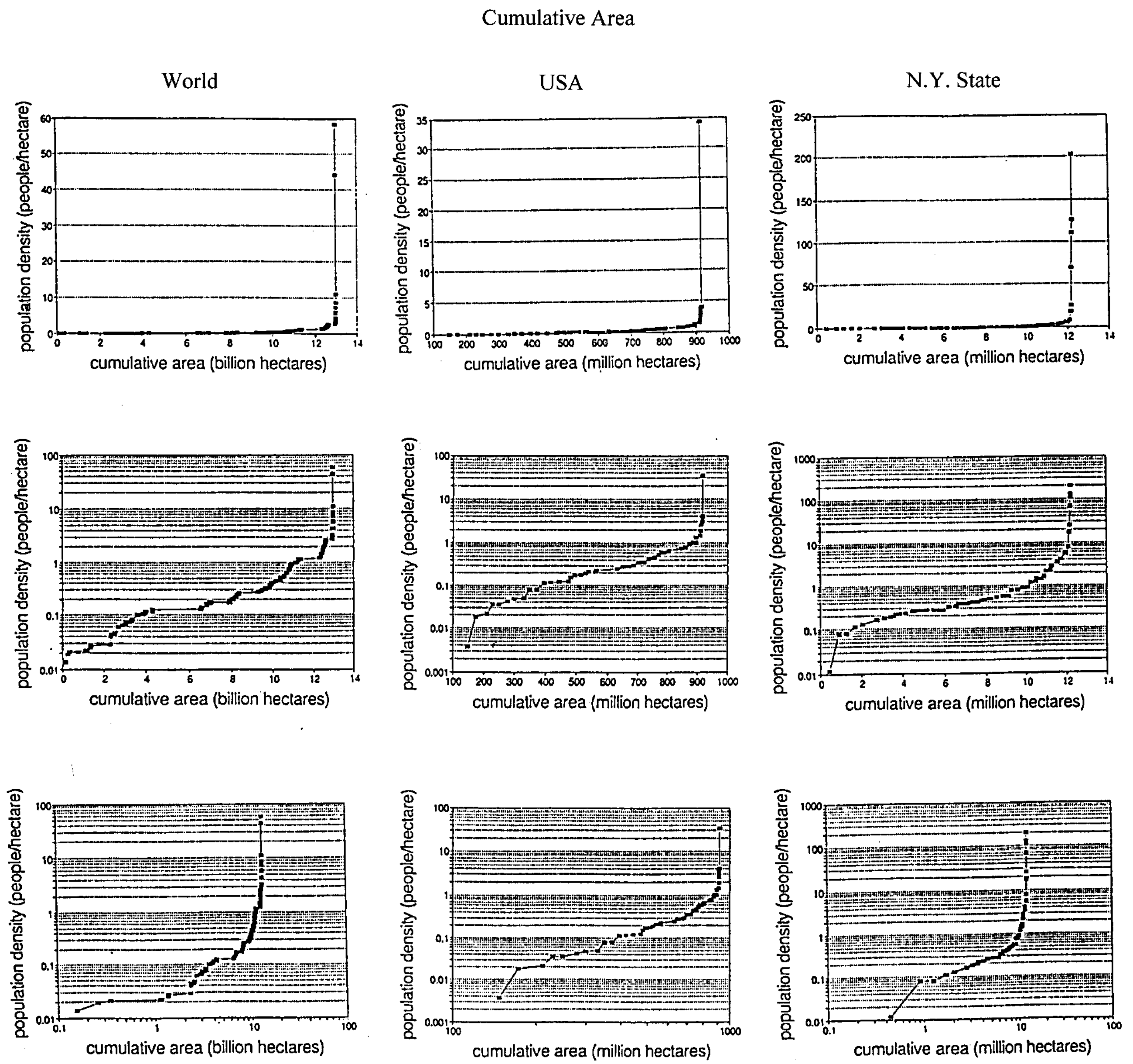

Fig. 2. Cumulative land area (horizontal axis) with population density equal to or less than the value shown on the vertical axis. Left column: countries of the world in 1989 (data: World Resources Institute 1992); middle column: 50 states of the United States plus Washington, D.C. (data: U.S. Census 1990); right column: 62 counties of New York State (data: U.S. Census 1990). First row: both axes are on a linear scale. Second row: vertical axis is logarithmic; horizontal axis is linear. Third row: both axes are on a logarithmic scale. Source: Cohen (1997). Copyright © 1997 by Joel E. Cohen.

lation density hold for other countries and other states? for the human population at earlier times? for non-human species? How can the apparent self-similarity be quantified and evaluated more quantitatively?

In spite of uncertainty about the generality of this finding, visual inspection suggestions that the cumulative distribution of population density is similar on scales of area ranging over three orders of magnitude, from the area of New York State to the land area of the entire earth not covered by ice. Over this range of spatial scales, it seems likely that a growing fraction of the human population will live on a diminishing fraction of the land.

2.3 Early History of Land Use

Massive human alteration of grasslands and forests probably began with human mastery of fire hundreds of thousands of years ago. Prior to the evolution or invention of agriculture, closed forest may have covered 4.6 billion ha, and woodland 1.5 billion ha, of the globe, respectively about 35% and 12% of the total ice-free land area. By around 1970 (based on maps dated from 1969 to 1976), about 3.9 billion ha of closed forest and 1.3 billion ha of woodland remained, together covering about 40% of earth's ice-free land (Matthews 1983: 482, Williams 1990: 179). Tropical rainforests had declined about 50 million ha (3.75% of their original extent) while all other forests declined about 650 million ha (19.5% of their original area) (Matthews 1983). These estimates, even for present land cover, are uncertain. For example, Matthews' (1983: 483) estimate of 3.9 billion ha of contemporary forest falls between a 1979 estimate of 3.7 billion ha and a 1975 estimate of 4.9 billion ha; the divergence among published estimates of woodland and shrubland areas are also large. The estimates of pre-agricultural land cover must be still more uncertain.

About half the world's forests and woodlands lie in the tropics, the rest in temperate and boreal regions (Johnson 1996). Six countries — Russia, Canada, Brazil, the United States, Zaire, and Indonesia have just over half the world's forests and woodlands. (For recent surveys of human population growth and land use, see Richards (1990), Turner et al. (1990), Rudel (1991), Grainger (1993), Jolly and Torrey (1993), Pearce and Warford (1993), and Marquette and Bilsborrow (1994).)

Europeans cleared their forests energetically in the centuries up to A.D. 1300 (Cipolla 1994). Clearing the European forests slowed temporarily in the 14th century in the presence of the plague, the onset of the "Little Ice Age" around A.D. 1300 (a drop in global mean temperature of 1.5°C. that lasted to the beginning of the 19th century) (Turekian 1996: 82–83), and economic stagnation. By the 16th century, economic activity recovered, nutrition improved, and population growth rates began to rise. The cutting of European forests was renewed to feed a slowly expanding population, to supply imperial requirements for ships and naval supplies, and to support growing industry, mining, and metal extraction. When England exhausted its own supplies of large timber for shipbuilding, it looked outward to trade with Sweden, Russia, British colonies in North America, India, Burma, and Australia. France and other colonial powers exhausted their forests and looked outward.

Many regions of the world experienced extensive deforestation. While 95% of central and western Europe was originally forested, now about 20% is forested; China, originally 70% forest, is now 5% forested; and the United States lost one-third of its forests between 1790 and 1890 (Ponting 1990: 4).

As human numbers increased, people changed their use of the land by extending their activities to new lands (extensification) and by intensifying their productivity on land already occupied (intensification). These processes are discussed in the following sections.

2.4 Extension of Croplands with Population Growth since 1700

Between 1700 and 1980, the area of croplands increased from 0.3 billion ha to 1.5 billion ha, an absolute increase of 1.2 billion ha and a nearly five-fold increase (Fig. 3) (Richards 1990: 164). Over the same period, while grasslands and pasture changed little, the area of forests and woodlands declined from 6.2 billion ha to 5.1 billion ha (nearly 19%). For comparison, the land area of the 50 United States is about 0.93 billion ha; thus the reduction in area of forests and woodlands approximates the entire land area of the United States. Kates et al. (1990: 1) estimated "the net loss of the world's forests due to human activity since pre-agricultural times" at roughly 0.8 billion ha, an area about the size of the conterminous United States (the lower 48 states). Kates' "net loss" may underestimate human impact if it excludes massively disturbed areas that were abandoned and subsequently regrew as well as extensive areas that were disturbed but not destroyed. Meanwhile, the global population rose from around 650 million in 1700 (estimates vary from 610 million to 680 million; Cohen 1995b: 400) to around 4.4 billion in 1980, nearly a seven-fold increase.

This historical association of increasing population with increasing croplands and decreasing forests must be regarded with some caution because the estimated area of agriculture in 1700 was derived from historical population estimates (Richards 1990: 164). However, the changes in croplands versus the changes in forests

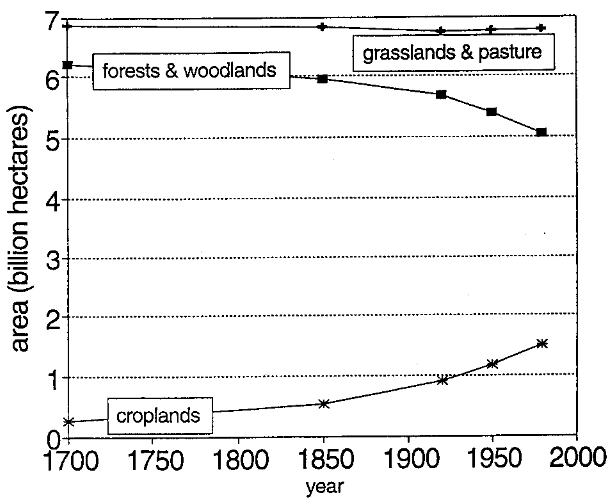

Fig. 3. Land use since 1700. Original figure, based on data of Richards (1990: 164).

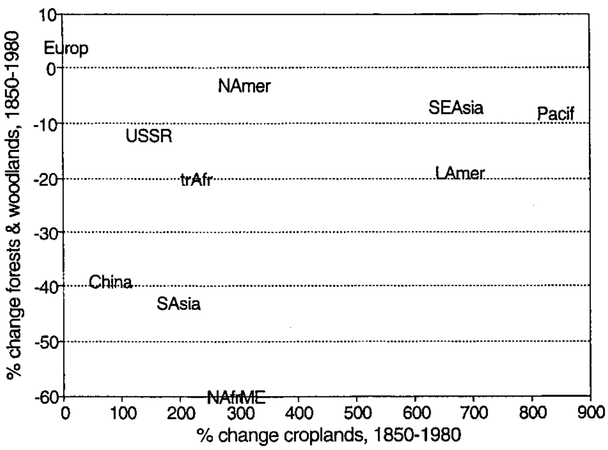

Fig. 4. Changes in areas of croplands versus changes in areas of forests and woodlands, 1850–1980, for 10 regions of the world: trAfr = tropical Africa; NAfrME = North Africa and Middle East; NAmer = North America; LAmer = Latin America; China = China; SAsia = South Asia; SEAsia = Southeast Asia; Europ = Europe; USSR = former Soviet Union; Pacif = Pacific developed countries. Original figure, based on data of Repetto and Gillis (1988: 3–5), which are attributed to World Resources Institute (1987: 272).

and woodlands for 10 regions of the world from 1850 to 1980 confirm, and reveal the diversity concealed by, the global picture (Fig. 4).

In every region except Europe, as croplands increased, forests and woodlands shrank. The ten regions fall into three groups. In the now relatively wealthy regions, Europe, North America, and the USSR, the relative loss of forests and woodlands during this period was small (Europe had a gain), as was the increase in croplands, in comparison with the percentage changes in other regions. In three regions, Southeast Asia, the Pacific developed countries, and Latin America, the relative increase in croplands was enormous compared to the relative decrease in forests. Finally, in three regions that must qualify among the poorest, China, South Asia, North Africa and the Middle East, the percentage loss in forests and woodlands was larger than in the other regions, while the percentage increase in croplands was comparable to that in the wealthy regions. In Fig. 4, tropical Africa is anomalously close to the group of three wealthy regions, perhaps because tropical deforestation has not yet run its full course, or perhaps because the starting base of forest and woodland in 1850 was so large. Even so, Europe alone is the exception to the pattern of increasing croplands and decreasing forests and woodlands between 1850 and 1980.

Kates et al. (1990: 13) stated categorically that "the global transformation of the biosphere is driven first by population growth, followed by technological capacity and sociocultural organization." This assertion has to be evaluated in the light of our earlier observation that the richest one-fifth of today's population commands about 80% of global income and consumption, although the rich countries' population grows very slowly (doubling in five centuries or longer). The rich and poor nations, as well as scholars, disagree whether the levels of consumption of the rich or the numbers of consumers among the poor contribute more to human impacts on the biosphere. Many of the impacts from rich and poor are different.

When population density and forest coverage are measured independently and directly in some subsets of countries today or recently, an inverse relation appears (Preston 1994). For example (Fig. 5), in 60 tropical countries in 1980 (excluding eight arid African countries), the larger the number of people per square

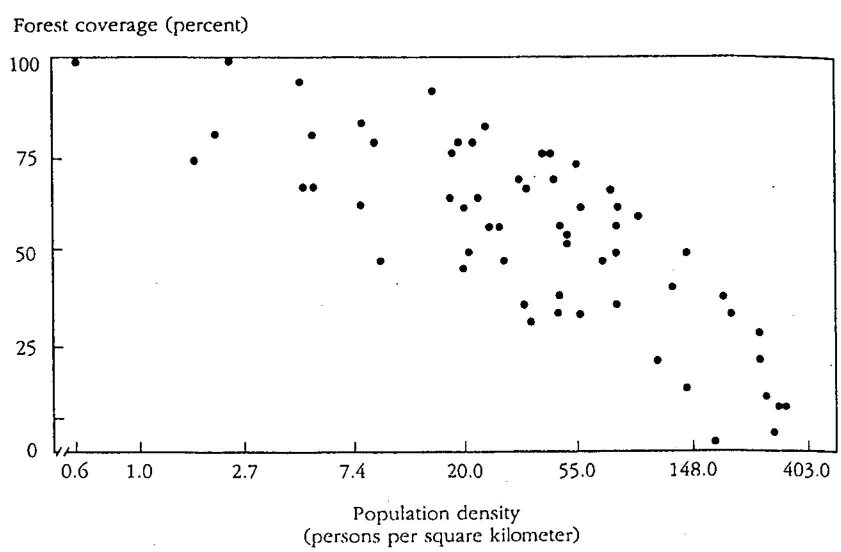

Fig. 5. Relation between forest coverage and population density in 60 tropical countries, 1980. Source: Pearce and Warford (1993: 166).

kilometer, the smaller the percentage of land covered by forest (Pearce and Warford 1993: 166). Although such data suggest that humans are responsible for the smaller forest cover, the data are also compatible with the contrary hypothesis that countries that started off with less forest cover were more easily settled and ended up with higher human population densities. To distinguish between these two hypotheses, data are required on changes over time. When Harrison (1992: 323) ranked 50 countries (of unstated geographic distribution) from high to low percentage of "habitat loss" (not explicitly defined as a measurement of status or of change) in the mid-1980s, the amount of habitat loss decreased with decreasing population density. The top 10 countries had 85% habitat loss and 1.89 people per ha while the bottom 10 countries had 41% habitat loss and 0.29 people per ha.

Statistical associations such as these suggest that rising human numbers increase the demand for agricultural products (including but not limited to food for subsistence), and expanding the area of agricultural production at the expense of forests and grasslands is a frequent response to the rising demand. On the average, when technologies, capital, credit, and farmer skills for intensifying food production are not available, the inferred global historical association of rising population and expanding croplands is largely valid (Preston 1994).

More detailed investigation reveals a more complex interaction between population growth and forest cover. Where relatively small areas of rainforest are surrounded by cleared land, as in Central America, the Philippines, Rwanda, and Burundi, peasants in the cleared areas expand their areas of cultivation, little by little, by nibbling away at the forests. In these cases, variations in rates of deforestation may be explained by variations in local rates of population increase (Rudel 1991: 56).

Where there are large blocks of rainforest, population growth is not enough to explain deforestation. In addition to rapid population growth, substantial capital investment in access roads and an absence of enforced property rights are also necessary for rapid deforestation. For example, rates of deforestation were far higher during the 1970s in Brazil, which was relatively capital-rich, than in capital-poor Bolivia and Zaire. In times of economic hardship, if capital becomes scarce, fewer roads may be built in regions with large extents of rainforest. As these large tracts then remain inaccessible to most migrants from other regions, many potential migrants may stay home and pursue the nibbling form of deforestation. Hence, scarcity of capital may shift the location and nature of deforestation (Rudel 1991).

Mertens (1994: 26) concluded from a review of empirical studies of tropical countries that "if deforestation is to be limited, the most direct policy is to minimize new road construction in the humid tropics, particularly in areas where there are no roads. In some cases, though, as in ... Nepal, improvements in infrastructure can create conditions which make it easier to control deforestation."

When forests are cleared for farmland to feed an increasing population, the rate of cutting depends in part on how much land is required to produce food for one more person. That requirement depends on yields, farmer education, credit for agricultural investments in land and equipment, culturally acceptable crop varieties, soil types, water resources both natural and human-built, and so on through every aspect of culture and economics and the environment. Forests are sometimes cut because governments give land tenure or tax advantages to those who clear trees, and sometimes because domestic and international markets demand wood in quantities determined more by wealth and population density in cities than by human numbers in forested regions. A one-directional causal model like "human population growth causes forest clearing or land conversion" is far too simple in general (Jolly 1994, Marquette and Bilsborrow 1994).

In recent decades as global population has grown and global forests have declined, the price of timber in international commodity markets has increased. According to the World Bank Price Index for the Primary Commodities (revised April 1995) (World Resources Institute 1996: 170), timber was alone among the major categories of commodities to experience an increase in price between 1975 and 1994. In constant prices with the price in 1990 set equal to 100, the price of petroleum fell from 101 in 1975 to 63 in 1994. The prices of metals and minerals fell over the same period from 118 to 77. The price of nonfuel commodities as a whole (including timber) fell from 167 in 1975 to 102 in 1994. Total food commodity prices fell from 224 in 1975 to 98 in 1994; cereal prices in particular fell from 258 in 1975 to 98 in 1994. By contrast, timber prices (separated from other nonfuel commodities) increased from 92 in 1975 to 143 in 1994.

In 1993, a study of population and land use in developing countries offered the following major conclusions (Jolly and Torrey 1993: 9–11): "In the long run, population growth almost certainly affects land use patterns. The effects of population growth occur mainly through the extensification and intensification of agricultural production. ... Most of the changes in land use associated with very rapid population growth are likely to be disadvantageous for human beings. ... Population growth is not the only, or in many cases, the most important influence on land use. Other influences include technological change and changes in production techniques ... inequality itself, however, is in part influenced by rates of population growth ... with clear property rights, robust soils, and efficient markets, population growth is less likely to result in land degradation. ... Rapid population growth is likely to make the survival of other members of the animal and plant kingdom more difficult. Accompanying rapid population growth in the past has been greater species loss and a higher attrition within species than would have occurred in the absence of human expansion."

2.5 Increased Farming Intensity with Population Growth

On a long historical time scale, rising population density has been associated with rising farming intensity (Pingali and Binswanger 1987). Hunters and gatherers, who do not cultivate the land, practice a farming intensity of zero. If land is cropped once every year, the farming intensity equals 100%. If multiple crop cycles are completed within a single year and the land is never fallowed, the farming intensity exceeds 100% (Table 1).

A given value of farming intensity between 0 and 100% does not specify the duration of a cycle of cultivation and fallow. For example, a farming intensity of 5% could mean that, on the average, each year of cultivation is followed by 19 years of fallow. It could also mean, in principle, that five consecutive years of cultivation are followed by 95 years of fallow. Quite different amounts of succession and forest recovery can take place under these two regimes. Thus a given value of farming intensity is consistent with very different effects on biological diversity and forest cover.

In the schema of the economist Ester Boserup (1981: 19), forest fallow consists of 1–2 annual crops and 15–25 years of fallow; bush fallow of 2 or more crops and 8–10 years of fallow; short or grass fallow of 1–2 crops and 1–2 years of fallow; annual cropping of 1 crop per year, with fallow for only part of a year; and multicropping of 2 or more crops on the same land each year with no fallow. Bush fallow and more intense farming systems inhibit or prevent forest regeneration.

Boserup (1981: 23) investigated the association between population density and agricultural systems. Her definition of population density is not simply the ratio of people to all land, but rather the ratio of people to potentially arable land (Boserup 1981: 16). Potentially arable land excludes areas under ice, unirrigable deserts and mountains too steep for terracing or pasturing. Potentially arable land includes land that could be developed into agricultural land with suitable

Table 1. Population density, farming intensity, and farming systems in low-technology countries.

Farming system	Farming intensity* (%)	Population density (people/ha of potentially arable land)	Climate	Tools used
Hunter/gatherer	0	0–0.04		
Pastoralism	0	0–0.04		
Forest fallow	0–10	0–0.04	humid	axe, matchet, and digging stick
Bush fallow	10–40	0.04–0.64	humid or semi-humid	above tools plus hoe
Short fallow	40–80	0.16–0.64	semi-humid, semi-arid, high altitude	hoes and animal traction
Annual cropping with intensive animal husbandry	80–100	0.64–2.56	semi-humid, semi-arid, high altitude	animal traction and tractors
Multi-cropping with little animal husbandry	200–300	2.56 and up		

*Farming intensity (expressed in percent) is defined as 100 times the total number of crops (in one cycle of cultivation and fallow) divided by the total number of years in which the land is cultivated and fallowed (in one cycle of cultivation and fallow).
Sources: Boserup 1981: 9, 19, 23; Pingali and Binswanger 1987: 29.

investments in infrastructure and inputs; land now covered by forests that could be cleared and then farmed; grazing lands that are arable; and long-term fallow lands. This definition of "potentially arable land" is difficult, perhaps impossible, to measure in practice. For example, who knows whether never-cleared tropical forest land will be suitable for agriculture for more than a very few years? Compromising with the available international statistics on land use, Boserup (1981: 16) simply excluded land statistically classified as "other" "only if it is likely to be arctic or desert and accounts for ... a large share of total territory ..." For low-technology countries, she proposed that farming systems are associated with the population densities per area of arable land as shown in Table 1.

The global average population density of 0.42 people per ha would be compatible with bush fallow or short fallow farming if all ice-free land were arable (an unlikely possibility, especially with low levels of technology). Domesticated land (cropland plus permanent pasture) approximated 37% of all land excluding Antarctica during 1986-89 (World Resources Institute 1994: 284). If all domesticated land were potentially arable using low technology, then the global population density per unit of arable land would be 0.42/0.37 = 1.14 people/ha. According to Table 1, annual cropping is required when the population density exceeds 0.64 people per ha of arable land. It follows that nearly all arable land (defined here, for the sake of calculation, as domesticated land) should be cropped at least annually if farmers respond to global population densities rather than to local population densities only, and if farmers use low technology. Because some farmers sell food to remote dense populations, domestic and international trade and transport spread the ecological effects of locally dense populations to less populated regions.

In summary, the effect of global population growth on land use for agriculture, forestry, and other purposes depends in part on domestic and international politics, economics and transport, and in part on the level of technology farmers use. It has been argued that more intensive agriculture would preserve more land for nature (Waggoner 1994, Waggoner et al. 1996). A full accounting of the positive and negative external effects of more intensive agriculture remains to be provided.

2.6 Dynamic Theories of Land Use Change

Several theories have been developed to explain how changes in land use take place. These include qualitative models, such as the Richards' center-periphery model, and quantitative models, such as the Malthus–Condorcet–Mill model.

2.6.1 Richards' Center-periphery Model: A Qualitative Model

Richards (1990: 165) proposed a dynamic overview of human land exploitation that combines extensification and intensification. This center-periphery model may provide a qualitative basis for the quantitative self-similarity at different spatial scales in the spatial distribution of human population density.

According to Richards (1990: 165), "Intensification of human land use — both conversion and extraction of natural resources — is an essential feature of the spiraling, ever-extending domain of the modern capitalist states and the modern world economy. ...At the heart of this model is the urge to make complementary use of lands at the center and those in the peripheral areas. ...Intensive land use at the center ... relied upon resources extracted ruthlessly from lands in ... dependent regions. ... Urban demands for foodstuffs, energy, water and other commodities dr[o]ve land conversion and resource extraction in their immediate hinterlands. Rising populations and improved access enlarged each city's immediate hinterlands. Highly intensive market-gardening pushed outward extensive grain farming and livestock raising in belts around most early modern European cities. We find therefore a center-periphery model replicated in the regions surrounding each city."

He continued, "Over time, colonial or dependent states moved closer to the European model of intensive land use and control. ... dependent regions were subjected first to heavy resource extraction and commodity production typical of the periphery. In time, indigenous core regions of intensive land use coalesced to form a new land-use hierarchy within each region. At this secondary or intermediary level, core regions directed extraction of resources from their own peripheries as new frontiers of settlement were opened." Richards gave the example of Calcutta, on the periphery of London, becoming a center for extraction from surrounding eastern Bengal, Assam, and Orissa. "At a still deeper level, subregional centers emerged in which the process of urban-dominated land use commenced. Dacca in Eastern Bengal and Assam directed the expansion of settlement, land clearing, timbering, and other exploitative activities in their hinterlands. At this and even lower levels, we can see arrays of smaller frontier regions and subregions merging one into the other. In this fashion, intensified control and productivity on the world's lands gained momentum in each succeeding century."

This hierarchical self-similar pattern of a central city dominating peripheral regions of supply, which spawn their own new cities, provides a qualitative explanation of the observed self-similarity in the distribution of population density. It would be valuable to see how well this model explains the dynamics of population growth and land use in earlier empires of Mesopotamia, China, Meso-America, the Middle East (Ottoman), South Asia (Moghul) and elsewhere. How much of Richards' expanding cycle of intensification and extensification depends on western technologies for transportation and communication and western institutions for administration, accounting and control, and how much is general to the building of empires?

2.6.2 The Malthus–Condorcet–Mill Model: A Quantitative Model

Richards' center-periphery model envisions an autocatalytic process in which population growth and growing demands for consumption drive the development or exploitation of additional resources by extensification and intensification, leading to further population growth and consumption. I recently proposed a highly schematic model called the Malthus–Condorcet–Mill model, which presents a possible quantitative version of this process (Cohen 1995a, also see Cohen 1995b, Appendix 6). The model's underlying concepts derive from a debate in the late 18th century between Malthus and Condorcet. The British philosopher John Stuart Mill (1806–1873) contributed to this debate (Mill 1848) by picturing a stationary population as both inevitable and desirable. The views of Condorcet and Malthus are still represented today in the approaches of neoclassical and classical economists (sections 1.1.1 and 1.1.2), respectively.

Malthus described a dynamic relation between human population size and a society's capacity to support itself at a level of living that it defines as satisfactory (Malthus 1798, Chap. VII: 51): "The happiness of a country does not depend, absolutely, upon its poverty or its riches, upon its youth or its age, upon its being thinly or fully inhabited, but upon the rapidity with which it is increasing, upon the degree in which the yearly increase of food approaches to the yearly increase of an unrestricted population." Malthus opposed the optimism of the Marquis de Condorcet (1743–1794), who saw the human mind as capable of removing all obstacles to human progress. Demeny (1988: 232) generalized Malthus's view to incorporate all aspects of economic output, not just food: "Posed in the simplest terms, the economics of population reduces to a race between two rates of growth: that of population and that of economic output."

The Malthus–Condorcet–Mill model is a highly idealized mathematical sketch of the race between the size of the human population and the capacity to provide human well-being, which I shall call human carrying capacity for the moment. Suppose that it is possible to define a current human carrying capacity $K(t)$ as a numerical quantity measured in numbers of individuals. Suppose also that $P(t)$ is the total number of individuals in the population at time t and that

$$dP(t)/dt = r\,P(t)\,(K(t) - P(t)).$$

The constant $r > 0$ is called the Malthusian parameter. I call this the equation of Malthus because it expresses the limitation of population growth by the current carrying capacity, and recognizes, as Malthus did, that the current carrying capacity can change over time. The equation of Malthus is the same as the logistic equation except that the constant K in the logistic equation is replaced by variable carrying capacity $K(t)$ here.

To describe changes in the carrying capacity $K(t)$, let us recognize, in the phrase of former United States President George H.W. Bush (1992) that "every human being represents hands to work, and not just another mouth to feed." Additional people clear rocks from fields, build irrigation canals, discover ore deposits and antibiotics and invent steam engines; they also clear-cut primary forests, contribute to the erosion of topsoil, and manufacture chlorofluorocarbons and plutonium. Additional people may increase savings or dilute and deplete capital; they may increase or decrease the human carrying capacity.

Suppose that the rate of change of human carrying capacity is directly proportional to the product of two factors: (1) the rate of change in population size (the Condorcet factor), and (2) the average resources available per person (the Mill factor). In the language of President Bush, the change in capacity to produce well-being depends on both how many additional hands there are and what those hands have to work with. We assume here, contrary to fact, that each additional pair of hands shares equally in the productive resources available to all existing hands.

Suppose, for example, that there is a constant $L > 0$ such that the productivity of an additional person is $L/P(t)$ (think of land per person); L is the Mill parameter. The assumption that $L/P(t)$ is positive, no matter how big $P(t)$ is, models the dilution of resources, but not their depletion or degradation. The Condorcet–Mill equation supposes that the increment in human carrying capacity equals the product of the productive resources available to an average person, namely, $L/P(t)$, and the increment in population size:

$$dK(t)/dt = (L/P(t))\,(dP(t)/dt).$$

This model assumes no migration and ignores the population's age composition, geographical distribution and distribution of well-being or income. The model ignores stochastic fluctuations in environmental and human factors.

Assume further that $L/P(0) > 1$; this means that, initially, productive resources are so abundant that the average person can provide well-being for more than himself or herself alone. Then the population initially grows faster than exponentially. As $P(t)$ increases past L, $c(t)$ passes through 1 and the population experiences a brief instant of exponential growth. Then $c(t)$ falls below 1 and the population size thereafter grows sigmoidally. Population size rises to approach a unique stationary level, which is independent of r. The larger the initial carrying capacity $K(0)$ and the larger the supply L of land or other basic natural resource, the larger the stationary level is, other things being equal.

Figure 6 shows a trajectory of human carrying capacity $K(t)$ (dashed upper curve) and population size $P(t)$ (solid lower curve) according to the Malthus–Condorcet–Mill model; $P(t)$ is compared with the estimated human population history (filled boxes) over the past 2,000 years. The theoretical trajectory of population looks sigmoidal on a logarithmic scale. Values of $P(t)$ beyond $t = 1995$ are intended only to illustrate the qualitative behavior of the model, not to predict future human population. Nothing guarantees that the actual human population will reach or remain at the high plateau shown. For example, the model neglects the possibilities that people could increasingly choose to divide the available material resources among fewer offspring, trading numbers for wealth, and that pollution or exogenous climatic changes could diminish human carrying capacity. Further, nothing guarantees that the productive resources available per additional person in the future will be described by a function as simple as $L/P(t)$.

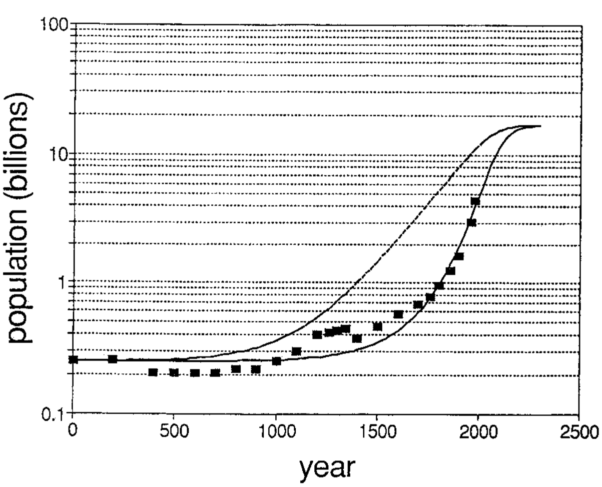

Fig. 6. Numerical illustration of the equations of Malthus and Condorcet–Mill: human carrying capacity $K(t)$ (dashed line) and model population size $P(t)$ (solid line); for comparison, estimated actual human population (solid rectangles). Equations: $P(t + \delta t) - P(t) = rP(t)(K(t)-P(t))\,\delta t$, $K(t + \delta t) - K(t) = L\,r\,(K(t)-P(t))\,\delta t$. Initial conditions and parameters: δt = 20 years, $P(0) = 0.252$, $K(0) = 0.252789$, $r = 0.0014829$, $L = 3.7$. $P(0)$, $K(0)$, L are measured in billions. Reprinted with permission from Cohen (1995a). Copyright © 1995 by The American Association for The Advancement of Science.

Up to about $t = 1970$, population sizes (theoretical and actual) are convex on the logarithmic scale; after roughly $t = 1970$, they are concave. The human carrying capacity $K(t)$, initially only slightly above $P(t)$, began to exceed $P(t)$ substantially at times corresponding to the 9th and 10th centuries, and experienced nearly exponential growth (linear increase on the logarithmic scale shown) from the 11th to the mid-20th century. According to the model, the acceleration of population growth in the 17th century was preceded by a long period of increasing human carrying capacity.

Europe grew technologically and economically for a millennium before the Industrial Revolution (Cipolla 1994: 137–159); England developed economically from the 12th century onward (Wilkinson 1973, Hardesty 1977: 209–210). In the 13th century, English forests were cleared, swamps drained, and new lands exploited for cultivation; yields improved as a result of liming, plowing straw ash into the field, and planting new varieties of seeds. At the same time, the mining and smelting of tin, lead and iron; the manufacture of pottery; and the production of salt and wool all increased greatly. Additional surges of economic development occurred in the 16th century.

This allegorical model focuses attention on the factors, natural and human-made, that determine the productivity of each additional person.

2.7 Defining Human Carrying Capacity: Natural Constraints and Human Choices

Human transformations of the earth have changed the earth's ability to generate human well-being as well as human definitions of well-being. No concept of carrying capacity in basic and applied ecology is adequate as a concept of human carrying capacity because none of the many variants takes account of the human choices in defining and determining human carrying capacity (Cohen 1995b, Chap. 12).

Estimating how many people the earth or any region of it can support, and defining the variable $K(t)$ in the Malthus–Condorcet–Mill model, involve both natural constraints that humans cannot change and do not fully understand, and human choices that are yet to be made by this and by future generations. Therefore the earth's human carrying capacity is not a single fixed number, now or as long as the earth is habitable (Cohen 1995b, Chap. 13). Because the earth's human carrying capacity is constrained by facts of nature, human choices about the earth's human carrying capacity are not entirely free, and may have consequences that are not entirely predictable. Because of the important roles of uncertainty, natural constraints, and human choices (both individual choices and social decisions), estimates of human carrying capacity cannot aspire to be more than conditional and probable estimates: if future choices are thus-and-so, then the human carrying capacity is likely to be so-and-so.

No sharp line separates human choices and natural constraints. For example, technology obeys the laws of physics, chemistry and biology, but humans choose how, and how much, to invest in creating and applying technology. Hence the technology that people use depends jointly on human choices and natural constraints. The fuzzy zone between choices and constraints shifts as time passes. Changes in knowledge can reveal constraints that had not been recognized previously, and can also make possible new choices. Furthermore, a choice open to rich people may be a constraint for poor people. A rich landowner may choose to leave forest uncut and cropland idle; a subsistence farmer with small holdings may not enjoy the luxury of choosing.

To define and estimate the earth's or a region's human carrying capacity, at least the following questions of human choice need to be answered:

1. What is the desired average level of material well-being?
2. What is the desired distribution of material well-being?
3. What is the desired technology?
4. What are the desired domestic and international political institutions?
5. What are the desired domestic and international economic arrangements?
6. What are the desired domestic and international demographic arrangements?
7. What are the desired physical, chemical and biological environments?
8. What is the desired variability or stability?
9. What is the desired risk or robustness?
10. What is the time horizon?
11. What values, tastes and fashions will people hold?

2.7.1 Average Level of Material Well-being

Material well-being includes food (people choose variety and palatability, beyond the constraints imposed by physiological requirements); fiber (people choose cotton, wool or synthetic fibers for clothing, wood pulp or rag for paper); water (tap water or Perrier or the nearest river or mud hole for drinking, washing, cooking and watering your lawn, if you have one); housing (Auschwitz barracks or Thomas Jefferson's Monticello); manufactured goods; waste removal (for human, agricultural and industrial wastes); natural-hazard protection (against floods, storms, volcanoes and earthquakes); health (prevention, cure and care); and the entire range of amenities such as education, travel, social groups, solitude, the arts, religion, and communion with nature. Not all of those features are captured well by standard economic measures.

2.7.2 Distribution of Material Well-being

Estimates of human carrying capacity rarely take into account the scatter or distribution of material well-being in a population. Yet people who live in extreme poverty may not know or care that the global average is satisfactory, and the press of present needs may keep them from taking a long-term view. For example, thanks to genetic engineering, any country with a few PhDs in molecular plant biology and a modestly equipped laboratory can insert the genes to create stronger, more disease-resistant, higher-yielding plants. If every region has the scientific and technical resources to improve its own crop plants, the earth can support more people than it can if some regions are too poor to help themselves.

2.7.3 Technology

Will people collectively choose to develop technologies for mass transportation or for individual cars? Will people develop new electrical generators based on sunlight, oil, coal, uranium, plant wastes, refuse from cities, agriculture, industry, wind, tidal motion, wave motion, falling water or heat deep in the earth's crust? The human carrying capacity will depend on the choices made by voters, businesses, research organizations, civic groups and governments. Those choices will depend in turn on the economics, environmental effects, cultural acceptability, institutional governability and other features of the technologies.

The complexities of technological choices often disappear in heated exchanges between environmental pessimists and technological optimists:

- *Ecologist*: When a natural resource is being consumed faster than it is being replenished or recycled, an asset is being depleted, to the potential harm of future generations.
- *Technologist*: If new knowledge and technology can produce an equivalent or superior alternative, then future generations may turn out to be better off.
- *Taxpayer*: Which natural resources can be replaced by technology yet to be invented, and which can-

not? Will there be enough time to develop new technology and put it to work on the required scale? Could we avoid future problems, pain and suffering by making other choices now about technology or ways of living?

- (No answer from ecologist or technologist.)

The key to the argument is time. Richard E. Benedick, an officer of the U.S. Department of State who has also served with the World-Wide Fund for Nature, worried (Benedick 1991: 201): "While it is true that technology has generally been able to come up with solutions to human dilemmas, there is no guarantee that ingenuity will always rise to the task. Policymakers must contend with a nagging thought: 'what if it does not, or what if it is too late?'"

2.7.4 Domestic and International Political Institutions

Political organization and effectiveness affect human carrying capacity. For example, the United Nations Development Program estimated that developing countries could mobilize for development as much as $50 billion a year (an amount comparable to all official development assistance) if they reduced military expenditures, privatized public enterprises, eliminated corruption, made development priorities economically more rational and improved national governance (Gardner 1992: 30). Conversely, population size, distribution and composition affect political organization and effectiveness.

Political choices that affect human carrying capacity involve a host of questions. How will political institutions and civic participation evolve with increasing numbers of people? As numbers increase, how will people's ability to participate effectively in the political system change? What standards of personal liberty will people choose? How will people bring about political change? By elections and referendums, or by revolution, insurrection and civil war? How will people choose to settle differences between nations, for instance, over disputed borders, shared water resources or common fisheries? War consumes human and physical resources. Negotiation consumes patience and often requires compromise. The two options impose different constraints on human carrying capacity.

2.7.5 Domestic and International Economic Arrangements

What levels of physical and human capital are assumed? Tractors, lathes, computers, better health, and better education all make workers in rich countries far more productive than those in poor countries. Wealthier workers make more wealth and can support more people.

What regional and international trade in finished goods and mobility in productive assets are permitted or encouraged? How will work be organized? The invention of the factory organized production to minimize idleness in the use of labor, tools, and machines. What new ways of organizing work should be assumed to estimate the future human carrying capacity?

2.7.6 Domestic and International Demographic Arrangements

Almost every aspect of demography (birth, death, age structure, migration, marriage, and family structure) is subject to human choices that influence the earth's human carrying capacity. If global population eventually becomes stationary (unchanging birth rates, death rates and total size), people will have to choose between a long average length of life and a high birth rate. They will also have to choose between a single average birth rate for all regions, on the one hand, and a demographic specialization of labor on the other (in which some areas have fertility above their replacement level, whereas other areas have fertility below their replacement level).

Patterns of marriage and household formation will also influence human carrying capacity. For example, the public resources that have to be devoted to the care of the young and the aged depend on the roles played by families. In China national law requires families to care for and support their elderly members. In the United States each elderly person and the state are largely responsible for supporting that elderly person; his or her relations may choose whether to assume responsibility for care.

2.7.7 Physical, Chemical, and Biological Environments

What physical, chemical, and biological environments will people choose for themselves and for their children? Much of the heat in the public argument over current environmental problems arises because the consequences of present and projected choices and changes are uncertain. Will global warming cause great problems, or would a global limitation on fossil-fuel consumption cause greater problems? Will toxic or nuclear wastes or ordinary sewage sludge dumped in the deep ocean come back to haunt future generations when deep currents well up in biologically productive offshore zones, or would the long-term effects of disposing of those wastes on land be worse? The choice of particular alternatives could materially affect human carrying capacity.

2.7.8 Variability or Stability

The earth's human carrying capacity depends on how steadily people want the earth to support the human population. If people are willing to let the human population rise and fall, depending on annual crops, decadal weather patterns and long-term shifts in climate, the average population with ups and downs would include the peaks of population size, whereas the guaranteed level would have to be adjusted to the level of the lowest valley. Similar reasoning applies to variability or stability in the level of well-being; in the quality of the physical, chemical and biological environments; and in many other dimensions of choice.

2.7.9 Risk or Robustness

The earth's human carrying capacity depends on how controllable people want the well-being of the population to be. One possible strategy would be to maximize numbers at some given level of well-being, ignoring the risk of natural or human disaster. Another would be to accept a smaller population size in return for increased control over random events. For example, if people settle in a previously uninhabited hazardous zone (such as the floodplain of the Mississippi River or the hurricane-prone coast of the southeastern United States), they demand a higher carrying capacity of the hazardous zone, but they must accept a higher risk of catastrophe. When farmers do not give fields a fallow period, they extract a higher carrying capacity along with a higher risk that the soil will lose its fertility (as agronomists at the International Rice Research Institute in the Philippines discovered to their surprise).

2.7.10 Time Horizon

Human carrying capacity depends strongly on the time horizon people choose for planning. The population that the earth can support at a given level of well-being for 20 years may differ substantially from the population that can be supported for 100 or 1,000 years. The time horizon is crucial in energy analysis. How fast oil stocks are being consumed matters little if one cares only about the next five years. In the long term, technology can change the definition of resources, as ores that were useless rock 10,000 years ago have been converted to valuable sources of metals today. No one can say whether industrial society is sustainable for 500 years.

Some definitions of human carrying capacity refer to the size of a population that can be supported indefinitely. Such definitions are operationally meaningless. There is no way of knowing what human population size can be supported indefinitely (other than zero population, since the sun is expected to burn out in a few billion years, and the human species almost certainly will be extinct long before then). The concept of indefinite sustainability is a phantasm, a diversion from the difficult problems of today and the coming century.

2.7.11 Fashions, Tastes, and Values

The earth's human carrying capacity depends on what people want from life. Many choices that appear to be economic depend heavily on individual and cultural values. Should industrial societies use the available supplies of fossil fuels in households for heating and for personal transportation, or outside of households to produce other goods and services? Do people prefer a high average wage and low employment or a low average wage and high employment (if they must choose)?

Should industrial economies seek now to develop renewable energy sources, or should they keep burning fossil fuels and leave the transition to future generations? Should women (and, by symmetry, should men) work outside their homes? Should economic analyses continue to discount future income and costs, or should they strive to even the balance between the people now living and their unborn descendants?

Humans seem to resolve conflicts of values by personal and social processes that are poorly understood and virtually unpredictable at present. How such conflicts are resolved can materially affect human carrying capacity, and so there is a large element of choice and uncertainty in human carrying capacity.

3 HISTORY OF POPULATION GROWTH AND LAND USE IN THE UNITED STATES

Prior to written records, the North American continent was shaped by repeated glaciations and peopled by Amerindians (MacLeish 1994). This long prehistory framed the stage on which immigrant Americans from Europe, Africa, and Asia enacted their settlement.

3.1 U.S. Forest History

In outline, the recorded history of American forests has two phases: a decline until 1920, and a gradual, recently variable, recovery since 1920. Likewise, the Federal Government's purpose in dealing with public lands has gone through two phases. At first, the Government aimed to transfer public lands into private hands; later, it aimed to retain and manage public lands. Reviews of land use and forestry in the United States have been written from diverse points of view by Williams (1989, 1990), Sedjo (1991), Alverson et al. (1994), Meyer (1995), Johnson (1996), Diamond and Noonan (1996), Wernick et al. (1997), and MacCleery and LeMaster (this volume).

When Europeans began to settle North America, about half of the conterminous United States was forested. Most of the forests lay in the eastern half of the continent (Meyer 1995: 29). But these were not "forests primeval": many had long been affected by repeated burning, extraction, and other management by an estimated 12 million pre-Columbian Amerindians of North America. Euro-American farmers in the north felled a hectare or so per year, mainly by clearcutting (Williams 1990: 182). As many as 10 million ha of forest were probably cleared to support the population present by 1776 (Williams 1989, 1990).

As might be expected from a dynamic interpretation of the global association between higher population density and less forest cover, the absolute area of American land covered by forests declined steadily during this period; the fraction of forested land declined more rapidly because much of the added territory was not forested. Forested area fell by about 36 million ha between 1780 and 1850 (Williams 1989, 1990). The wooded area of the (then) entire United States declined a further 121 million ha from perhaps 364 million ha around 1850 to about 243 million ha around 1920. (The estimates plotted by Wernick et al. [1997, their Fig. 1], based on other sources, indicate more than 300 million ha of forested land in 1920, and correspondingly higher estimates at other dates. Their numbers may include all of present U.S. territory.)

The wooded area of the conterminous United States slowly increased from 1920 until around 1960. Croplands were abandoned in the east and forests regrew in many cutover areas that were found to be unsuitable for agriculture. From 1930 onward, many timber companies gradually abandoned a frontier style summarized as "cut out and get out" (Williams 1990: 186) in favor of management for sustained yields.

Forested lands in the United States have probably declined slightly since 1960, unlike the forest lands of most industrial democracies, which increased. In 1992, forest lands occupied about 298 million ha (about 32% of the entire United States). By coincidence, the same fraction of the conterminous U.S. is forested. For comparison with the 32% of forest land in the United States, about 10% of the land of the United Kingdom and two-thirds of the area of Japan is forest and woodland. To preserve its mountainous forests, Japan imports far more timber than it exports. Japan's timber imports come mainly from the Americas and from southeast Asia.

Despite the possible decline in U.S. forested area since 1960, between 1952 and 1992 U.S. Forest Service timber inventories reported a 30% increase in timber volume. During this period, the volume of hardwoods rose 80% and that of softwoods 4% (Wernick et al. 1997, citing U.S. Forest Service reports). The carbon stored in U.S. forests increased by one-third (Wernick et al. 1997, citing Birdsey et al. 1993). The increases in timber volume and stored carbon are probably at least partly a result of a very dramatic decline in forest fires: the area burned annually by wildfire dropped an estimated 90% between 1920 and 1990 (Johnson 1996: 13).

In 1850, the public domain covered nearly two-thirds of the conterminous United States. Through the late 19th century, the Federal Government aimed to transfer public land to private holders. This was what Meyer (1995: 28) called "the disposal era." The intent was to raise revenue, to encourage settlement by Euro-Americans, and to "improve" the land, largely by clearing forests and draining wetlands for agriculture. Vestiges of the disposal era remain in present mining laws.

The phase of Federal land management began with the creation of Yellowstone National Park, the world's first national park, in 1872 and gathered force in the 1890s when more than 16 million ha of western lands became Federal forest preserves (Meyer 1995: 28). In recent decades, domestic issues spurred major new laws governing U.S. Forest Service management of National Forest lands, including the Multiple Use–Sustained Yield Act in 1960, the Forest and Rangelands Resource Planning Act in 1974, and the National Forest Management Act in 1976 (Johnson 1996: 1).

According to the 1987 U.S. National Resources Inventory (as reported by Meyer 1995: 27), of the roughly 763 million ha of land (including 40 million ha of wetlands) in the conterminous United States, about 21% is forest, 21% is rangeland, 22% is cropland, and 21% is Federal land. Pasture accounts for about 7%, developed land about 4%, and other land covers and surface water about 3%. Federal land is approximately half forest (thus roughly 10% of the conterminous United States) and half rangeland (another 10% or 11%). Much of this Federal land is leased for private use. Combining Federal and other lands, about 32% of the conterminous United States is forest (as mentioned above), and a roughly equal fraction is rangeland. In each of these categories, about one-third is Federal land. The Federal role in managing forests and rangelands is large, but so also is the role of businesses, individual private owners and other levels of government.

Like American agriculture earlier, many American cities are going through a period of extensification, as transportation has enabled the dispersal of residences and lower densities of settlement (Meyer 1995: 31). Growing urban populations, and higher amounts of land per person in settlements, have converted agricultural and forested land around cities to developed land. Nevertheless, again contrary to what might be expected from the contemporary association in developing tropical countries between population density and forested area, the Northeast region of the United States is both most densely populated and most heavily wooded: three-fifths of its area is forested (Meyer 1995: 28). The intense urbanization of most of the northeastern states makes possible this combination of forest cover and dense population. Cropland dominates the Midwest, rangeland the West. The South has about 40% forest, 20% rangeland, and 20% cropland.

3.2 U.S. Population

Between 1790, the year of the first U.S. Census, and 1920, the population of the United States rose from 3.9 million to 106 million, while the land area (excluding inland water) rose from 224 million ha to 769 million ha (U.S. Bureau of the Census 1975: 8). Thus the average population density rose from one person per 57 ha to one person per 7 ha.

In the second phase of American forests, from 1920 to 1990, the population of the conterminous United States more than doubled to about 247 million while the land area of the conterminous United States hardly changed. The population density of the conterminous United States rose from one person per 7 ha to one person per 3 ha.

Current levels of U.S. fertility are below replacement level: the average American woman would bear 2.0 children if she experienced current age-specific birth rates throughout her life. If current levels of fertility were to continue long enough, absent immigration, the U.S. population would peak and gradually decline. However, because the United States currently has many people in their peak years of childbearing, current births exceed deaths by about 1.6 million per year. In 1987, the most recent year for which this information is available, nearly two in five births in the United States resulted from unintended pregnancies, that is, pregnancies that were either mistimed or unwanted at any time (Brown and Eisenberg 1995: 26). In addition, current immigration exceeds emigration by about 1 million per year, although the amount of unauthorized immigration included in this figure can only be guessed. Thus the U.S. population is growing by roughly 1% per year, a rate — if continued — sufficient to double the population in about 70 years. About half the population lives within 80 km of the east or west coast.

Projections of U.S. population in 2020 range from 286 million to 385 million, depending on assumptions about mortality, fertility, and immigration. For 2050, projections range from 280 million to 553 million (Ahlburg and Vaupel 1990: 644). If fertility levels increase and immigration continues at a high level, the U.S. population could more than double by 2050.

Does continued population growth in the United States imply a collision with limited forest resources, especially if public forests will not be managed primarily to produce timber and other commodities? This chapter suggests that the answer depends on economics, technology, politics, and cultural values as much as it depends on rising numbers of humans.

3.3 U.S. Forest Economics

Over the long-term, real lumber prices in the United States grew roughly exponentially with a five-fold increase per century since 1800, but with substantial short-term fluctuations. For lumber, the relative producer price index (the actual price index divided by the all-commodities price index) grew from 6 or 7 in the decade 1800–1810 to 35 or 45 in the decade 1900-1910. It fluctuated between 100 and 150 in the years between 1970 and 1990 (U.S. Department of Agriculture 1989: 6).

Rising lumber prices, reflective of relative scarcity, and the availability of less expensive substitutes must explain, at least partially, a remarkable observation: between 1900 and 1993, the aggregate U.S. consumption of all timber products (as fuel, pulp, plywood, and lumber) increased 70%, while gross domestic product rose 16-fold (Wernick et al. 1997). The 16-fold increase was the product of a more than tripled population size and a gross domestic product per person that grew nearly 5-fold. Over the past century, and decade by decade, Americans' impact on their forests, as measured by consumption of timber products, has not varied in proportion to the product of American population size and American affluence, as measured by gross domestic product per person. Future demands on forests cannot reliably be projected by assuming a proportionality between population size and the consumption of forest products.

The consumption per American of all timber products fell by roughly half between 1900 and 1993. Timber ceased to be used to surface roads. Fossil fuels replaced much use of wood for fuel, although fuelwood consumption has had a resurgence since the oil price shocks of 1973. Railroad ties and pier timbers were treated with preservatives to prolong their lives, and sometimes were replaced with other materials such as concrete. Brick, concrete and other materials replaced timber as construction materials. While U.S. demand for wood as a fuel and as a construction material diminished, the demands for plywood and for wood fiber for paper and paperboard rose (Wernick et al. 1997). (Although the annual consumption of timber products per American fell during this century, it does not follow that the annual output of carbon (from timber products plus fossil fuels plus all other sources) to the atmosphere per American fell. Whether environmental impact rises in proportion to, faster than, or slower than population depends on how narrowly or comprehensively the environmental impact is measured.)

The consumption of raw wood per person grew by one-third from 1970 to 1990, to 2.3 cubic meters per person in 1990 (Johnson 1996). Consumption grew for all major categories of wood products, such as paper and paperboard, lumber, and wood-based panels. Currently, average timber productivity is 3.1 cubic meters per ha. If it is harvested to produce a sustained yield at the current average level of timber productivity, the 198 million ha of U.S. forest land that is presently productive enough to harvest and is not legally protected from harvesting can supply domestic wood consumption for roughly 270 million people, at the current level of consumption per person (Johnson 1996: 5). The estimated population of the United States in 1996 was about 265 million and was increasing by roughly 3 million per year (Population Reference Bureau 1996).

In 1993, the United States imported 67 million m^3 of forest products (about 10% of total forest product inputs of 646 million m^3, including 65 million m^3 of recycled material), and exported 65 million m^3 (again about 10% of total forest product outputs of 637 million m^3 delivered to consumers), according to a synopsis of material flows in the U.S. forest products industry (Wernick et al. 1997). These numbers assume that one metric ton of forest products occupies 2 m^3. Thus the volume of forest product imports roughly equals that of exports. It would be of great interest to compare the ecological, economic and social impacts of the growth, extraction, processing and sale of the wood and wood products that the U.S. imports with the impacts of the forest products it exports.

Land use and land cover are most critical to three sectors of the economy: agriculture, livestock, and forest products (Meyer 1995: 32). The share of these sectors in U.S. economic output has steadily declined over the last century and a half. Around 1870, agriculture provided more than one-third of the U.S. gross domestic product (GDP). By 1950, agriculture, forestry and fisheries together accounted for 7% of GDP, and today they represent about 2%. As a fraction of total U.S. energy consumption, wood fell from 90% in 1850 to a few percent today. Meanwhile, Americans began to seek non-timber products, recreation, wildlife habitat, watershed protection, and other values in their forested lands instead of or in addition to timber production. The National Forest system registered 10 times as many recreational visitor days per year in the early 1990s as it did in 1950 (Johnson 1996: 7).

4 FUTURE TRADEOFFS FOR AMERICAN CITIZENS AND LAND MANAGERS

American land use and American forestry have never been isolated from demographic, economic, environmental and cultural factors outside of American boundaries. It was the influx of European settlers that launched the large-scale Euro-American onslaught against the forests. With the first settlement of Maine, as British woodlands were depleted and rivalry between European colonial powers mounted, the British Crown claimed Maine's tall pines as masts and spars for its navy.

In future American land use and forestry, it seems likely that purely domestic factors will increasingly have to be balanced against demographic, economic, environmental, and cultural influences that originate outside of American boundaries. Domestic trends — a growing U.S. population, increasing domestic aggregate demand for forest products and non-timber forest services, and rising prices for timber — seem likely to make the tradeoffs more difficult and to sharpen the competing demands that will be made on private and public forest managers.

Without pretending to any completeness in enumerating the external influences and competing demands that will bear on American land use and forestry, I give some current examples from each of the broad categories of demography, economics, environment, and culture.

Observers of the history of human use of land and forests differ greatly about whether existing governmental policies, market institutions, and market forces will permit a smooth adaptation to problems (e.g., Sedjo 1991), or whether fundamental reforms of existing institutions, policies, and practices will be required (e.g., Barber et al. 1994). Historical data can be deployed on both sides, and a resolution seems more likely to emerge from the arena of politics than of science.

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Without pretending to any completeness in enumerating the external influences and competing demands that will bear on American land use and forestry, I give some current examples from each of the broad categories of demography, economics, environment, and culture.

Observers of the history of human use of land and forests differ greatly about whether existing governmental policies, market institutions, and market forces will permit a smooth adaptation to problems (e.g., Sedjo 1991), or whether fundamental reforms of existing institutions, policies, and practices will be required (e.g., Barber et al. 1994). Historical data can be deployed on both sides, and a resolution seems more likely to emerge from the arena of politics than of science.

One clear lesson from studying past expectations about the future is that those expectations are frequently wrong: unexpected problems arise from unexpected sources. I claim no crystal ball. Instead of relying heavily on forecasts and projections, I will focus on issues that are already of concern.

4.1 Population

The U.S. population will probably increase in coming years, but at a rate much less than the rate of population increase in poor countries. How much the U.S. population will increase depends on the future balance of domestic births and deaths and on future authorized and unauthorized immigration. How many people attempt to immigrate to the United States without authorization will depend in part on economic and political conditions in other countries.

Domestic policies can influence the incidence of births resulting from unintended pregnancies, the levels of authorized and unauthorized migration, and settlements in areas vulnerable to natural hazards such as coastal storms, river flooding, and forest fires. If Americans continue to settle preferentially in coastal zones (with the encouragement of federally subsidized disaster aid and insurance), forests inland could experience reduced demand for conversion to urban uses. Forests around urban centers could experience increased demand for conversion at the same time that city dwellers increasingly seek nearby forests for recreation and second homes.

Abroad, population growth is most rapid in the poor countries, but the four-fifths of the world that is poor commands only one-fifth of the world's income. If the income of poor countries rises, their peoples may become contenders with Americans for the products and services of American forests.

4.2 Economics

Along with human numbers, wealth drives demand for forest resources, both domestically and internationally, and often by a larger multiple than human numbers alone. For example, in 1993, the average person in the United States had a gross domestic product of $24,000 and consumed about 320 kilograms of paper per year. In Latin America, the average person had a GDP below $2,000 and consumed 30 kilograms of paper per year (Johnson 1996: 8). According to Johnson (1996: 9), "The vast majority of internationally traded forest products are consumed in developed countries. It is the appetite of developed countries that drives the global search for fiber — a search that is now expanding to new parts of the world such as the natural forests of the Amazon Basin and Guyana Shield in South America, Central Africa, the Russian Far East, and Canada, the plantations of Chile, New Zealand, and Brazil, and maturing secondary forests in parts of the United States."

At the same time, wealth enables more productive forestry, more efficient milling, and technological substitutions. Americans burned more wood as fuel in the decade 1936–1945 after the Great Depression and in the decade 1973–1982 after the oil shocks. Wernick et al. (1997) concluded that "in America as in many developing countries, poverty and costly oil cut forests." A full view of the data suggests that both poverty and wealth lead people to cut forests.

The long-term rise in the price of timber domestically and internationally testifies that demand has been and is growing faster than supply. As rich and poor countries seek to increase their wealth, the competition for products derived from forest resources can be expected to intensify. In many tropical countries, the area of this resource base is declining rapidly (Repetto and Gillis 1988: 7). Demands for greater forest productivity, reforestation or other preservation of the global forest stock, and more equitable access to the benefits of forests can be expected to intensify.

Johnson (1996: 18) suggested that it may prove increasingly difficult to satisfy growing expectations of "more wilderness and cheaper 2×4s and toilet paper at the same time." Wernick et al. (1997) suggested optimistically that the present annual timber harvest of roughly 500 million m^3 could be grown on only 23% of present timberland if the sites assessed as having the highest "potential" growth achieved that potential (over 5.9 m^3 per ha per year, compared with present yields of 3.1 m^3 per ha per year). Both the fears and the hopes rest on assumptions that may or may not be realized.

Most markets for land and forestry products and services, and many economic analyses based on market indicators of value, neglect externalities, that is, consequences of market exchanges that fall on parties other than those willingly involved in the exchange. For example, clearcutting a forest may benefit the landowner and the logging operator and all the employees and manufacturers who depend on the timber. At the same time, clearcutting may adversely affect the owners of a downstream hydroelectric project (because accelerated soil erosion increases siltation behind a dam), farmers who depend on the dam for irrigation, future owners of the forest land who acquire a thinner soil cover, future generations who inherit a diminished biodiversity, and people on the other side of the globe who experience an increment in the carbon dioxide concentration of the atmosphere (Sharma 1992). None of the adversely affected parties participated in the exchange that made the clearcut possible. Most economists are well aware of externalities as important market imperfections, but economic ideas about how to counteract the adverse effects of externalities apparently remain insufficiently used in practice. As population growth and rising consumption increase the interdependence among human actions, often across the boundaries of national sovereignty, it seems likely to become increasingly important to account and pay for the externalities of managing lands and forests.

4.3 Environment

Domestically, the large-scale suppression of forest fires has invited developers to build homes on the edges of forests with a growing load of flammable dead wood, has interfered with normal patterns of biodiversity that depend on fires started by natural causes, and has led to conflict between some lumbering-based local communities and timber companies, on one side, and some ecologists and conservationists, on the other side. Forest managers sit in the crossfire of these conflicts.

Growing international trade in logs and lumber and growing international travel for purposes unrelated to forests have brought insects and diseases (for example, the Gypsy moth and Dutch elm disease) to forests not prepared by evolution to resist them. Tree plantations of one or a few tree species will become increasingly vulnerable to catastrophic pest outbreaks.

The atmospheric concentrations of carbon dioxide, methane, other greenhouse gases and chlorofluorocarbons, as well as changes in global average temperatures and stratospheric ozone concentrations, affect all countries, although not equally. Acid precipitation and air pollution cross national boundaries in North America and Europe. According to the Intergovernmental Panel on Climate Change (1995: 39–40), "the management of forests, agricultural lands and rangelands can play an important role in reducing current emissions of CO_2, CH_4 and N_2O and in enhancing carbon sinks. A number of measures could conserve and sequester substantial amounts of carbon (approximately 60–90 GtC (gigatons of carbon) in the forestry sector alone) over the next 50 years. ... Land-use and management measures include: sustaining existing forest cover; slowing deforestation; regenerating natural forests; establishing tree plantations; promoting agroforestry; altering management of agricultural soils and rangelands"; and others. If the recommendations of the IPCC are followed, climate-change mitigation will become another factor for managers of forests and rangelands to consider, along with demands of growing populations and expanding economies for food, fibers, forest products, recreation, biodiversity conservation, and other ecosystem services (Daily 1997).

4.4 Culture

Culture includes a society's underlying attitudes toward land and forests. Faced with similar scientific data, Germany and the United States arrived at similar controls on acid precipitation. However, Germany implemented controls a decade before the United States did because Germans saw the threatened forests as central to the origin and myths of German culture, whereas Americans saw their forests more as an exploitable, and for some people an expendable, resource (Tosteson 1994). Today, the U.S. conservationist, the Amazonian aborigine, and the Japanese international timber merchant endow the Amazonian rainforest with three very different cultural overlays. Conflicts of values and attitudes concerning land and forests are likely to intensify as diverse cultures make contact across increasingly permeable national boundaries.

Conflicts over different values arise between different groups within the United States who seek to influence forest management. For example, Donald Waller, a professor of botany at the University of Wisconsin, tried unsuccessfully to make the U.S. Forest Service plan to conserve biological diversity (other than diversity of the ages of tree stands) in its forest management plans for northern Wisconsin in the mid-1980s (Alverson et al. 1994). He wrote of his experience (Waller 1997: 1): "I think a difficulty I had in the mid-1980s was naiveté; ... It was hard for me to wake up to the fact that many trained foresters did not share the same basic values; they were trained in a ... utilitarian mind set, one that placed a lot of emphasis and training on economics, on details of productivity and site conditions, while neglecting in my opinion important ecological characteristics of the rest of the biotic community: the soils, the understory forest herbs, interactions with animals and so on. There was a difference in values, ... grounding, information and training."

Roger A. Sedjo, a forest economist at Resources for the Future in Washington, DC, criticized the U.S. Forest Service from nearly the opposite perspective (Sedjo 1995: 10): "In recent years, ... the leadership of the Forest Service ... has focused on forest ecology — the totality of relationships between forest organisms and their environment. This concern with forest ecology is embodied in the leadership's advocacy of ecosystem management. In accordance with this philosophy, the service has all but abandoned the notion of forests as primarily a vehicle for producing multiple goods (or 'outputs') desired by society. ... More to the point from the perspective of taxpayers, these decisions are being driven almost exclusively by biological considerations, with little attention paid to economic and other concerns. In short, when identifying objectives, ecosystem management ignores the social consensus implicit in the congressionally legislated objective of producing multiple market and nonmarket forest outputs and, instead, attempts to achieve some arbitrary forest condition about which society has little say."

Culture includes political institutions for allocating the benefits of public resources and for resolving conflict. Interest groups attempt to influence these institutions for their own benefit. Interest groups may view their scope as local, national, global, or in between (Sharma 1992). Local people may clear forests for their own subsistence and commercial purposes, or as agents of commercial interests headquartered elsewhere. Nationally, forests may be viewed as a source of employment, foreign exchange, government revenue, and land for other purposes such as industry, mining, agriculture or settlements; economic pressures may favor short-term exploitation. People in one country may look to forests in another country to sequester carbon from the atmosphere and to preserve biodiversity, or as potential lands for profitable ranching and timber extraction. Political change, which shifts the benefits and costs of current practices to different parties, may become increasingly difficult as interests at different local, national, and global scales become increasingly intertwined.

International demand is growing for the products and services that forests provide other than timber (Johnson 1996: 9). Most ferns, mosses and other floral display materials and most mushrooms collected from the forests of the Pacific Northwest are exported to European and Japanese restaurants and other markets. Tourism to natural sites, or ecotourism, has been growing at 7% per year, and may generate as much as $50 billion a year (an amount comparable to all official development assistance). Demand for floral displays and ecotourism is driven by aesthetic values. Forests also have "existence value" to people who value them even when they make no direct use of them (Sharma 1992). Continued conflicts can be expected between those who value forests for timber and those who defend other values, within and outside the United States.

A step that could reduce some of these conflicts, although it is no panacea, would be to make individuals, corporations, and other private interests pay market or closer-to-market prices for the private benefits they receive from forests. As suggested by Repetto (Repetto and Gillis 1988: 380), forest management would apply the same test of economic efficiency to its decisions whether to provide services for timber extraction, for recreation (fishing, hunting, camping, hiking) and for other services (such as fuel-wood extraction): do the marginal benefits, based on recoverable fees, exceed the separable or avoidable costs? If some forests turned out to be simply uneconomic for timber production or recreational use or both, the market test would prevent political conflict over presently free or subsidized services. If some services could be shared between recreational and timber users, economic common interests could be found.

National forests are public institutions in part because they protect public goods (Repetto and Gillis 1988: 380). Some public goods include private beneficiaries. A goal is to set prices that reflect as many as possible of the positive and negative externalities of transactions, and to assure broadly equitable access to the services offered. For example, watersheds serve people and corporations who use the water provided; in this case, water could be priced in a way that covers (at least partially) the costs of protecting the watershed. Some public goods, notably genetic diversity, species diversity, and ecosystem diversity, have uncertain immediate instrumental value but many taxpayers agree there is value in preserving them for the next generation. In such cases, bond issues could distribute the cost of protective services over the present generation and the next. But these measures can be expected to generate opposition. More rational economic approaches to forestry management may change the terms of conflict but will not eliminate it.

5 CONCLUSIONS

Population Growth

The global population growth rate of 1.5% per year in 1996 implies a doubling in 46 years. This growth rate is extremely rapid compared to rates of global population growth experienced before 1945, though it is less than the all-time peak growth rate. While it took until 1830 for human population size to reach 1 billion people, the most recent increment of 1 billion people was added in 12 years. The poor countries have more than twice the population density of the rich, on average, and their populations are increasing 10 to 20 times faster.

In the last two centuries, people moved in large numbers from the countryside to cities. Today's rich countries are 75% urban. Today's poor countries are 35% urban and are urbanizing rapidly. Globally, and at national and regional spatial scales, a relatively small fraction of the land is occupied at a high human population density while most of the land is lightly or very sparsely occupied.

The population density of the conterminous United States rose from one person per 57 ha in 1790 to one person per 3 ha in 1990. The population is growing by about 2.5 million, or roughly 1%, per year.

Land Use

The fraction of the earth's total ice-free land area covered by closed forest and woodland fell from about 47% prior to the invention of agriculture to about 40% by 1990. As people became more numerous, they extended their activities to new lands (extensification) and increased the productivity of their activities on land already occupied (intensification). In recent decades, the price of timber in international commodity markets has increased, while the price of most other primary commodities has fallen.

In the United States, forested areas declined until 1920, rose gradually from 1920 to 1960 and fell slightly since 1960. Over the last century and a half, real lumber prices in the United States grew roughly five-fold per century, while the share of agriculture, livestock, forest products and fisheries in U.S. economic output declined steadily.

The goal of some timberland owners changed from "cut out and get out" to management for sustainable yield. The Federal Government's purpose in dealing with public lands was originally to transfer public lands into private hands. Its present goal is to retain and manage public lands, which now cover about one-fifth of the conterminous United States.

Between 1900 and 1993, the aggregate U.S. consumption of all timber products (as fuel, pulp, plywood and lumber) increased 70% while gross domestic product rose 16-fold. The 16-fold increase was the product of a more than tripled population size and a gross domestic product per person that grew nearly 5-fold. The consumption per American of all timber products fell by roughly half between 1900 and 1993.

At 1990 levels of U.S. wood consumption (2.3 m^3/person) and U.S. timberland productivity (3.1 m^3/ha), about three-quarters of a hectare of timberland (2.3/3.1 = 0.74 ha/person) are required to produce the wood consumed by an average American. Americans are increasingly seeking non-timber products, recreation, wildlife habitat, watershed protection and other values in their forested lands instead of or in addition to timber production.

Relations Between Population Growth and Land Use

On a long historical time scale, rising numbers of people have been associated with an increase in land areas farmed, largely at the expense of a decline in forests, and with rising farming intensity. But a one-directional causal model like "human population growth causes forest clearing or land conversion" is too simple to cover all real cases. What the growing human population puts on the earth and takes from the earth depends not on numbers alone, but also on the human economy, the physical, chemical and biological environment, and the human culture.

For neoclassical economists, population growth is a neutral factor in land degradation. For classical economists and some natural scientists, population growth is the principal independent cause of land degradation. For dependency theorists, both population growth and land degradation are symptoms of poverty and inequity. For intermediate variable theorists, population growth exacerbates the adverse effects of other ultimate causes of land degradation.

Richards' center-periphery model envisions an autocatalytic process in which population growth and growing consumption drive the development or exploitation of additional resources by extensification and intensification, leading to further population growth and consumption. A highly schematic model called the Malthus–Condorcet–Mill model presents a possible quantitative version of this process.

No purely ecological concept of carrying capacity is adequate as a concept of human carrying capacity. Human choices are important in defining human carrying capacity. Choices influence the average and the distribution of the level of material well-being; technology; political, economic, and demographic institutions and arrangements; physical, chemical, and biological environments; variability or stability; risk or robustness; time horizons; and fashions, tastes, and values.

Tradeoffs

The institutions and policies that deal with problems in land use, particularly forestry, may provide useful models for other environmental concerns, because changes in the forests have led other human-induced changes in the environment.

American planners, managers, and citizens must consider the global perspective, even if they are concerned only to protect American resources and interests, because the United States is and will be intimately linked to the rest of the world. In future American land use and forestry, purely domestic factors will increasingly have to be balanced against demographic, economic, environmental, and cultural influences that originate outside of American boundaries.

Domestic trends — a growing U.S. population, increasing domestic demand for wood products and non-timber forest services, and rising prices for timber — seem likely to sharpen the competing demands that will be made on private and public forest managers. To reduce conflicts, individuals, corporations and other private interests could be required to pay market or closer-to-market prices for the private benefits they receive from forests.

As worldwide and domestic population growth and rising consumption make management decisions increasingly interdependent, often across the boundaries of national sovereignty, it seems likely to become increasingly important to account and pay for the externalities of land use and forest management.

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