Article Navin Ramankutty, Jonathan A. Foley and Nicholas J. Olejniczak

People on the Land: Changes in Global Population and Croplands during the 20th Century

This study reviews the major changes in global distribution of croplands during the 20th century. During the 20th century, the cropland base diminished greatly (from ~ 0.75 ha person^{-1} in 1900 to ~ 0.35 ha person^{-1} in 1990). This loss of croplands was not globally uniform: more than half the world's population, living in developing nations, lost nearly two-thirds of their per capita cropland base. The distribution of croplands has become increasingly skewed—in 1990, 80% of the population lived off less than 0.35 ha person^{-1}. While agricultural yields have generally increased, they have barely kept pace with population growth in developing nations. Overall, the global food production system is becoming increasingly vulnerable to regional disruptions because of our increasing reliance on expensive technological options to increase agricultural production, or on global food trade.

INTRODUCTION

The global land base is fundamental to our success as a civilization. Croplands are the sites of world food production, while savannas and grasslands provide areas for grazing, and forests and woodlands are sources of fuelwood, paper, timber, and pharmaceutical products. Yet we still have a poor understanding of the conditions of these crucial land resources. Here we review the recent history of human agricultural activities across the globe, focusing on the worldwide spread and intensification of cropland ecosystems that has occurred in the last century.

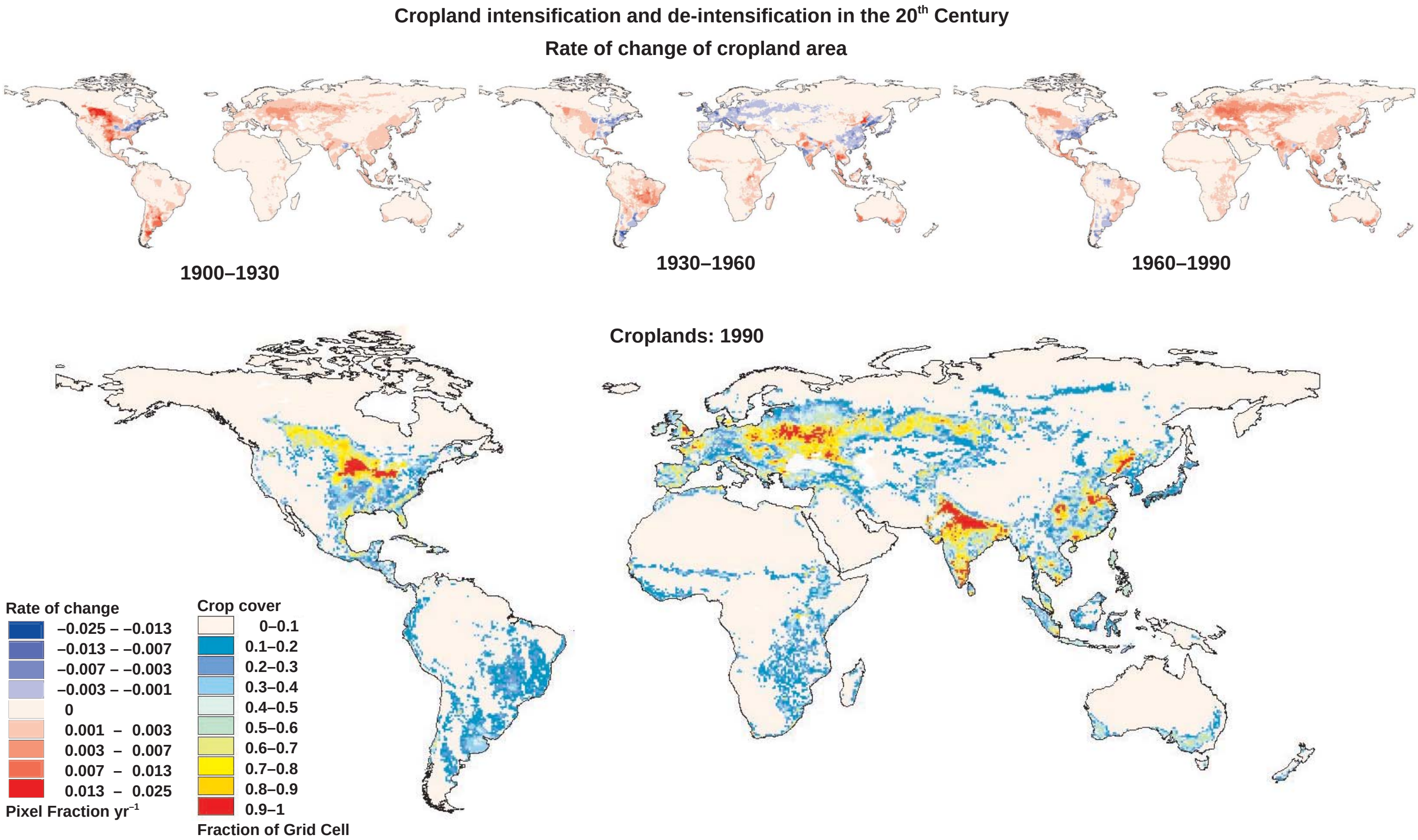
WHERE DOES OUR FOOD COME FROM?

One of the clearest manifestations of human activity within the biosphere has been the conversion of natural landscapes to highly managed ecosystems, such as croplands, pastures, forest plantations, and urban areas.

Until recently, however, we have only had rough estimates of the extent of human dominated landscapes. For example, Turner et al. (1) indicated that roughly 1400–1500 million ha (an area nearly the size of South America) is in some form of cultivation, while about 7000 million ha (nearly half the global land surface) in pasture and grassland. While these types of estimates are useful, they only indicate the extent of land use within gross national units. More explicit accounts of land-use practices, with greater geographic detail, are needed to evaluate the environmental impact.

In a recent study, Ramankutty and Foley (2) presented a new technique for documenting and monitoring cropland areas around the world. This method reconciles satellite-based land-cover imagery and worldwide agricultural census data using a simple statistical technique. In particular, they fused the IGBP-DIS 1-km

Figure 1. Global cropland change during the 20th century. (Top) cropland rate of change calculated over 30-yr intervals from 1900 to 1990. (Bottom) global crop cover in 1990.



(Note: The historical cropland data were derived by statistically synthesizing a satellite-derived land-cover classification data set for 1992 with historical cropland inventory data collected from numerous census organizations) (14).

land-cover dataset (3) with numerous agricultural census records compiled from international and national organizations to create a geographically explicit global map of current croplands (Fig. 1).

The Ramankutty and Foley (2) dataset indicates that roughly 1800 million ha (or 12% of the global land-surface area) was under cultivation in the 1990s. This number is on the high end of the 1500–1800 million ha reported by other sources (4–7). In our calibration technique, the satellite data provide additional information on the distribution of croplands—our estimate is the best statistical fit that reconciles both the satellite and census information. Furthermore, several studies have shown that official statistics, especially in China, may be under-reporting agricultural land area by as much as 50% in some regions (8–10). Nevertheless, even if our global total cropland area may be an overestimate, the spatial distribution of crop-cover is reasonable.

Here we present a brief discussion of agricultural geography for 16 different regions of the world, with information compiled from numerous sources (2, 7, 11, 12). Detailed maps of croplands and more discussion of agricultural geography are also presented as supplemental web material (http://sage.aos.wisc.edu). The geographic distribution of croplands shows that the major cultivation zones of the world lie in regions with agriculturally productive soils and adequate climate conditions (13). In particular, we see the breadbaskets of the world: the Corn Belt of the United States, the prairie provinces of Canada, the wheat-corn belt of Europe, paddy in the Ganges flood-plain, the wheat- and rice-growing regions of eastern China, the grain-growing regions of the Pampas in Argentina, and the wheat belts of Australia. Less dense cultivation occurs throughout much of the developed world. In addition, large sections of Africa are characterized by low- to moderate-intensity subsistence agriculture. Generally speaking, croplands are largely absent in regions characterized by extremely dry or cold climates. For instance, croplands are absent in the subtropical deserts, high alpine regions, and high-latitude zones.

The modern extent and intensity of crop-cover is a relatively new feature on the Earth's surface. For example, Richards (7) estimated that there has been greater expansion of cropland areas since World War II than in the 18th and early 19th centuries combined. Even though many authors have recognized the importance of such large-scale land-use activities, relatively few studies have attempted to quantify the history of human land-use and land-cover change within the biosphere.

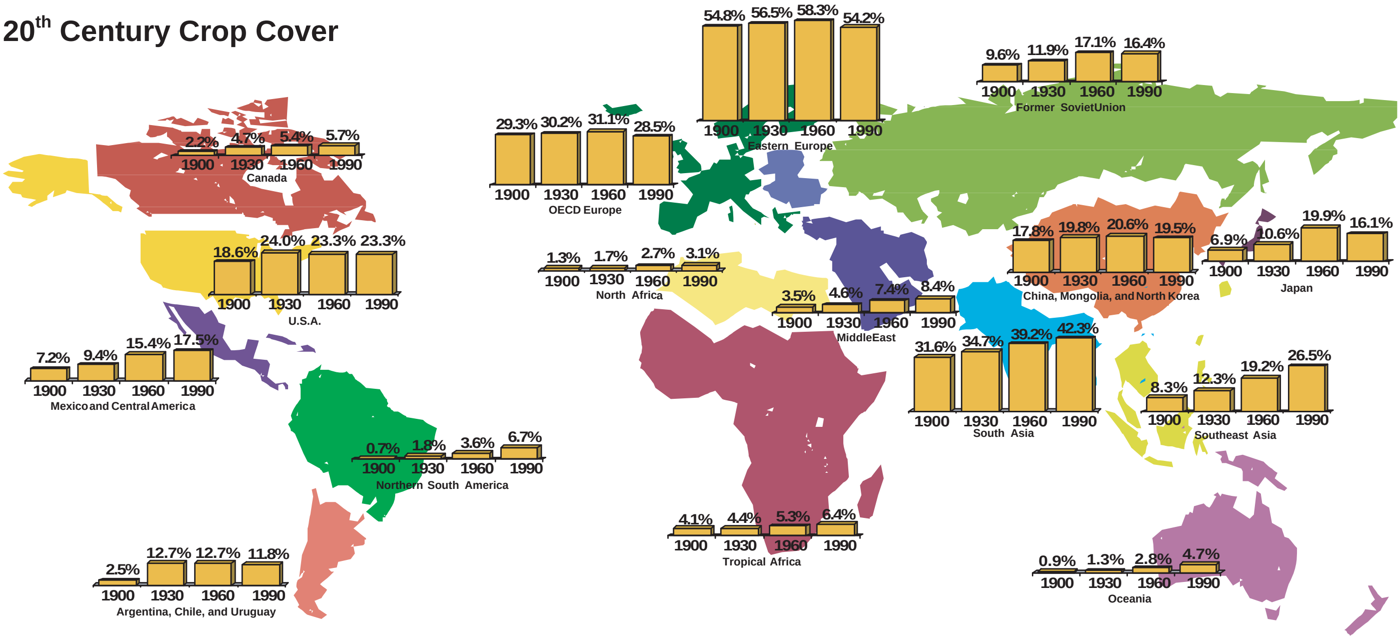
Recently, Ramankutty and Foley (14) reconstructed a historical (from 1700 to 1992), geographically explicit dataset of cropland areas for the entire globe (Fig. 1). This data set was constructed by statistically combining the 1990s croplands dataset with historical cropland census data (for the last 3 centuries). It indicates that croplands expanded by 50% during the 20th century, from roughly 1200 million ha in 1900 to 1800 million ha in 1990. This net increase in cropland area includes the abandonment of 222 million ha of cropland since 1900.

From this historical dataset, we selected data over the 1900-1990 period for analysis in this study. The general pattern of global crop-cover change shown in this dataset (Fig. 1) is consistent with the history of human civilizations as well as the patterns of economic development and European settlement (7, 15, 16). The regions of the world with a long history of agricultural practice—Europe, India, China, and Africa—have extensive crop-cover in 1900. Eastern North America and southeastern Australia are cultivated in 1900 following European settlement.

Cropland Expansion during the 20th Century: 3 Periods

1900–1930: Agriculture in North America migrated westward, with intensification of the corn-belt in the USA, and cultivation of the prairie provinces in Canada. We also see extensive cropland abandonment extending all the way from New England and the mid-Atlantic states to the midwestern United States. The Pampas grassland region in Argentina was cleared for crops during this period; parts of Brazil were also beginning to be cultivated. By 1930, cultivation began in southwestern Australia. The rest of the world gradually intensified its cultivation during this time. Some croplands in northeast India were also abandoned.
1930–1960: There was further intensification of crop-cover in the American corn-belt and the Canadian prairie provinces. However, cropland abandonment became more extensive in the eastern parts of North America, extending into the southern coastal plains. We see some clearing along the Paranaiba River, Brazil, along with some cropland abandonment to the west. After 1930,

Figure 2. Croplands in the 20th Century.



(Note: We aggregate the results in figure 1 into 16 major regions of the world. The results are presented as the fraction of cropland occupying the total land area of each region. As a percentage of total land area, the greatest cropland expansion occurred in South and Southeast Asia, while in absolute amounts, the greatest expansion occurred in the FSU and northern South America).

crop-cover in the Pampas region stabilized and even decreased. The "virgin lands" project of the Former Soviet Union (FSU hereafter) led to an intensification of croplands there (although, the dataset misrepresents the spatial pattern of this change due to the lack of subnational data; it ought to be an eastward movement of croplands rather than an intensification). While the rate of cropland change increased in the FSU, cropland expansion slowed down in Europe. Cultivation also intensified in India and China, although some cropland abandonment is also seen in India, in the northeast and the southeastern coastal regions. Clearing for croplands intensified in Southeast Asia and Oceania.

1960–1990: The most significant change in croplands was the expansion in southeast Brazil. Cropland abandonment continued in the Pampas. Cropland expansion slowed down in the midwestern USA, while abandonment in the eastern portions continued. Cropland areas in northern Europe, the FSU, and China stabilized and even decreased in some regions, while it intensified in portions of northeast China. Some croplands were abandoned in Japan. Parts of India continued to clear for crops, while others abandoned croplands. Clearing for cultivation continued in Southeast Asia and Oceania.

We now compare the 20th century cropland-cover across 16 major regions of the world (Fig. 2). As a fraction of total land area, Eastern Europe is the most extensively cultivated region in the world, with more than half its land area in crop-cover. However, in absolute terms, the FSU has the largest cropland area. The greatest expansion of croplands in the 20th century (in absolute amounts) also occurred in the FSU (mainly during expansion into the Virgin Lands) and in northern South America (in the last 50 years, with cultivation in the Brazilian highlands). However, as a percentage of total land area, the greatest cropland expansion occurred in South and Southeast Asia (11% and 18% of their total land area, respectively, was cleared for cultivation during the 20th century). In these regions, cropland areas increased exponentially matching an exponentially growing population.

THE CROPLAND BASE

The ability of a region of the world to produce or access food is determined by 3 factors: *i*) access to an adequate amount of productive cropland; *ii*) the ability to maintain high crop yields on that land (often with the aid of expensive inputs, such as fertilizers, pesticides, and irrigation); or *iii*) the ability to purchase and import food from other regions. These factors only account for the capacity of a particular region to produce or access food, and ignores the economics of food supply within the region and the ability of individuals and families within each region to be able to access the available food.

First, we examine the availability of productive cropland around the world. Specifically, we look at the changes in amount of cropland area per person over the 20th century. Per capita cropland area is an important measure of a region's land base.

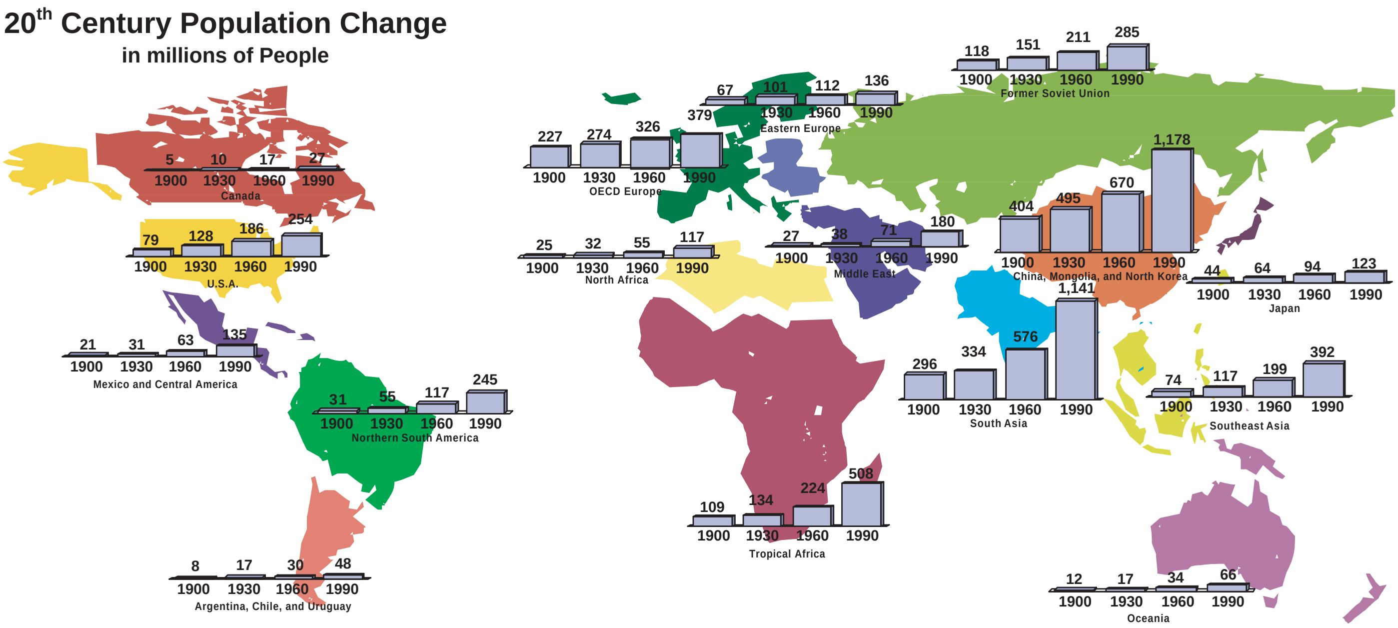
Changes in Human Population

During the 20th century, world population more than tripled, increasing from approximately 1500 million people in 1900 to 5200 million in 1990 (Klein Goldewijk, pers. comm., 1999). Today, the world population is roughly 6000 million, and is increasing by 1.3% yr^{-1}, adding roughly 78 million people (equivalent to the population of Vietnam) to the planet every year (17). At this rate, the population of the planet would double in 52 years; however, current projections suggest that the rate of population growth is declining, and that our population will instead reach 8900 million by 2050 (17).

In addition to the overall global increases in population, the geographic distribution of human population underwent massive changes during the 20th century (Fig. 3). For example, between 1900 and 1990, the population of northern South America increased by 214 million (681%, compared to the global average population increase of 3700 million, 236% (Fig. 3). Overall, South Asia and China, Mongolia, and North Korea increased in population most rapidly (845 million and 774 million, respectively); Canada and Argentina, Chile, and Uruguay had the slowest rates of population growth.

Increasing human population has undoubtedly driven global changes in land-cover. However, land-cover change attains global significance through the cumulative addition of locally specific changes (1). Thus, we examine the regional relationships between population change and crop-cover change.

Figure 3. Human population in the 20th century.



(Note: Klein Goldewijk and Battjes (5) compiled historical national and subnational level population statistics from various sources. We obtained the data at a country level (Klein Goldewijk, pers. comm., 1999) and aggregated to 16 regions. South Asia and China, Mongolia, and North Korea increased in population most rapidly, while Canada and Argentina, Chile, and Uruguay had the slowest rates of population growth. The units are millions of people).

The Changing Distribution of Cropland Resource

Comparing the population and amount of cultivated land in 16 major regions of the world (Fig. 4), we find that, in general, regions with high populations have larger cropland areas. The nature of this relationship has not changed over the 20th century because it is the greater demand from growing populations that has led to cropland expansion. Furthermore, people tend to live near regions that are agriculturally productive; historically, cities were located close to the major food production centers of the world.

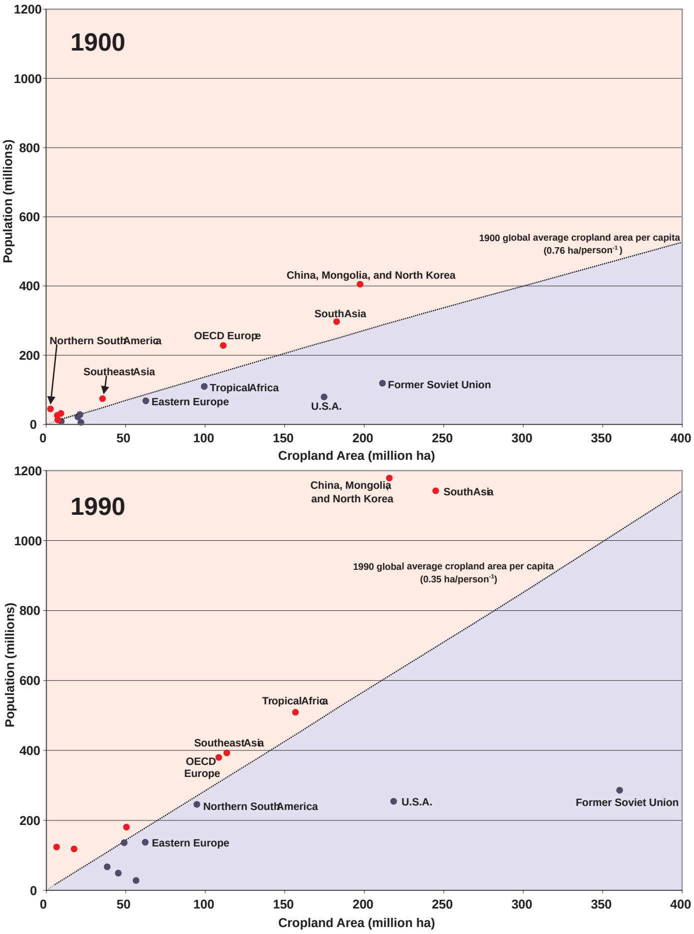
However, the wide scatter around the general linear relationship also reveals an uneven distribution of the cropland base (Fig. 4). Developed countries such as the USA and the FSU, with roughly 10–13% of the world population, contain nearly a third of the global cropland area. On the other hand, the populous and poorer nations of the world such as China, Mongolia, and N. Korea and South Asia, with roughly 45% of the global population, have only a quarter to a third of the global cropland area.

A good measure of the global distribution of cropland resources is the per capita cropland area (Fig. 5). The 20th century changes in per capita cropland area in the 16 regions of the world shows that population growth was not met by a corresponding increase in cropland expansion both globally and regionally. This is primarily due to 2 factors.

i) Most of the 20th century increases in food production were achieved by increased productivity on cultivated land (i.e. by higher yields per unit land area through the use of fertilizers, mechanization, pesticides, irrigation, etc.) Thus, the per capita cropland area decreased in all regions of the world during the 20th century except in northern South America (Fig. 5) (in northern South America, it increased from 1900 to 1930, but decreased afterward, and was still higher in 1990 than in 1900). Globally, the per capita cropland area decreased by more than half, from around 0.75 ha person^{-1} in 1900 to only 0.35 ha person^{-1} in 1990.

ii) Expansion of cropland area did not always occur in the regions with greatest population growth. For example, the FSU had the greatest cropland expansion in the 20th century (Fig. 2), but its population growth was lower than in all the developing nations (Fig. 3). On the other hand, South Asia, which had the greatest population increase in the 20th century, did not have a commensurate expansion of cropland area (Figs 2 and 3). In-

Figure 4. The population of 16 major regions of the world plotted against their cropland area in 1900 and 1990.



(Note: The dotted line diagonally cutting across the figure represents the global average per capita cropland area in 1900 and 1990. Regions of the world that lie in the lower section of the figure have relatively higher per capita cropland area, while the regions of the world in the upper section have lower per capita cropland area with respect to the global average. The global distribution of croplands is skewed: the USA and the FSU, with roughly 10–13% of the world population, have nearly a third of the global cropland area, while China, Mongolia, and N. Korea and South Asia, with roughly 45% of the global population, have only a quarter to a third of the global cropland area).

Table 1. Change in per capita agricultural production during the 1990s.

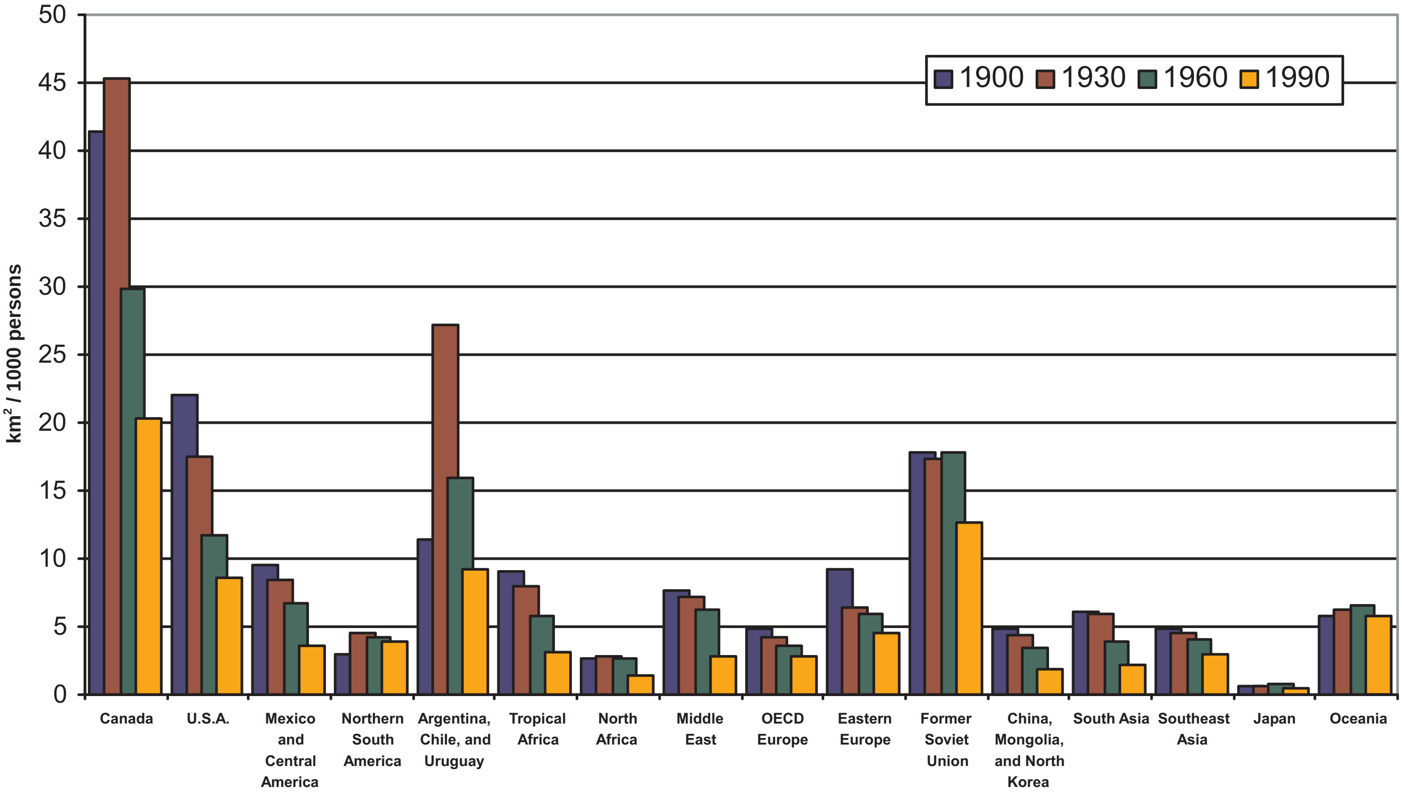
	Agricultural production (million m tonnes yr^{-1})		Population (millions of people)		Per capita agricultural production (tonnes person^{-1} yr^{-1})		
	Early 1990s	Late 1990s	Early 1990s	Late 1990s	Early 1990s	Late 1990s	Late 90s–Early 90s
Japan	20	18	124	126	0.16	0.14	–0.02
North Africa	28	34	118	138	0.24	0.25	0.01
Mexico and C. America	35	40	136	158	0.26	0.25	0.00
South Asia	307	365	1172	1364	0.26	0.27	0.01
Middle East	68	73	187	225	0.36	0.33	–0.04
Northern S. America	91	105	248	283	0.37	0.37	0.01
Southeast Asia	174	195	447	509	0.39	0.38	–0.01
Tropical Africa	189	242	493	607	0.38	0.40	0.01
Globe	2526	2781	5252	5882	0.48	0.47	–0.01
China, Mongolia, and N. Korea	545	643	1186	1290	0.46	0.50	0.04
Former Soviet Union	273	183	291	292	0.94	0.63	–0.31
OECD Europe	240	262	381	390	0.63	0.67	0.04
Argentina, Chile, and Uruguay	27	45	49	54	0.55	0.84	0.29
Eastern Europe	130	116	119	118	1.09	0.98	–0.11
USA	318	364	254	274	1.25	1.33	0.07
Oceania	24	37	20	22	1.18	1.67	0.49
Canada	57	58	28	31	2.04	1.88	–0.16

The agricultural production data (sum of cereals, pulses, and roots and tubers production rates) were obtained from the Food and Agricultural Organization's online FAOSTAT database (http://apps.fao.org). Data were collected at the country level, annually, for the period 1990–1998. The data were aggregated to the 16 regions, and a linear regression was fit to the 9 years of data. The end points of the regression line were chosen to represent the conditions in the early- and late 1990s. The data are sorted by the per capita agricultural production rates in the late 1990s. Regions of the world that lie above the global value have relatively lower per capita agricultural production rates in the late 1990s with respect to the globe, while regions of the world below have higher per-capita agricultural production rates during the 1990s.

creased food demand in South Asia was met by a large increase in land productivity during the Green Revolution (in addition, fish forms a large portion of the diet). In northern South America, cropland expansion was so large that there was more cropland per person at the end of the century than in 1900. Increased global trade and food aid during the 20th century undoubtedly provided food to the nations without sufficient cropland base.

It is estimated that a minimum cropland area of 0.5 ha person^{-1} is required to provide an adequate diet (18). Of course, this makes certain assumptions about the climatic and soil conditions, and about the level of technology used. However, it is a rough, but useful, number to compare against the cropland base of the different regions of the world during the 20th century. Canada had the greatest per capita cropland area during the 20th century (3.4 ha person^{-1}, on average), followed by the FSU, Argentina, Chile, and Uruguay, and the USA (roughly 1.5–1.6 ha person^{-1}). Japan had the lowest per capita cropland base (0.07 ha person^{-1} on average, almost 50 times smaller than Canada) (however, a substantial portion of the Japanese diet is fish). The greatest loss of per capita cropland was seen in Canada and the USA

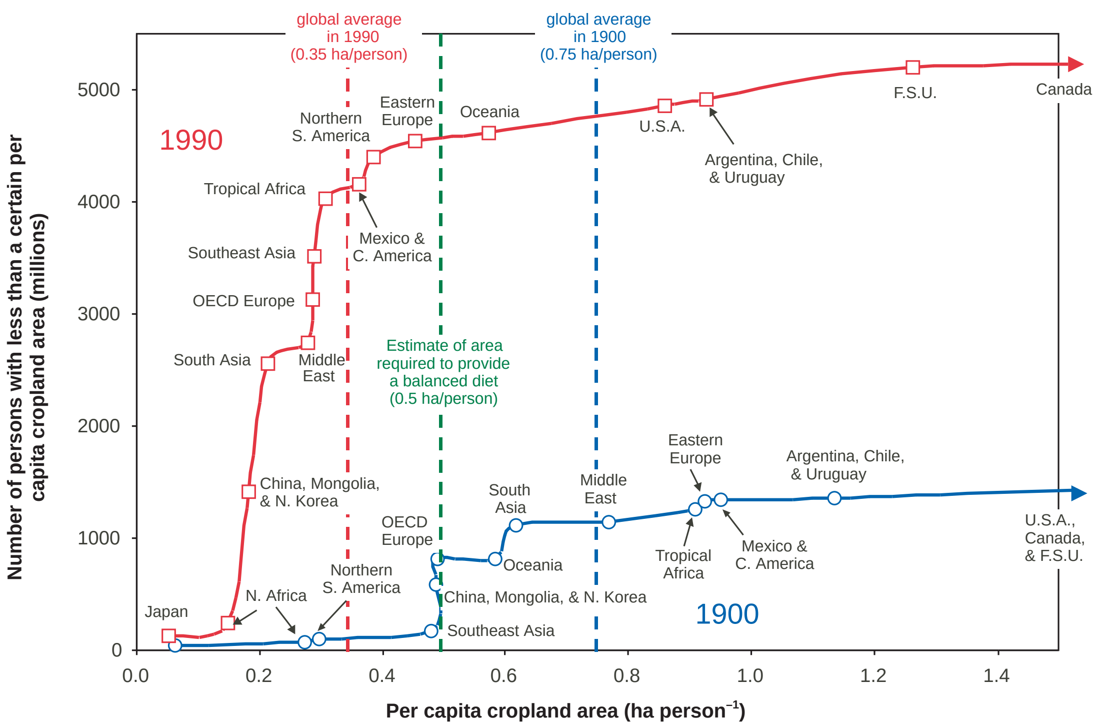
Figure 5. The per-capita cropland area in 16 major regions of the world from 1900 to 1990.



(Note: The estimates were obtained as the ratio of the land-cover data shown in Figure 2 and the population data in Figure 3. Tropical Africa, South Asia, and China, Mongolia, and N. Korea hosting more than half of the world's population lost nearly two-thirds of their per capita cropland area during the 20th century).

Figure 6. Cumulative distribution of population *vs* per-capita cropland area in 1900 and 1990.

(Note: The ordinate on the figure indicates the total number of people who live in regions with less than a given per capita cropland area on the abscissa (1900 conditions shown by open circles and 1990 by open squares). Each symbol has been labeled by a region—the values read against the abscissa indicate the region's per capita cropland area, while values on the ordinate indicate the cumulative population of that region and all the regions below it.



In these countries, cropland areas stabilized during the latter half of the 20th century while populations continued to increase. However, these regions already have a large share of the world's cropland base, and relatively fewer people live there.

In relative terms, Tropical Africa, South Asia, China, Mongolia, and N. Korea, Mexico and Central America, the Middle East, and the USA experienced the greatest loss of per capita cropland area during the 20th century (losing nearly two-thirds between 1900 and 1990). All of these regions except for the USA had less than 0.5 ha of cropland per person by 1990. Also, Tropical Africa, South Asia, and China, Mongolia, and N. Korea host more than half of the world's population and are also relatively poor.

The scarcity of the cropland base can be better illustrated by examining the distribution of human numbers *vs* per capita cropland area (Fig. 6). In 1900, more than 1000 million people (74% of the 1900 population) lived below the 1900 global average per capita cropland area of 0.75 ha person^{-1}. In 1990, the global average cropland per capita itself decreased to 0.35 ha person^{-1}. And in 1990, more than 4000 million people (nearly 80% of the 1990 population) possessed less than 0.35 ha of cropland person^{-1}. Eight regions of the world fall in to this category, and 5 of them,—North Africa, Tropical Africa, China, Mongolia, and N. Korea, South Asia, and Southeast Asia,—comprise the developing nations of the world. The remaining 3 nations in this category,—Japan, OECD Europe, and the Middle East,—are probably wealthy enough to import their food. On the other hand, in 1990, roughly 10% of the global population (living in the developed nations of USA and the FSU) enjoyed greater than 0.8 ha of cropland person^{-1}. In comparison to the estimated minimum cropland area requirement, there were 800 million people in 1900 (52% of the 1900 population) with less than 0.5 ha person^{-1}, while in 1990, there were 4500 million people (87% of the 1990 population) with less than 0.5 ha person^{-1}. Thus, during the 20th century, the trend indicates that more people (mostly living in developing nations) are living off less land area.

A major caveat regarding the above analysis is that the same extent of land can produce different amounts of food in different parts of the world because of differences in climate, soils, etc., even with the same technological advancement. For example, Canada, with a large cropland extent is hampered by a short growing season, while the small extent of cropland in Southeast Asia may permit 2 to 3 growing seasons. A more complete analysis of regional food status will need to include models of annual crop production. Thus, in the next section, we briefly examine the trends in regional food production over the last decade.

AGRICULTURAL PRODUCTION

While cropland area is vital for producing food, the agricultural yield of the land, crop production per unit area, is also a critical factor. In fact, much of the increase in food production during the 20th century came from increases in yield rather than from an expansion of the cropland area. Here, we briefly examine the status of agricultural yields and total food production during the decade of the 1990s.

We compare the population of 16 major regions of the world with their agricultural production in the early and late 1990s (Table 1). Regions of the world that lie on the right-hand side of the dashed line (representing global average production per capita in 1990s) have a relatively favorable food supply compared to the rest of the world. We ignore differences in consumption styles in this simple analysis. Canada has the highest per capita agricultural production, while Japan has the lowest per capita production (however, fish is a larger portion of the Japanese diet).

The direction of change from early to late 1990s for the different regions is also indicated in Table 1. The USA, China, Mongolia, and N. Korea, OECD Europe, Argentina, Chile, and Uruguay, and Oceania had food production rates that exceeded their population growth rates during the 20th century. The FSU and Eastern Europe had population growth rates that far exceeded their food production rates. However, they already had favorable production per capita to begin with in the early 1990s. Per capita food production rates barely remained steady in the developing countries comprising the regions of South Asia, Tropical Africa, Southeast Asia, northern S. America, Mexico and Central America, and N. Africa. The developing region with the worst trend is South Asia, which is also relatively poor and incapable of importing a lot of food. For the most part, regions with favorable per capita agricultural production in the 1990s also experienced the greatest fluctuation during that period.

FUTURE TRENDS

In the 20th century, because of technological advances, the food production per capita remained stable or even increased in some places. However, the forecast for the future does not look promising. There will be an additional 2000 million people on this planet within the next 30 yrs (17). Furthermore, food consumption is expected to increase as per capita incomes rise (19). In this context, the general trend toward less land per person is disturbing. It implies a greater reliance on continued technological advances in food production; technology that many developing nations cannot afford. Furthermore, there is no fertile frontier left to be exploited, since the vast majority of the world's fertile land is already under cultivation. Much of the remaining cultivable land lies in marginal areas or in the richly forested regions of tropical Latin America and Africa (20). Clearing for cultivation implies an enormous loss of valuable forestland. Furthermore, we are already losing existing prime farmland to urbanization and soil degradation that will further increase the pressure on the remaining croplands. Thus, our global food production system is becoming increasingly vulnerable because of its sole dependency on technological improvements to meet future food demands; poor nations are likely to be the most affected as they can scarcely afford the expensive technological options or to import food to meet their needs.

CONCLUSION

Humans require a secure and renewable natural-resource base to sustain their basic needs and economic activity into the future. However, while deriving natural resources from the terrestrial biosphere, humans also inadvertently modify their environment. The 20th century has seen a growing human population, increasing agricultural yields, and a resultant decrease in the land-resource base. From 1900 to 1990, global population increased 236%, while global cropland area increased 56%, resulting in a halving of the global per capita cropland area.

The loss of land-resource base has not been globally uniform. More than half the world's population living in developing nations—constituting South Asia, China, Mongolia, and N. Korea, and Tropical Africa—lost nearly two-thirds of their per capita cropland area during the 20th century. The impact of rapid population growth in regions with a low cropland base has led to the increasing pressure of more people living off less cropland area per capita. In 1990, nearly 4000 million people possessed less than the global average per capita cropland area of 0.35 ha person^{-1}, and most of these people lived in poor nations of the world.

A review of food production data in the 1990s indicates that developing nations, especially South Asia, are just maintaining their per capita food production rates. In the future, these nations might have to import much of their food, unless they can continue to enhance the productivity of their land. The FSU, Eastern Europe, the Middle East, and Japan also had lower (or even decreasing) food production rates compared to their population growth rates. However, the former 2 regions had favorable production rates to begin with, while the latter 2 regions are wealthy enough to buy food.

In addition to the loss of per capita cropland area due to the sheer increase in population size, recently, the pressure on the land base has increased further due to the loss of prime farmlands to urbanization and to soil degradation (21, 22). During the 20th century, there has been a large shift of humans from rural to urban areas. As most of the urban centers were established close to prime cropland areas, with exploding urban population sizes, human settlements are now encroaching on regions with the best climate and soils for growing crops. For example, in the USA and China, large areas of prime farmland are being lost to urbanization (21, 23). Similarly, with the intensification of cultivation and the expansion of cropland into more marginal areas, large areas of cultivated land are being degraded. A U.N. study (24), as well as a more recent study by the International Food Policy Research Institute (25), estimated that roughly 40% of global cropland area is degraded to some degree due to agricultural mismanagement. Thus, in addition to the loss of our per capita cropland base due to the sheer increase in human population, we are also losing prime farmland due to urbanization and soil degradation.

In this study, we have only considered pressures on land due to human population growth. We have to recognize, however, that population growth by itself does not drive changes in land-cover. It is also crucial to consider the per capita resource consumption of those individuals. There are vast differences in resource consumption between different economic strata of the human population. To illustrate the importance of per capita resource consumption as an environmental driver, Wackernagel et al. (26) used the notion of an "environmental footprint" to characterize the land area needed to produce the resources consumed and assimilate the waste generated by a given population. According to Wackernagel et al. (26), the average American currently requires roughly 20 times as much land as an average Bangladeshi. In fact, if all the people on Earth lived like an average North American, it would require 3 times the global land area to sustain them. Clearly, differences in economic development, political structure, and culture play a significant role in determining the consumption of natural resources across the globe.

The challenge that lies ahead is to feed an increasing population with increasing per capita consumption. As there is little fertile land remaining to be plowed, future increases in crop production will necessarily have to come from increases in crop productivity. Such increases in productivity will have to be achieved in a sustainable fashion without loss of soil quality and environmental pollution. Can the green revolution that greatly increased productivity in South and Southeast Asia and Latin America also be repeated in tropical South America and Africa? How will such agricultural technology transfers be achieved? Can the failures of the green revolution (salination, environmental pollution) be avoided in these new areas of intensified crop production?

References and Notes:

1. Turner II, B.L., Moss, R.H. and Skole, D.L. 1993. *Relating Land Use and Global Land-cover Change: A Proposal for an IGBP-HDP Core Project*. International Biosphere-Geosphere Program: A study of global change and the human dimensions of global environmental change programme, 65 pp.
2. Ramankutty, N. and Foley, J.A. 1998. Characterizing patterns of global land use: An analysis of global croplands data. *Global Biogeochem. Cycles 12*, 667–685.
3. Belward, A.S. and Loveland, T.R. 1996. The DIS 1 km land cover data set. In: *Global Change Newsletter*, The International Geosphere-Biosphere Programme: A study of global change (IGBP) of the International Council of Scientific Unions, pp. 7–8.
4. Food and Agriculture Organization 1995. *Land Use, FAOSTAT-PC*. Food and Agric. Organization of the U.N., Rome.
5. Klein Goldewijk, C.G.M. and Battjes, J.J. 1997. *A Hundred Year (1890–1990) Database for Integrated Environmental Assessments* (HYDE, version 1.1). National Institute of Public Health and the Environment (RIVM).
6. Matthews, E. 1983. Global vegetation and land use: New high resolution data bases for climate studies. *J. Climatol. Appl. Meteorol. 22*, 474–487.
7. Richards, J.F. 1990. Land transformation. In: *The Earth as Transformed by Human Action*. Turner, B.L. et al. (eds). Cambridge Univ. Press, New York, pp. 163–178.
8. U.S. Department of Agriculture 1991. *China Agriculture and Trade Report*. Economic Research Service, U.S. Department of Agriculture.
9. Frolking, S., Xiao, X.M., Zhuang, Y.H., Salas, W. and Li, C.S. 1999. Agricultural land-use in China: a comparison of area estimates from ground-based census and satellite-borne remote sensing. *Global Ecol. Biogeogr. 8*, 407–416.
10. Seto, K.C., Kaufmann, R.K. and Woodcock, C.E. 2000. Landsat reveals China's farmland reserves, but they're vanishing fast. *Nature 406*, 121–121.
11. Central Intelligence Agency 1999. *The World Factbook*. (http://www.odci.gov/cia/publications/factbook/index.html).
12. US Department of Agriculture 1994. *Major World Crop Areas and Climatic Profiles.* 279 pp.
13. Ramankutty, N. 2000. *The Role of Croplands in the Terrestrial Biosphere: Past, Present, and Future*. Ph.D. Dissertation, Land Resources/Institute for Environmental Studies, University of Wisconsin, Madison, USA, 260 pp.
14. Ramankutty, N. and Foley, J.A. 1999. Estimating historical changes in global land cover: Croplands from 1700 to 1992. *Global Biogeochem. Cycles 13*, 997–1027.
15. Grigg, D.B. 1974. The growth and distribution of the world's arable land 1870–1970. *Geogr. 59*, 104–110.
16. Robertson, C.J. 1956. The expansion of the arable area. *Scottish Geogr. Magazine 72*, 1–20.
17. United Nations 2000. *Charting the Progress of Populations*. United Nations Population Division, (http://www.undp.org/popin/wdtrends/chart/contents.htm).
18. Lal, R. 1989. Land degradation and its impact on food and other resources. In: *Food and Natural Resources*. Pimentel, D. and Hall, C.W. (eds). Academic Press, San Diego, pp. 85–140.
19. Daily, G., Dasgupta, P., Bolin, B., Crosson, P., du Guerny, J., Ehrlich, P., Folke, C., Jansson, A.M., Jansson, B.O., Kautsky, N., Kinzig, A., Levin, S., Maler, K.G., Pinstrup-Andersen, P., Siniscalco, D. and Walker, B. 1998. Policy forum: Global food supply - Food production, population growth, and the environment. *Science 281*, 1291–1292.
20. Buringh, P. and Dudal, R. 1987. Agricultural Land Use in Space and Time. In: *Land Transformation in Agriculture*. Wolman, M.G. and Fournier, F.G.A. (eds). John Wiley & Sons, Chichester, pp. 3–43.
21. Gardner, G. 1996. *Shrinking Fields: Cropland Loss in a World of 8 Billion*. Worldwatch Institute, 56 pp.
22. Kindall, H.W. and Pimentel, D. 1994. Constraints on the expansion of the global food supply. *Ambio 23*, 198–205.
23. Mather, A.S. 1986. *Land Use*. Longman Inc., New York.
24. Oldeman, L.R., Hakkeling, R.T.A. and Sombroek, W.G. 1991. *World Map of the Status of Human Induced Soil Degradation: An Explanatory Note*. International Soil Reference and Information Centre, Wageningen, the Netherlands, 34 pp.
25. International Food Policy Research Institute 2000. Press release. (http://www.cgiar.org/ifpri/pressrel/052500.htm).
26. Wackernagel, M., Onisto, L., Linares, A.C., Falfan, I.S.L., Garcia, J.M., Guerrero, A.I.S. and Guerrero, M.G.S. 1997. *Ecological Footprints of Nations: How Much Nature Do They Use? How Much Nature Do They Have?* Commissioned by the Earth Council for the Rio+5 Forum. International Council for Local Environmental Initiatives, Toronto.
27. An electronic supplement to this paper will be made available online at our web site, http://sage.aos.wisc.edu. It features more detailed maps of agricultural lands in 1992.

28. We are grateful to Kees Klein Goldewijk of the RIVM, the Netherlands, for sharing his population data set. We appreciate the valuable support of this paper and useful feedback from Chris Field and Don Kennedy. We would like to thank Simon Donner, Christine Delire, and Peter Snyder for constructive comments on the manuscript. This research was supported by the National Aeronautics and Space Administration (NASA) and the Electric Power Research Institute (EPRI).
29. First submitted 11 Oct. 2000. Accepted for publication after revision 16 July 2001.

Navin Ramankutty is a scientist at the Center for Sustainability and the Global Environment (SAGE) of the Institute for Environmental Studies (IES), University of Wisconsin (UW). He completed his graduate degrees at the University of Illinois at Urbana-Champaign and the University of Wisconsin-Madison. His major research interest is in developing data sets of historical land use and land-cover change, and assessments of natural resource use.
E-mail: nramanku@facstaff.wisc.edu

Jon Foley is the director of SAGE at the UW. In addition, he is a professor of Environmental Studies and Atmospheric and Oceanic Sciences. Foley's work focuses on the dynamics of global environmental systems, and their interactions with human societies. In particular, Foley's research emphasizes the use of computer models to analyze and simulate changes in climate, global ecosystems, and natural resources.
E-mail: jfoley@facstaff.wisc.edu

Nicholas Olejniczak is a graduate student in the Land Resources program of IES. He has a bachelor's degree in atmospheric science from the UW. His major interest is in internet-based dissemination of scientific data.
E-mail: njolejni@students.wisc.edu

Their address: Center for Sustainability and the Global Environment (SAGE), Institute for environmental Studies, University of Wisconsin, 1225 West Dayton Street, Madison, Wisconsin 53706, USA.