Population and the Environment

Joel E. Cohen, Ph.D.
Director, Laboratory of Populations
Rockefeller University and Columbia University

Humans have influenced environmental changes in the past, and vice versa. The two-way interaction between people and their environments will continue in the future. In the coming half-century, the human population will probably be

- larger,
- more slowly growing,
- more urban, and
- older

than in the twentieth century. No one knows whether humans will be more internationally mobile. These changes, with uncertain environmental consequences, result from human choices, individual and collective, and are therefore subject to influence by programs and policies.

Population and environment in the twentieth century: A retrospective look

Demographic and environmental changes in the twentieth century were dramatic. The human population of the Earth grew nearly four-fold, from 1.6 billion in 1900 to 6.1 billion in 2000. Many indicators of human impact on the environment grew by far more than a factor of four. Carbon dioxide emissions grew by a factor of 17, sulfur dioxide emissions by 13, lead emissions to the atmosphere by 8, water withdrawals 9-fold, and the marine fish catch 35-fold. If human population growth alone were responsible for humanity's impacts on the environment, all of these indicators would have been expected to grow about four-fold, on the naive but mistaken theory that, for example, four times as many people would necessarily emit four times as much carbon dioxide. The size of the cattle population, like that of the human population, grew four-fold, but the number of pigs grew nine-fold.

These changes (summarized, along with others, in the table at the end of this paper) show that human numbers alone were not the sole determinant of environmental changes in the twentieth century. Economic growth (the increase of capital, production, and income) and technological change also affected humans' environmental impact.

Economic growth, illustrated by the reported 40-fold increase in industrial production and the increase in energy use by 10-fold or 16-fold, was partly responsible for increased carbon and sulfur emissions to the atmosphere, as well as for a roughly four-fold rise in global average income per person during the twentieth century. Economic growth also enabled environmental clean-ups in wealthy countries that chose to clean up.

Technological and other changes brought environmental tradeoffs in agriculture. For example, the spread of agricultural irrigation increased demands for fresh water but decreased demands for additional lands to feed

a growing population. Up to 1960, cultivated cropland increased nearly in direct proportion to population, which roughly doubled from 1.6 billion in 1900 to 3 billion in 1960. Because irrigated cropland can be much more productive than rain-fed cropland, the spread of irrigated cropland since 1960 contributed importantly to keeping the total area of cultivated cropland more or less steady since 1960. In addition to increased irrigation, other factors that enabled the same amount of land that fed 3 billion people in 1960 to feed more than 6 billion in 2000 were new genetic varieties of major cereals, pesticides, artificial nitrogenous fertilizers, credit and market institutions, improved transport, and farmer education. More nitrogen (and methane) into the atmosphere, more nitrogen into groundwater, more water use, and massive global genetic change (evolution under human guidance) in cultivars of wheat, rice, and maize were part of the price paid for a leveling off of the area under cultivation and a savings by 2000 of cultivated cropland roughly equal to all currently cultivated cropland.

During the twentieth century, other environmentally influential technological changes included the displacement of horses with cars and tractors, the invention and worldwide diffusion of stainless steel, new varieties of agricultural plants and animals, modern contraceptives, radio, television, films, computers, the Internet, antibiotics, vaccines, the chainsaw, the airplane, chlorofluorocarbons, antibiotics, semiconductors, cheap plastics, synthetic fertilizers and the deployment of physical, chemical, and biological weapons of unprecedented destructive power. Technological changes also increased industrial water usage and helped to decimate the whales and many other oceanic, freshwater and terrestrial species.

The collective environmental impact of humans depends not only on how many people there are, but also on how wealthy the people are and on the technology they use to generate and enjoy their wealth. Environmental scientists John Holdren and Paul Ehrlich proposed in 1972 a simple, very influential formula, widely taught, used, and criticized, which is commonly called the IPAT formula: I=PAT, or

Impact on the environment =
Population x Affluence x Technology

In his environmental history of the twentieth century, *Something New Under the Sun*, the environmental historian John McNeill emphasized three additional factors in human impacts on the environment, at least equally important but perhaps not so tidily quantified as PAT:

- culture, including "big ideas," environmental ideas, domestic and international politics, war, and environmental policies;
- market size and structure; and
- autonomous or exogenous environmental change not caused by humans.

Here are a few examples of these factors at work.

Culture, especially politics

In the Po Valley in northern Italy, in the Tennessee Valley Authority and the Colorado River system in the United States, along the Volga River in Russia, in India, China, Egypt and elsewhere, dams to extend irrigation, control floods, and generate electricity always also served larger political purposes. They demonstrated to the people the power of the state to control nature for the social good. This demonstration helped whoever was in power at the time, be it Roosevelt, Stalin, Nehru, Nasser, Nkrumah, or many other leaders. In the 1960s, more than one large dam at least 15 meters high was completed every day on average. By 1990, two-thirds of all the world's streamflow passed over or through dams. The diversions of water from natural courses reduced the Aral Sea from the world's fourth-largest lake to its eighth-largest lake. The full environmental consequences of damming the rivers that drain into the Mediterranean Sea have yet to be felt.

Market size and structure

Economic integration has environmental consequences beyond those of increases in industrial production and income because economic integration makes it possible to focus the demand of millions of dispersed buyers on limited areas of supply. When the object of purchase is biological, such as elephant ivory, rhinoceros horn, giant panda skin, or tortoise shell, the rate of production often cannot keep up with the increased demand. In such cases, instead of taking only a sustainable yield, extraction may draw down the productive stock, pushing the exploited species toward extinction.

Technology interacts with economic integration. Information technology spreads news about what is for sale. The invention and spread of canning factories diverted the catch of many salmon runs on the American West Coast from local consumption to global markets.

Exogenous environmental change

Exogenous environmental change also influenced the twentieth century. When drought hit Saskatchewan in the 1930s, dust storms destroyed 3 to 4 million hectares of prairie wheat lands. Farmers in Oklahoma and Kansas experienced similar distress in the Dust Bowl of 1931-38. Farmers left these drought-stricken regions en masse. If farmers had not brought cultivation techniques more appropriate to humid lands of eastern North America and Europe into the prairies of the United States and Canada, the massive soil erosion experienced in the 1930s might have been avoided. However, if there had not also been sustained drought, there would not have been dust bowls.

In summary, major environmental changes in the twentieth century were influenced by population, affluence, technology, culture, market size and structure, and exogenous environmental change.

Demographic changes of the next 50 years

It took from the beginning of time until about 1927 to put the first 2 billion people on the planet; less than 50 years to add the next 2 billion people (by 1974); and just 25 years to add the most recent 2 billion (by 1999). During the two centuries before 1950, Europe and the New World experienced the most rapid population growth of any region, while the populations of most of Asia and Africa grew very slowly. Then rapid population growth shifted from Western countries to Africa, the Middle East and Asia.

The next century will have billions more people in it. More young men and women than ever before are now entering the age of childbearing. Barring catastrophes, their children are likely to increase the world population by perhaps 2 billion to 4 billion people by the middle of the twenty-first century. No one can know precisely how many billions of people will be added because the future additions depend on current human choices about education, health, economics, peace and the environment.

In the next century, the human population will probably grow at a slower rate than in the twentieth century, both absolutely and relatively. By contrast, for most of the last five centuries, including most of the twentieth century, the rate of growth of the human population was increasing. The all-time peak rate of growth, 2.1 percent per year, was reached around 1965. Since 1965, the population growth rate has dropped by one-third, to roughly 1.3 percent per year. The absolute increase in population peaked around 1990, when the number of human beings added each year rose to perhaps 86 million. Since 1990, the absolute increase has fallen to 75-80 million additional people per year. Currently 44 percent of people live in countries where fertility is below the level required to replace the population in the long run.

While absolute population growth is now slower than at its peak, it still vastly exceeds the estimated 10 million people who were added to the population annually around 1900. Population growth, though slowing globally, remains very rapid in the economically less developed regions from sub-Saharan Africa through the Middle East to South Asia.

According to the 2000 revision of United Nations World Population Prospects, the total fertility rate (lifetime number of children per woman, according to present fertility rates) in the five years up to 2000 ranged from a low of 1.32 children per woman in southern Europe to highs of 5.77 in sub-Sahara Africa, 3.86 in Western Asia, 3.58 in northern Africa and 3.58 in South-central Asia. A total fertility rate of roughly 2.1 children per woman would be required for a population to cease growth or decline in the long run. While more than half of all couples in developing countries now use contraception, hundreds of millions more do not because of poverty, lack of education, and lack of access. (Even in the opulent United States, an estimated 57 percent of all conceptions are not intended.)

In the coming half-century, more than half of all people will live in cities, for the first time in human history. Almost all population growth in the next half century will be in cities, demographers expect, while the world's rural population will remain flat near 3 billion people.

This acceleration of urbanization has deep roots. In Europe, widespread urbanization began in the eleventh century. Worldwide urbanization has been taking place for at least two centuries but accelerated greatly in the twentieth century. In 1900, no cities had 10 million people or more. By 1950, one city did: New York. In 2000, perhaps 19 cities had 10 million people or more. Of those 19 cities, only four (Tokyo, New York, Los Angeles, and Osaka) were in industrialized countries. Between 1900 and 2000, the number of city dwellers rose nearly 14-fold, from 200 million to 2.9 billion. Now 47 percent of people live in cities, and nearly 10 percent of those city dwellers live in cities of 10 million people or larger.

According to United Nations projections published in 2000, the urban population will rise to 60% of the total by 2030 (84% of the population in more developed regions, 56% of the population in less developed regions). By 2030, the urban population would total 4.9 billion, 1.0 billion in the more developed regions and 3.9 billion in the less developed regions. These figures on urbanization disguise major ambiguities and variations among countries in definitions of "cities" and "urban." The numbers should not be taken literally, but the trend toward urbanization is clear.

The coming half-century, again barring catastrophes, will see dramatic population aging, a higher proportion of the population in elderly age groups. The twentieth century will probably be the last in human history in which younger people outnumbered older ones. During the past century, the proportion of children aged four years and under gradually declined, and that of people aged 60 years and older gradually increased. Each group constituted about 10 percent of humanity in the year 2000. This convergence reflects improved survival and reduced fertility. Improved survival raised the average length of life from perhaps 30 years at the beginning of the century to more than 66 years at its end. Reduced fertility rates added smaller cohorts to the younger age groups. The aging of the human population is likely to continue. According to one UN estimate, by the year 2050 there will be 3.3 people aged 60 years or older for every child four years old or younger.

The median age of a population is the age such that half the people are older and half are younger. The median age of world population rose from 23.5 years in 1950 to 26.6 years in 2000. By 2050, the median age will rise to 37.8 years according to the 1998 medium projection of the United Nations. Thus the median age will increase by 14.3 years from 1950 to 2050. In the same century, the median age of the more developed regions is projected to increase by 17 years while that of the less developed regions increases by 15.4 years, even though the more developed regions started with a median age 7.3 years older than that of the less developed regions.

Economists and some demographers summarize the age structure of a population by dependency ratios. The elderly dependency ratio is defined as the ratio of the number of people aged 65+ to the number aged 15-64, expressed

as a percentage. The elderly dependency ratio rose from 1950 to 2000 at a rapid rate in the more developed countries, slightly less rapidly in the United States, and still less rapidly in the world as a whole. The ratio rose only slightly in the less developed countries, and hardly at all in the least developed countries. According to the United Nations 1998 medium projection, after 2010, the more developed countries, the United States, and even the less developed countries will experience a sharp acceleration in the rate of increase of the elderly dependency ratio. This acceleration will be greater in the more developed countries and the United States than in the less developed countries. The least developed countries will experience a slow increase in the elderly dependency ratio following 2020 and by 2050 will be approaching the elderly dependency ratio of the more developed countries in 1950.

Could different international migration scenarios greatly affect the United States' dependency ratios projected for the coming century? Apparently not. Holding fertility as assumed in its middle series of projections, the United States Census Bureau in 2000 found that different migration scenarios profoundly influenced the projected United States' population size in 2050 compared to that in the year 2000, ranging from a 20 percent increase assuming zero international migration, to an 80 percent increase assuming the highest level of migration (hypothetical net annual migration to the United States increasing from 1.2 million in 1999 to 2.8 million by 2050). But regardless of the migration scenarios, the United States' elderly dependency ratio will rise sharply from 2010 until around 2035 and will gradually increase thereafter. By 2050, the United States' elderly dependency ratio is projected to rise to 39% with zero international migration, and to 30% with the highest international migration. High international migration will not materially affect the aging of the United States population, but could nearly double American numbers.

The interest in measuring and projecting dependency ratios depends on the questionable assumptions that individuals aged 15-64 years represent the potential workers of a population, and that the other individuals represent dependents. In many less developed and some more developed countries, children begin working with or without pay before age 15. In more developed countries where a high fraction of young people pursue secondary and higher education, only a fraction of the population aged 15-25 may be available to the labor force. For women, labor force availability during the middle years interacts with levels of fertility, institutions available locally for childcare, and cultural restrictions on the economic activity of women. Average ages of retirement have dropped below 65 years in some countries and some individuals continue working far beyond age 65.

How much of an economic burden the elderly population will represent depends on the health of the elderly and on the economic and social institutions available to offer them work and to support their care, to the extent it is needed. Nationally representative longitudinal surveys from 1982 through 1994 of the United States population aged 65+ residing in the community and in institutions indicated that the rate of chronic disability could be declining among the elderly as rapidly as 1.5% per year. A fall of 1.5% per year in disability would keep the ratio of economically active persons aged 20-64 to the number of chronically disabled persons aged 65+ above 22:1, the value in 1994 when the Hospital Insurance Trust Fund was in fiscal balance, until 2070. However, this same ratio would fall to 8:1, a level 63% below a cash flow balance, if disability rates among the elderly did not change. Unfortunately, the beneficiary projections of the Social Security Administration and the Medicare Trust Fund do not directly represent trends in health, education or socioeconomic status. Extrapolating directly from dependency ratios to economic and social burdens can be hazardous.

Will vastly larger numbers of people cross national and continental boundaries in the coming half-century than in the recent past? No one knows. A national or regional population grows

larger as a result of births or immigration, smaller as a result of deaths or emigration. National governments vary widely in how much they try to control births and emigration, but almost all have active policies to encourage, discourage or restrict immigration. Consequently, more than most demographic variables, future international migration is subject to policy choices, and therefore almost impossible to predict.

In a 1999 report, the United Nations admitted: "International migration is the component of population dynamics most difficult to project reliably. This occurs in part because the data available on past trends are sparse and partial, and in part because the movement of people across international boundaries, which is a response to rapidly changing economic, geopolitical or security factors, is subject to a great deal of volatility." The United Nations Population Division was obliged to make some assumptions about future international migration to fulfill its mandate to prepare population projections. It classified 184 countries into four groups. Countries in the first group were assumed to have zero net migration during the projection interval. Countries in the second and third groups were assumed to experience non-zero net migration until 2005, 2015, 2020 or 2025, depending on their recent migration histories. These countries do not have a long migration history or policies that foster immigration or emigration. In the fourth group, countries with a long history of labor migration or migrant workers, either as origin or destination, were assumed to have nonzero net migration until 2050. This group includes Australia, Canada, New Zealand and the United States as well as one-fifth of the countries in Africa and Asia. The influence of international migration on global population growth was small, but was substantial for the roughly one-sixth of countries with sustained labor migration.

Though the global demographic significance of future international migration is impossible to assess, international migration is likely to remain important for some identifiable countries including the United States.

Environmental consequences of anticipated demographic trends

It is highly risky to predict environmental impacts from demographic changes, given the combined uncertainty of the demographic projections themselves and of the linkages between demographic and environmental changes. The following suggestions are plausible speculation at best.

From the past lack of proportionality between human population growth and the magnitude of environmental changes, it seems reasonable to anticipate that if global human population growth slows or ends in the twenty-first century, human impacts on the environment will not necessarily level off in parallel.

Urbanization offers exciting opportunities for educational and cultural enrichment, which could include improved environmental understanding and protection. Urbanization also threatens frightening hazards from infectious diseases unless adequate sanitation supplies clean water and removes wastes.

Many major cities were established in regions of exceptional agricultural productivity, typically the floodplains of rivers, or in coastal zones or islands with favorable access to marine food resources and maritime commerce. If the world's urban population roughly doubles in the next half-century (from 3 billion to 6 billion people) while the world's rural population remains roughly constant (at 3 billion people), and if many cities expand in area rather than increasing in density, fertile agricultural lands around those cities could be removed from production and the waters around coastal or island cities could face an increasing challenge from urban wastes. Assuming that most food consumed in urban regions is and will be produced in rural regions, on average each rural person will have to shift from feeding herself (the majority of the world's agricultural workers are women) and one urban person today to feeding herself and two urban people in half a century. The spread of cities onto surrounding prime agricultural land will make this transition more difficult. Coastal mariculture will face similarly

increasing challenges. The intensity of food production (measured as yield per worker per unit of area or coastline) will have to double unless new lands or coastal zones are converted to agricultural production. If the intensity of food production is increased by application of chemical fertilizers and feedstocks, the health and environmental hazards posed by poorly controlled effluents will increase. If the intensity of rural agricultural production increases, the demand for food and the technology supplied by the growing cities to the rural regions may ultimately lift the rural agrarian population from poverty, as has happened in much of Northern America and western Europe. On the other hand, if the intensity of food production does not increase but instead new lands and coastal zones are brought into agricultural production, these added zones are likely to be less productive on average than zones already in production or recently removed by urbanization, unless there are compensating technological changes. The spatial extension of agricultural production could collide with increasing demands from a doubled urban population for recreational spaces outside of cities.

It is difficult to avoid anticipating increasingly serious threats to the survival of biological diversity from the combination of continued population growth, urban growth and spread, increasing intensity or spread of food production, growing global energy exploration and extraction, growing global trade in energy commodities, timber, foodstuffs and manufactured goods, and pervasive climate change, currently warming. It is not possible to predict with assurance that humanity's present global perturbations of the physical, chemical and biological infrastructure of the earth will have only good effects on the health, prosperity and psychological well-being of humans in the coming century. A proactive response to these challenges is desirable.

Programs and policies

Demographic trends result from choices by individuals and societies. They are not inevitable outcomes of a mechanistic world. How much governments and societies invest in public health, biomedical research, education and economic equity, how many children individuals and families decide to have, where people choose to live and governments permit people to live, and whether individuals and nations settle differences peacefully or violently—all strongly influence the next century's demographic trends and environmental consequences.

A 1997 United Nations report on critical trends summarized: "There is increasing evidence that successful policy interventions to influence long-term demographic trends involve simultaneous action targeting a range of determinants: income distribution, improvement in the status of women, basic education, information and communication, primary health care (including family planning) and employment opportunities." A study of 14 African countries, among many similar studies in Africa and other regions, found that "primary education reduced fertility in half the countries, and ... secondary education did so in every case. The greatest success in reducing fertility was evident in the countries with the highest levels of female schooling, the lowest child mortality rates and the most vigorous family planning programmes."

Multiple factors, prominently including primary and secondary education, affect economic as well as demographic development. For example, the World Bank analyzed the economic rate of return in 1,265 World Bank projects in countries with low or high levels of education, and low or high economic openness. Projects that benefited from both more open economies and high levels of education had substantially higher economic rates of return on average than those where either factor or both were less favorable.

Demography poses big challenges to education in the next half century. The number of children of primary and secondary school age (roughly 6 to 16 years old) will drop by a quarter in today's more developed countries. The number of children of school age will rise by

more than 70 percent in today's least developed countries over the next three decades, despite rapidly falling global population growth rates. The countries with the least means will face the most rapid growth in the numbers of school-age children. The numbers of school-age children are a 10-year leading indicator of the numbers of young adults of military age. Thus, while the number of military-age youth will be declining in the West, it will be rapidly climbing in the poorest countries, if today's poorest countries remain poor in coming decades and if fertility forecasts are correct. If people so choose, all children could complete primary and secondary schooling of vastly better quality than is now offered. In combination with other programs and policies, universal basic and secondary education could transform the twenty-first century.

Table. Changes in selected environmental, economic, and demographic indicators during the twentieth century. Example: world population increased by a factor of 3.7 to 4.

Item	Increase factor	
	McNeill's estimate, 1890s-1990s*	My estimate, 1900s-2000**
World population	4	3.7
Annual increment to world population		7.8
Life expectancy at birth		2.2
United States population		3.7
China population		3.3
Urban proportion of world population	3	3.6
Total world urban population	13	13.7
Population of single largest metropolitan area		4.3[c]
World economy	14	16
Gross domestic product per person		4.1
Industrial output	40	
Energy use	16[a]	10[c]
Coal production	7	
Air pollution	≈5	
Nitrogen released in NOx from fossil fuels		21
Carbon dioxide emissions	17	14.6
Carbon dioxide emissions, 1900-1996b		12.2
U.S. carbon dioxide emissions, 1900-1996b		8
CO2 partial pressure in the atmosphere		1.2-1.3
Sulfur dioxide emissions	13	
Lead emissions to the atmosphere	≈8	
U.S. nonfuel minerals consumption, 1900-1995c		29
U.S. nonfuel wood products consumption, 1900-1995c		3
U.S. metals consumption, 1900-1995c		14
U.S. fossil-fuel-based synthetics consumption, 1900-1995c		82
Water use	9	7-9
Marine fish catch	35	
Cattle population	4	
Pig population	9	
Horse population	1.1	
Blue whale population (Southern Ocean only)	-99.75%	
Fin whale population	-97%	
Bird and mammal species	-1%	
Irrigated area	5	6[c]
Forest area	-20%	
Cropland	2	
World grain harvest		4.8[c]

* McNeill, J. R. 2000 *Something New Under the Sun: An Environmental History of the Twentieth-Century World.* W. W. Norton, New York, from pp. 360-361.

** Unless here attributed to another source, estimates are derived from Cohen, Joel E. 2002 The future of population. In: *What the Future Holds: Insights from Social Science,* ed. Richard N. Cooper & Richard Layard, pp. 29-75. MIT Press, Cambridge, MA, pp. 30-32, where citations to original sources are given.

a Revised to 13 in the 2001 British Penguin paperback edition.

b Hunter, David 1999 Global environmental protection in the 21st century. *Foreign Policy in Focus,* Special Report #4, September. Interhemispheric Resource Center, Albuquerque, New Mexico, p. 13.

c Starke, Linda, ed. 1999 State of the World 1999. New York: W. W. Norton.

The Convergence of U.S. National Security and the Global Environment

Sixth Conference

MAY 27 - JUNE 2, 2002

DIRECTOR AND MODERATOR:
Dick Clark

THE ASPEN INSTITUTE
Washington, DC

Table of Contents