Lightening the Tread of Population on the Land: American Examples

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FOR THE PLANET to continue at least its present hospitality for Nature as people multiply in number and wealth, the human tread must lighten and narrow. Remembering that land for habitat is the preeminent need for living things and that Americans are often excoriated for heavy feet, we concentrate here on the American footprints of building, forestry, and farming.

Many of the Earth's present 5.8 billion people look at the landscape, its waters and creatures, and hope no more hectares will be built upon, logged, or tilled. Because the number of persons has risen inexorably for centuries and most want to be wealthier, the hope of a steady environment must be realized by lightening the intensity of the tread per person and per dollar. Do American examples show promise for the world that, while people and wealth multiply, invention and changing habits can come close to holding constant the extent of paving and building, publishing and packaging, tilling and cropping? Let us search back through this century for principles, rates, and trends that may carry forward the same range of time, when Americans might number perhaps 100 million more than today and the number of all humans might be 10 billion.

The broad categories of present land use in the United States set the stage. The Food and Agriculture Organization (FAO 1994) of the United Nations classifies land use into cropland, pasture, forest, and "other"—the land not in the preceding three categories and including built-up and barren land. The US land use percentages in Table 1 can be grasped by comparing them, for example, to the 14 percent in forest and 10 percent in

TABLE 1 Land use in the United States, 1992

Use	Thousand hectares	Percent
Crop	187,776	19.6
Pasture	239,172	25.0
Forest	286,200	29.9
Other[a]	244,163	25.5
Total	957,311	100.0

[a]Includes built-up (e.g. urban) and barren land.
SOURCE: FAO (1994)

cropland in China, the 58 percent in forest and 7 percent in cropland in Brazil, the 68 percent in forest and 7 percent in cropland in Sweden, and the 27 percent in forest and 35 percent in cropland in France.

The spreading of the built environment

The weeds in the Roman Forum and on the Appian Way prove roofing and paving do not extinguish Nature forever—but almost. If twice as many people press onto the planet, will they cover twice as much land? The view from above the Chicago or Mexico City airport suggests at least twice.

The sprawling settlements where more and more people choose to build, commute, and engage in commerce frighten many reporters and analysts. Rationalizing the fears of land development in terms of famine comes easily to some. Periodically, news about grain supply prompts alarm. For example, "As Asia industrializes, the construction of thousands of factories, roads, parking lots, and new cities is wiping once-productive cropland off the map" (Brown 1995: 12).

In America after World War II, wealth, automobiles, and the construction of highways and "Levittowns" caused a burst of suburban land covering. By the 1970s, a national survey estimated "development" was each year covering about 1.2 million hectares, the area of the state of Connecticut (US Department of Agriculture 1990). The transformations experienced in Connecticut from farms to mill towns and then to suburbs caused by proximity to New York City make it an emblematic unit for measuring modern land development.

The amount of land covered or "developed," of course, depends crucially on definition.[1] A farmer might set the moment of the development of land early, perhaps when the perimeter of a city's suburbs reaches his farm, while a town dweller might perceive it later, perhaps when paving and building erase photosynthesis. The US Bureau of the Census defines "Developed Land" as "A combination of urban and built-up land and roads,

railroads and associated right-of-way." By that definition, the census in 1991 reported 31 million hectares of non-Federal land developed. This total, which is 5 percent of non-Federal land in the United States, equals the territory of Poland. About 20 percent of US land is owned by the Federal government and thus not subject to typical private development. Drawing on the census and its own estimates, the US Department of Agriculture estimated that development annually during 1958–82 overtook 0.6 million hectares. Instead of a full Connecticut, Americans evidently only covered half a Connecticut in one year (Baden 1984; US Bureau of the Census 1986, 1991a; US Department of Agriculture 1990).

To understand the dynamics of covering land and bring more precision to the matter, analysts compared photographs of the same places over time and computed the frequencies of conversions among half a dozen land uses in 135 fast-growth US counties, representing 12 percent of the US population in 1970 and nearly half its increase from 1970 to 1980. The analysts found that new people were adding to urban area at nearly the same rate as the 1,000 m^2 per person already living in those counties.[2] In more familiar units, that is one-quarter acre, or one-tenth hectare, per person for roads, shopping centers, lawns, and dwellings.

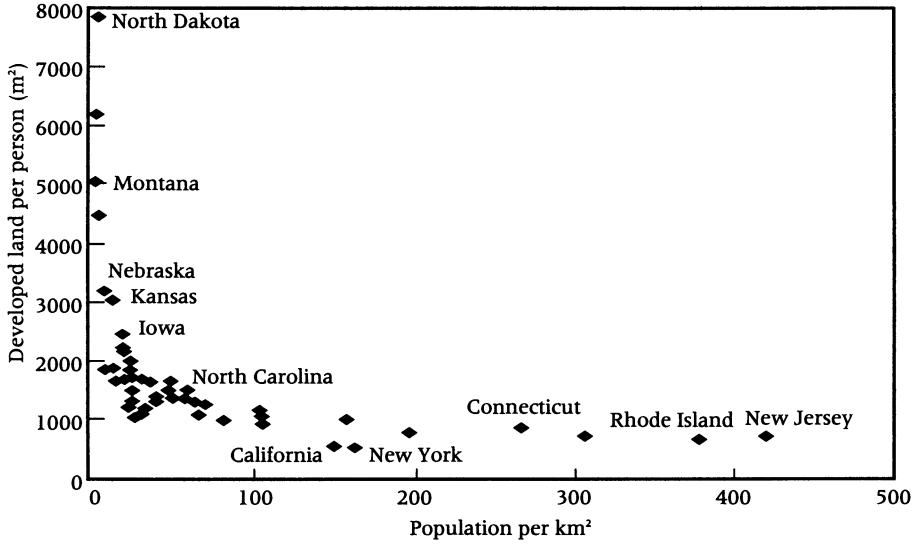
For those who feared urbanization was eliminating cropland differentially, especially in the suburbs, the studies of fast-growth counties turned up surprises. Conversions of forest and other rural land countered cropland losses to urbanization.[3] Urbanization did not consume prime agricultural land disproportionally. In the 29 fastest-growing counties, farmers shifted to more valuable products and actually sold more in constant dollars, and farmland shrank slightly less, compared with the rest of the country. As population grew in the counties, urbanization used less land per added household, unsurprising if land values rise. Our extrapolation for the indefinite future of the transitions observed among uses in the fast-growing counties suggests that less than two-thirds of their land will be eventually developed.[4]

Although the human tread was less than anticipated, development still spread. Ultimately it must stop. As the extrapolation just noted suggests, the limit is likely to be well below 100 percent. Present cities also hint at development's limits. Although wedged in Manhattan's 6,000 hectares with 1.5 million residents plus countless others during the day in its offices and shops, much of Central Park's 340 hectares still photosynthesizes. Clearly, a limit less than 100 percent tempers a proportionality between population and development. Looking at the United States as a whole, the percentage of land set aside for public parks in 17 American cities with densities of 320 to 9,000 people per km^2 ranges from 0.3 percent in Jacksonville, Florida to 19 percent in Dallas, Texas.[5] Embedded in cities, the green parks let people visit Nature with little trespass on Nature.

The ratio of developed land per person varies among the 48 contiguous American states despite their similar wealth, further indicating that development does not simply track population. The tread or square meters of the land actually covered per person is less in more populous states (see Figure 1). It ranges from a high of 7,900 m^2 per person in North Dakota to a low of about 400 in Rhode Island and New Jersey. Because the vast tracts of Federal land in the Rocky Mountains, Great Basin, and Pacific states are generally unavailable to private development, we eliminated Federal land by expressing the population density along the x-axis as people per km^2 of non-Federal land. Measured in non-Federal land, Nevada, for example, is less than half the size of Indiana. About half of California is Federal land, leaving the area of its non-Federal land available to private development little larger than in Kansas or Nebraska and less than twice that of New York or North Carolina. On its non-Federal land, California has about the same population density as New York, and, as we shall see, the two states exhibit similar development.

In the 48 American states the covered land per capita falls from more than 2,000 m^2 (about a half acre) in states where travel is fast, like Montana or Nebraska, to about 600 m^2 in slower, more urban California or New York with their similar population densities. The covered land per dollar of gross state product is also less in the more populous states.

FIGURE 1 Relation of developed land per person to population density on non-Federal land: 48 contiguous states of the United States



NOTES: Population data are from the 1990 census; land development data are for 1987. States indicated are those mentioned in the text.
SOURCES: FAO (1994); US Bureau of the Census (1991a).

The causes and consequences of the lighter tread include crowded roads in densely settled regions. A denser population lessens the kilometers of road per person, just as it lowers the number of developed hectares per person. Slower travel shortens the practical trip and compacts the metropolis. Also, dwellers in apartments and workers in skyscrapers have small footprints on the soil. In contrast, speed spreads.

If Californians and New Yorkers used land at an average level of 2,000 m^2 of developed land per person found in less densely populated states, they would claim as developed land another fifth of the non-Federal land in their states.[6] The four most densely populated states would so claim another 40 to 75 percent of their uncovered land. The actual pattern of development in these populous states has thus spared a lot of land from residential, industrial, and commercial uses, and from highways and other uses included in the Census Bureau's definition of developed land. By enduring crowding, urbanites spare land for Nature.

To grasp the scale of the land spared from development by, say, the lighter tread of Californians, who have so far developed 628 rather than 2,000 m^2 each, think of the expanse spared to date as three times the area of Connecticut. Similarly, by developing at a rate of 560 m^2 for each resident, New Yorkers spared twice the area of Connecticut. Californians and New Yorkers spared these multiples of Connecticut by developing fewer square meters per person than their fellow Americans in Arkansas or Iowa.

Metropolis will spread its net when transit quickens, and people will continue filling in the net. Greater wealth will enable more Americans to buy higher speed and thus cover more Connecticuts. But the example of American states depicted in Figure 1 indicates that the land covered will increase more slowly than in proportion to population.

The sparing of forests

We have written so far of people covering land for domicile, commerce, industry, and transport. They also tread on the forest, taking lumber, paper, and fuel wood—uses whose combined mass is twice that of all metals used (Wernick and Ausubel 1995). This source of products, however, exemplifies habitat for Nature. In 1992, US forests covered nearly 300 million hectares (ha), or one-third of all US land and about two-thirds of the area that was covered by forests in the year 1600.[7]

Most of the conversion of forest to other uses occurred in the nineteenth century. By 1920 clearing for agriculture had largely stopped. The Federal government owns about a third of all US forest land, and 6 percent of all forest land is reserved from timber harvest as parks, wilderness areas, and other places. During the past quarter-century, reservation of forest land rather than deforestation has shrunk the area classified as timberland by a few

percent. Can changing consumption, recycling, and innovations in forest management and products lighten the American tread represented by logging?

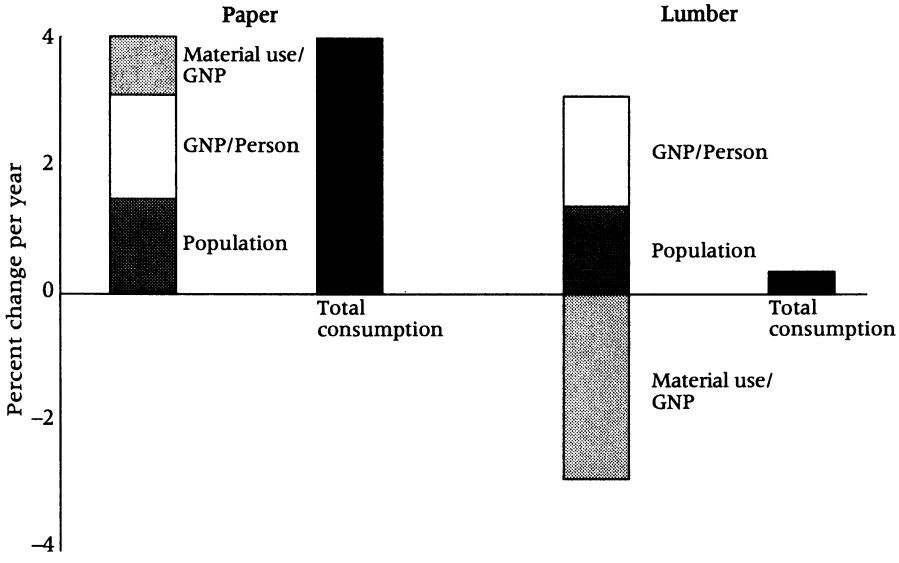
Between 1904 and 1990 Americans tripled their numbers and multiplied their GNP 14-fold.[8] Meanwhile total lumber production crept up by one-quarter, but paper use exploded 29-fold. These changes over 86 years can be translated into annual percentage changes, which contrast the carpenter and saw with the office worker and copier.

Relying on the identity between the national consumption of a mass of product (in tons of paper or lumber), and population, GNP per person, and product per GNP (in both cases GNP measured in constant dollars)—Product = (Population) x (GNP/Population) x (Product/GNP)—we can ferret out the determinants of total US consumption. Although the determinants multiply together to set the national consumption, their percentage changes per year add up to the change in the national consumption. In the adding and subtracting of the components of change, one can see the challenge of steadying national consumption by lightening "intensity of use," the mass of product consumed per dollar of national economic activity.[9] One can see the challenge of lessening the impact on Nature by invention and ingenuity rather than by scarcity and poverty.

Between 1904 and 1990, packaging, publication, and memos consumed more trees. Figure 2 shows the annual percentage change in US consumption of paper and lumber. The component changes in population, GNP (in constant 1982 dollars) per person, and mass of product consumed per dollar of GNP yield the average change represented by the solid bars. Expressed as an annual change, use of paper per dollar of GNP rose 0.9 percent per year. The combination of US population growing at 1.3 percent and per capita income rising 1.8 percent per year raised GNP 3.1 percent annually. Adding the 0.9 percent greater annual paper use per dollar of GNP indicates that total national paper use rose 4.0 percent annually. Lumber was a different story. Its intensity of use per dollar of GNP fell 2.8 percent per year, nearly counteracting growing population and income. The 2.8 percent fall reflects the fact that in 1990 the average American consumed about 60 percent less lumber than his counterpart in 1904.

The declining intensity of lumber use helped American forests expand. The abandonment of farmland returned relatively productive sites to forest. The control of fires, restocking, plantations, and imports helped as well. Mills lost less wood, converting former wastes into pulp for paper, composites such as plywood which Americans substituted for solid lumber, and heat and electricity; by 1980 American mills converted more than 96 percent of the wood entering their doors into useful products and energy (US Congress, Office of Technology Assessment 1984). Together, these changes caused an expansion of American forests commencing in the early 1920s. The trend continues: by 1992 the inventory of growing stock in US forests

FIGURE 2 Average annual percentage change in total US consumption of paper and lumber, and its components, 1904–90



SOURCES: US Bureau of the Census (1991b) and miscellaneous US government publications

was 27 percent larger than in 1952, the first year of comprehensive data collection (Sedjo 1991; Smith, Faulkner, and Powell 1994).

The ultimate goal of a lighter tread lies beyond saving paper cups and wooden pallets. The goal, sparing Nature, brings into consideration the recycled paper and residue from sawmills that are fed into the manufacture of paper. Residues from sawmills now supply more than one-third of the pulpwood used in the manufacture of paper. Driven by the costs of disposing of the full one-third of US municipal solid waste that currently is paper, recycling burgeons. It may soon contribute half the raw material for paper, an amount that would replace 10 to 15 percent of the current annual harvest of wood.[10] Recycling reaches limits because the manufacture of paper always costs the pulp some of its needed fiber and because less harvest would lower stumpage prices and thus favor use of lumber. The inevitable losses during recycling and other costs make a lower intensity of use of paper a greater potential means of sparing trees.

We can translate the harvest of fewer trees into forest area saved, the saving of diverse habitats. The simplest translation uses the ratio of all timber standing to the area of American forest land. We express the spared expanse as multiples of the area of an exemplar of Nature, Yellowstone National Park, the first national park created in the United States. Using the ratio of standing timber to land, the 15 percent harvest spared by mak-

ing half of American paper from recycled paper spares about 900,000 hectares, the area of Yellowstone, every year.[11]

A further route to sparing Nature lies in foresters raising yields so that less habitat is disturbed by harvesting the wood demanded. For example, one-quarter of American forest land could grow an average of 6 to 8 m^3 per hectare annually, or two to three times the present average annual growth. Harvesting only this potential annual growth on one-quarter of the forest land—not clear cutting the forest—would yield somewhat more than the annual removals from all American forests today and would demonstrate how foresters could spare habitat.[12] Tree farms in warm places annually yielding 5 to 90 m^3 per hectare (Carpentieri, Larson, and Woods 1993) could shrink the harvested area even more, and the promise of genetic engineering beckons ahead (Moffat 1996).

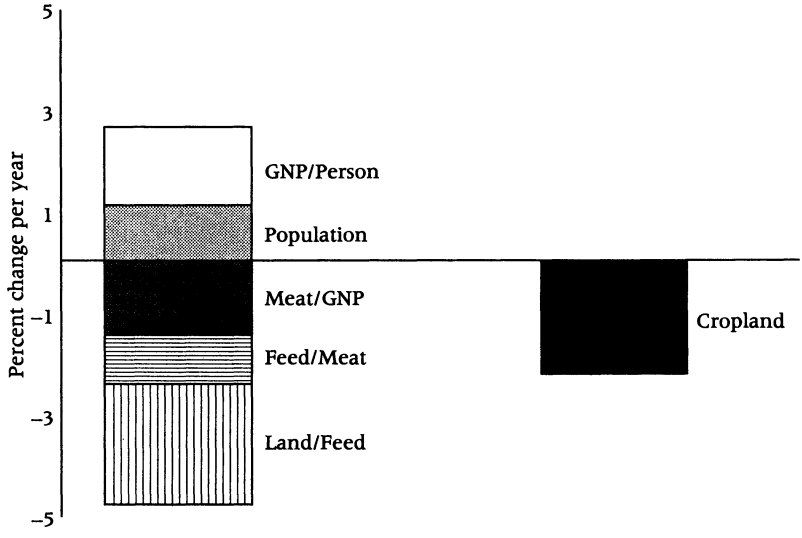
The sparing of cropland

US farmers use an expanse for growing crops far wider than urban development and nearly as wide as forests. After rising about a quarter from 1900 to the 1920s, US cropland has remained steady. While population grew by nearly one-fifth from 1975 to 1992, US cropland and pasture shrank by one percent. Like the forest, cropland yields products—food, feed, fiber, and flavoring.

Animal feed (corn, oats, barley, and sorghum) is grown on one-third of US cropland. The diet of consumers, their numbers, the efficiency of converting feed to meat, and the yield grown per hectare affect this expanse of cropland. Analyzing the components of change in the amount of cropland used to raise feed crops shows how a diet of meat affects the use of cropland area. Much meat, largely beef, comes from grazing rather than from feed crops, and to neglect grazing exaggerates the impact of beef consumption on cropland use and ignores its impact on pasture or range. By assuming that all meat comes from feed, however, we can calculate roughly how much the changing components of meat consumption and yield have lightened the tread on cropland and so countered the rising numbers and wealth of Americans.[13] Because meat typifies the diet of the rich and beans that of the poor, growing wealth and growing populations elsewhere lend special importance to this American example.

As with the example of paper and lumber, in Figure 3 the components of change in US cropland used to raise feed crops yield the average annual change represented by the solid bar. The first three components of change in national use of land for feed are the annual changes in population, GNP, and intensity of use—in this case the quantity of meat per dollar of GNP. The components of change in Figure 3, however, must be extended to reach land use.

FIGURE 3 Average annual percentage change in total US cropland used to raise feed crops for meat-producing animals, and its components, 1967–90



SOURCES: US Bureau of the Census (1991b); US Department of Agriculture (1993b); FAO (1994); and miscellaneous US government publications

Annually on average from 1967 to 1992, US population rose 1.0 percent, and GNP per person 1.5 percent, lifting GNP growth to just over 2.5 percent. But, surprising environmentalists and cattlemen alike, consumers lowered their annual meat consumption per dollar of GNP by 1.5 percent. Americans held average consumption per person steady by lowering their consumption per GNP as fast as they grew wealthier.

At the same time, Americans changed the mix of meats they ate, consuming somewhat more poultry, about the same amount of pork, and less beef. Because poultry convert feed to meat efficiently and because we assumed all beef is produced from grain, the calculated feed to produce a unit of meat fell at an annual rate of 0.9 percent. The declining amount of meat consumed per dollar and the declining mass of feed used to produce a unit of meat measure how much consumers lightened their tread.

Also, farmers raised yields of feed grain, lessening the area of land used per unit of feed produced by 2.4 percent annually. They did not tarnish this achievement by using more and more energy, pesticides, or fertilizer, or by eroding soil. For over a decade American farmers have lowered their consumption of energy and held steady the total quantity of organic pesticides and fertilizer. They have lessened erosion.[14]

When the lightening of steps wrought by consumers and those by farmers are summed, they outweigh the multiplication of people and their

incomes. The cropland calculated for grain-fed animals to produce meat for Americans shrank 2.2 percent annually. (Other calculations that allow for grazing temper this estimated shrinkage.) The 2.2 percent annual shrinkage adds up to 21 million hectares between 1967 and 1992, or one and a half times the area of the agricultural state of Iowa or 24 Yellowstones.[15]

Conclusion

Sparing Nature challenges people to lighten their individual tread as fast as or even faster than population and wealth multiply. The American experience in meeting this challenge offers enough hope that fear about our impact on land and natural habitat need not transfix us—or the Chinese (Smil 1995).

If during coming decades 100 million more people arrive on American land, how much land will they cover? In several less-populous states today, development covers more than 2,000 m^2 per person. Urbanization, however, seems destined to pack the 100 million into the more populous states. A more logical scenario than 2,000 m^2 of development per person, therefore, envisions the new arrivals developing land nearer the present lighter rate of 600 m^2 in populous California and New York rather than at 2,000 m^2. Indeed, history hints that, while development will spread at a rate modified by wealth and the speed of travel, it will not crush the countryside and Nature in a simple proportionality with population. One hundred million people developing land at 600 m^2 each would consume 6 million hectares or 7 Yellowstones. Nevertheless, the difference between 600 and 2,000 m^2 would spare 14 million hectares or 16 Yellowstones.

Should the new arrivals raise the number of Americans to 350 million and should all of them cause the same per capita removal of wood from timberland as in 1991, removal would then exceed the present net growth of timberland.[16] Although the tempered use of lumber brightens hope for no greater impact on Nature, the limited effect recycling can have on harvest and the expected rises in the use of paper dim the hope. Thus the burden for sparing forest habitat rests heavily on foresters raising the yield per hectare. The excess of potential above actual production on forest land and experiments with tree clones show that the foresters' task of sparing land is achievable. At the modest goal of annual net growth raised to 4 m^3 per hectare, the wood to be removed to satisfy the needs of 350 million Americans at the 1991 per capita rate could be grown on 82 percent of the present expanse of 198 million ha of timberland. The 18 percent of present timberland that could be thus protected equals 40 Yellowstones.[17]

During the past two generations, Americans cut cropland use per person in half while doubling their numbers and multiplying their GNP eightfold. They also exported much food and ate better. If American farmers

accommodate the next 100 million people by raising yields rather than expanding cropland, they will lighten the human tread enough to spare more than 70 Yellowstones.[18]

The weight of the tread modifies the impact of population on the environment. While humanity grows richer and multiplies toward 10 billion, it has work to do, reserving diverse Central Parks and shaping sprawling settlements, taming the copiers in offices, lifting timber yields, and continuing to raise crop yields. Past American successes in sparing Nature through invention, innovation, and changing habits rather than the negative checks of scarcity and poverty encourage this work. Its benefit may exceed 100 Yellowstones, equivalent to one Nigeria or one Bolivia.

Notes

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1 The uncertainty of estimating developed land can be read clearly on pp. 18–21 of US Department of Agriculture (1990), and the base amount to which the 1.2 million ha of the earlier appraisal was presumably added is uncertain. The US Bureau of the Census (1986) definition reads: "Urban and built-up land areas cover land used for residences, industrial sites, commercial sites, construction sites, railroad yards, small parks of less than 10 acres within urban and built-up areas, cemeteries, airports, golf courses, sanitary land fills, sewage-treatment plants, water-control structures and spillways, shooting ranges, and so forth. Rural transportation is land used for roads and railroads in rural areas." Publication of the developed area is a fairly new feature of census reports; in 1991 the Census Bureau combined urban, built-up, and rural transportation in the single class of developed land.

2 Vesterby, Heimlich, and Krupa (1994: 44) calculated conversion of land per household. When calculated per person, their rates of conversion from 1960 to 1980 ranged from 600 to 900 m^2. Whether calculated per person or per household, the rates of conversion were less than, say, the inventory of 900 to 1100 m^2 of urban land per person established by all the earlier settlement of the counties. The authors wrote, "Both U.S. population and the amount of urban land increased in the 1960s and 1970s, but the marginal rate of urban land conversion per household remained constant."

3 In terms of Table 1, the conversion of cropland (the top category) to urban (in the bottom or "other" category) was countered by conversions from the range and forest segments. From 1970 to 1980 in the fast-growth counties, some 5.6 percent of cropland and pasture was reportedly transformed, 0.5 percent to forest, 1.4 percent to range, and 3.7 percent to urban. In the same counties, gains of 1.0 percent from forest and 3.1 percent from range countered the loss of cropland and pasture.

4 Regarding prime land, gains from forest and other rural land, and urbanization per household see pp. 36, 40, and 48 of Vesterby, Heimlich, and Krupa (1994). About selling more and shrinking less land see p. 107 of Vesterby and Krupa (1993). Extrapolating the transitions among uses in the fast-growing counties in the United States as a stationary Markov chain gives a steady state of two-thirds of the land urbanized after several centuries. The state of the land is extrapolated by multiplying the matrix of transitions among the land use categories by itself. Underlying the extrapolation are two assumptions: (1) that the probabilities of conversions or transitions from one category to another are constant;

and (2) that the probabilities depend not upon how land enters a category but only upon the class it is in. Because events will inevitably change the transition probabilities estimated from only a decade or two of experience, the outcome of the calculation is only an orderly extrapolation of recent experience.

5 The cities are Atlanta, Baltimore, Boston, Cincinnati, Dallas, Jacksonville, Kansas City (Missouri), Los Angeles, New Orleans, New York, Omaha, Philadelphia, Phoenix, St. Louis, San Jose, Seattle, and Washington, D.C. The low of 0.3 percent is in Jacksonville's 600 ha and the high is attained by the 19,000 ha of public parks in Dallas. Six of the 17 cities have more than 10 percent of their land in public parks. The park areas were transcribed from pp. 754 et seq. of *Information Please Almanac* (1989).

6 For example, the 30 million Californians average 628 m^2 of developed land each. At 2,000 each, i.e., 1,372 m^2 more, they would have developed another 4 million hectares, which is about one-fifth of the 22 million hectares of non-Federal land in California.

7 Smith, Faulkner, and Powell (1994) provide a full glossary and data for US forests. For example, forest land is at least 10 percent stocked by trees, including formerly forested land where trees will be regenerated. About two-thirds of forest land is timberland, which is not reserved and is capable of producing more than 1.4 m^3 per ha per year. Sedjo (1991) gives information about trends.

8 Sources for population, GNP, and quantities of forest products are US Bureau of the Census (1991b) and US Department of Agriculture (1993a) and other volumes. GNP was measured in 1982 dollars. For the initial year of our series we chose 1904, the first year with a report of all components of paper and board production, imports, apparent consumption, and waste paper consumption. We call the pulp products of paper and board simply "paper."

9 As Wernick et al. (1996) illustrate, "intensity of use" is a core concern of industrial ecology.

10 If a ton of pulp equals 2 m^3 of wood, a flow chart of wood products in 1993 (Ince 1994a) indicates 258 million m^3 entering pulp and paper manufacturing. Increasing the present 53 million m^3 recycled to half the input of 258 (or 129 million m^3) would save 76 million m^3, which equals 15 percent of the harvest of 501 million m^3. An economic model that incorporates the impact of saving on price and lumber consumption projects a saving of only 10 percent (Ince 1994b).

11 The yield per land determines how much habitat will be spared by saving 76 million m^3 by recycling. A simple estimate of yield is the ratio of the 24,269 million m^3 of all timber standing on all 298 million hectares of US forest land (Smith, Faulkner, and Powell 1994). At that rate, not harvesting 76 million m^3 annually spares 0.9 million hectares, the area of Yellowstone Park. Another conversion of wood saved into area spared uses the increment of growth rather than the inventory of standing trees. The two-thirds of US forest land called timberland is producing or is capable of producing crops of industrial wood and is not set aside by the government. The average annual growth on this timberland is 3.1 m^3 per hectare. At that rate, not harvesting 76 million m^3 spares the annual growth on 24.6 million hectares or 25 Yellowstones.

12 Foresters judge that the 67 million hectares of US forest land capable of growing 6 to 8 m^3 of wood per hectare annually could produce 515 million m^3 in all. The 67 million hectares are 23 percent of forest land. In 1992, 462 million m^3 of wood were removed (Smith, Faulkner, and Powell 1994).

13 Waggoner (1996) calculated the use and production of meat, feed, and grain. He calculated the quantity of meat from the slaughter of beef and swine and the average weights of their carcasses as reported by FAO in its annual production yearbooks and by the US Department of Agriculture (1993b). Because reports of poultry meat in the United States in the latter reference began in 1967, he chose 1967 as the initial year. The ratio of feed to meat was assumed to be 12, 6, and 3 for beef, swine, and poultry; this is consistent with values reported by the US Department of Agriculture (1993a). By converting meat into grain equivalents and so neglecting grazing by cattle, we magnify the ef-

fect on cropland of changes in beef consumption. See Council for Agricultural Science and Technology (1980) for proportions of grazing versus feed grains for production of meat. Finally, land per feed was calculated from the yield of coarse grain reported by the US Department of Agriculture (1993b).

14 Rising yields and opportunity for more are described by Waggoner (1994). Between its maximum (in 1977) and 1991, total energy use in agriculture fell by 30 percent, while use per output of agricultural product fell by 45 percent (US Department of Agriculture 1994). The steady quantity of organic pesticides can be read in Table 367 of US Bureau of the Census (1991b). FAO reports fertilizer consumption in its annual yearbooks. Keeney and DeLuca (1993) showed that nitrate concentration in Iowa's Des Moines River was about the same in 1945, 1955, and 1976 as in 1980–90. The 1992 National Inventory shows that from 1982 to 1992 annual sheet and rill erosion per cultivated acre in Iowa declined by 28 percent and in Kentucky by 31 percent; in the entire nation during the decade, water plus wind erosion declined by one-third (US Department of Agriculture 1995).

15 The cropland calculated for feed fell from 50 to 29 million hectares between 1967 and 1992; this decline (21 million ha) is 1.5 times the 14.6 million ha of Iowa and 23.8 times the 0.9 million ha of Yellowstone. Because we calculated meat consumption from slaughter, assumed constant meat-to-feed ratios, and neglected grazing, our results need the test of comparison with other reports. Although the absolute quantity of meat consumed differed between our calculations and the reports of the US Department of Agriculture (1993b), the relative rise of poultry and decline of beef are similar. Further, the number of cattle in the United States has fallen by one-quarter since its peak in 1975. Our calculated 1.5 percent annual decline in meat per dollar of GNP agrees with the change reported by the US Department of Agriculture. The 0.9 percent annual decline we calculated for meat per feed, however, does not agree with the Department's report of a 0.1 percent rise for concentrates fed to animals per unit of meat produced. Our neglect of grazing likely caused this disagreement. As beef consumption lessened, the contribution of grazing declined, countering the theoretical improvement in the meat-to-feed ratio in our calculation. This in turn lessened the shrinkage of cropland to produce meat from our calculation of 2.2 percent to 1.2 percent per year. Our calculation of 2.2 shows the impact on cropland envisioned when feed ratios are quoted; the calculation of 1.2 indicates the impact when grazing played a real role.

16 Smith, Faulkner, and Powell (1994) report that in 1992 the area qualifying as timberland was 198 million hectares out of the 298 million hectares of forest land in the United States. They also reported that on the timberland in 1991 net growth was 612 million m^3 and removals 462. At the present annual per capita removal of 462/250 or 1.9 m^3, 350 million people would remove 647 million m^3, exceeding the net growth of 612 million m^3.

17 We calculated use [(Future population) / (Present) x (Million m^3 present removals)] or [350/250 x 462] = 647 million m^3. At 4 m^3 per hectare net growth, the 647 million m^3 could be grown on 162 million hectares, 82 percent of the present 198 million hectares of timberland. The difference between 198 and 162 million hectares is 40 times the area of Yellowstone Park.

18 In 1992 cropland in the United States was 0.63 hectares per capita. At that rate, 100 million more people would require 63 million additional hectares for raising crops. Conversely, assuming the rise in population, a static American diet, and an annual one percent rise in the average crop yield in the United States over the next century, the land spared from raising crops would be equal to over four times the area of Iowa and 70 times the area of Yellowstone Park. Note that this sparing is from all crops, not just feed, and that grazing complicates its calculation little.

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