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How Many People Can the Earth Support?

Joel E. Cohen

Introduction: Edward O. Wilson, Pelligrino University Professor Emeritus and Honorary Curator in Entomology, Harvard University

It is a pleasure and an honor for me to introduce one of the world's foremost ecologists and biological demographers—and a friend for thirty years. Joel Cohen graduated from Harvard summa cum laude in applied mathematics in 1965. While a Junior Fellow of Harvard's Society of Fellows, he earned doctorates in applied mathematics and population sciences. After serving on the Harvard faculty and being offered tenure at an early age, I am sorry to report (speaking on behalf of Harvard) that he moved to Rockefeller University—where, as Abby Rockefeller Mauze Professor, he heads the Laboratory of Populations. He also holds a joint appointment as professor of populations at Columbia University.

It is notably true that a scientist's style of investigation is a product of the discipline he chooses, further narrowed by aptitude and taste. If a naturalist at heart, he saunters at random, sometimes through woods thick with trees—or, as is more common nowadays, through cells thick with molecules—in search of objects and happenings still unimagined. His instinct is that of a hunter. If, on the other hand, the scientist is a mathematical theorist, he creates a mental picture of a known but poorly understood process, skeletonizes it into what intuition suggests are its essential elements, and recasts it in diagrams and equations. He looks for vindication by saying to the experimentalist, "If this is

This presentation was given at the 1806th Stated Meeting, held at the House of the Academy in Cambridge on December 10, 1997.

the way the process works, even if we can't see it directly, here are the parameters for an indirect proof, and here is the language by which we might come to experimental results."

Joel Cohen is the consummate theoretical scientist. In more than 250 articles and four books, he has made fundamental contributions to a wide range of subjects, including the structure of food webs (in which he is a major pioneer), epidemiology, population stability, and applied mathematics. He has been recognized with many fellowships and awards, including the MacArthur Fellowship, the Mercer Award of the Ecological Society of America, the Nordberg Prize of the Population Council, and memberships in the American Philosophical Society and the National Academy of Sciences. His visiting lectureships and other public services to the sciences are too numerous to mention.

Tonight, I can assure you that he will speak authoritatively on one of the most important issues—some would say, and I am one of them, *the* most important issue—facing humanity in the coming decades. It is my pleasure to call upon Joel Cohen to address the question, "How many people can the Earth support?"

How Many People Can the Earth Support?

Joel E. Cohen

Ed Wilson's introduction adds one more debt to a long list that I owe him. I'd like to mention two in particular. Around 1963, from Ed Wilson's Harvard undergraduate course in population biology, I learned that the scientific study of biological populations and biological communities was both possible and exciting. Thirty years later, Ed encouraged me to write a book based on a short article I had published on how many people the Earth can support. Given the example of his own books of magisterial synthesis, I was greatly encouraged. I am happy to have the chance to say thank you to Ed for these gifts, which have changed my life, as well as for the kind introduction.

The question "How many people can the Earth support?" is useful, though it is seriously incomplete. It focuses attention on the present and future numbers, qualities, activities, and values of humans in their relations with one another and with the Earth. To explain why people are interested in this question, I offer an overview of global human population, economy, environment, and culture. I then review some answers to the question and describe what is involved in answering it. Finally, I suggest actions that could alleviate some of the problems of population, economy, environment, and culture.

The Earth's capacity to support people is determined both by natural constraints, which some will emphasize, and by human choice, which others will emphasize. In the coming half century, we and our children are less likely to face absolute limits than difficult trade-offs—trade-offs among population size and economic well-being and environmental quality and dearly held values. Foresight and action now might make some of the coming trade-offs easier.

I hope to offer a perspective to protect you from those who say that rapid population growth is no problem at all and from those who say that population growth is the only problem. A rounded view of the facts should immunize you against both cornucopians and doomsayers. I give more details in my recent book *How Many People Can the Earth Support?* (1995).

Past Human Population

Population Size and Growth. Two thousand years ago, the Earth had roughly one-quarter of a billion people (the population of the United States around 1990). By 1650 the Earth's population had doubled to half a billion. When the Old World and the New World began to exchange foods and other resources in a serious way, the time required to double the population dropped from more than 16 centuries (after the inventions of agriculture) to less than two centuries. The human population passed one billion around 1830. The second billion people were added in only one century, by 1930. The next doubling, to four billion, took only 44 years. Until around 1965, the human population grew like an interest-bearing account in which the rate of interest increased with the balance in the account. Around 1965–70, the global population growth rate reached its all-time peak, then began to fall gradually and erratically. It still remains far above global growth rates experienced prior to 1945.

In the lifetime of anyone who is over 40, world population has doubled. Never before the second half of the twentieth century had any person lived through a doubling of world population. In absolute numbers, putting the first billion people on Earth took from the beginning of time to about 1830. Adding the latest billion took 12 years.

In spite of this rapid population growth, by demographic and nutritional standards, average human well-being has improved. For the world as a whole, life expectancy at birth rose from 46.4 years in 1950–55 to 64.4 years in 1990–95—an increase of 18 years. The advantage in life expectancy of the more developed regions over the less developed regions fell from 26 years in 1950–55 to 12 years in 1990–95. In developing regions, the absolute numbers and the fraction of people who were chronically undernourished fell from 941 million around 1970 to 786 million around 1990. In Africa, contrary to the world trend, the absolute number of chronically undernourished increased by two-thirds between 1970 and 1990. Africa also had the highest population growth rates during that period—and still does.

Economic Growth and Growing Economic Disparities. In the aggregate production of material wealth, the half-century since 1945 has been a golden era of technological and economic wonders. For example, in constant prices, with the price in 1990 set equal to 100, total

food commodity prices fell from 196 in 1975 to 85 in 1992. The price of petroleum fell from 113 in 1975 to 76 in 1992. The price of a basket of 33 nonfuel commodities fell from 159 in 1975 to 86 in 1992. However, timber prices increased from 62 in 1975 to 112 in 1992.

For many economists, the declining prices mean that human welfare is improving. Many participants in efficient market economies might agree. But global market prices, while useful for coordinating economic activity, are not universally reliable signals of changes in human well-being for at least three good reasons.

First, global prices do not reflect the depletion of unowned stocks, such as marine fisheries, the ozone layer, or water in internationally shared rivers and aquifers.

Second, prices need not reflect all environmental and social costs unless laws and practices bring those costs into the costs of production. Environmental and social costs may arise from extracting natural resources or from disposing of unwanted products and may be felt locally or globally, immediately or in the future. For example, in a local community, if a coal mine leaves behind an open pit or unfilled shafts, the price of coal does not reflect toxic effects of the mining, local erosion, or increased runoff. If the pit or mine is abandoned when the vein runs out, the price of coal does not reflect the cost of the collapse of the mining community left behind.

Likewise, market prices need not reflect future consequences of unwanted products such as spent nuclear fuels, carbon dioxide from power generation, solid wastes from discarded packaging and consumer goods, or asbestos, chlorofluorocarbons, and persistent pesticides. Assessing the costs varies in difficulty, from a relatively easy case like nontoxic solid waste, with a well-developed market in some countries, to a relatively hard case like chlorofluorocarbon disposal, apparently with no present market.

A third reason that prices are not always indicators of human well-being is that markets respond to effective demand, not to human need. Food commodity prices have dropped by half, while three-fourths of a billion people in developing countries chronically do not eat enough calories to grow normally and walk around, because the bottom billion are so poor that they cannot exercise effective demand in world commodity markets. They have no money to buy food, so they cannot drive up its price. The extremely poor are economically invisible.

As the world's average economic well-being rose, economic disparities between the rich and the poor increased. In 1960 the richest countries with 20 percent of world population earned 70.2 percent of global income, while the poorest countries with 20 percent of world population earned 2.3 percent of global income. Thus, the ratio of income per person between the top fifth and the bottom fifth was 30 to 1 in 1960. In 1970 that ratio was 32 to 1; in 1980, 45 to 1; in 1991, 60 to 1. In constant dollars, the absolute gap between the top fifth and the bottom fifth roughly doubled during this period.

While the global number and the global fraction of chronically undernourished people fell over recent decades, the share of global income earned by the poorest 20 percent of people fell even faster. Even if there is no global shortage of food relative to effective demand, and even if global food prices are steady or falling, a global pattern of local hunger in parts of Africa, south Asia, and Latin America is a serious problem.

Environmental Impact and Vulnerability. In the minds of many, human action is linked to an unprecedented litany of environmental problems. A grim list prepared by demographer Paul Demeny in 1991 includes loss of topsoil, desertification, deforestation, toxic poisoning of drinking water, oceanic pollution, shrinking wetlands, overgrazing, species loss, loss of wilderness areas, shortage of firewood, siltation in rivers and estuaries, encroachment on arable land, dropping water tables, erosion of the ozone layer, global warming, rising sea levels, consumption of mineral resources, nuclear wastes, and acid rain. Demeny complained that ecologists rarely provide enough information to quantify the relative importance of these problems in specific locales. More information is needed to evaluate the trade-offs among these problems. For example, what are the trade-offs among burying municipal wastes (soil and groundwater contamination), incinerating them (air pollution), dumping them offshore (marine contamination), and reducing them at the source (changes in manufacturing and packaging technology, consumer expectations and habits, laws and prices)?

Environmental vulnerability increases as humans make contact with the viruses and other pathogens of previously remote forests and grasslands. The number of people who live in coastal cities rapidly approaches one billion. Vulnerability to a rise in sea levels increases with the tide of urbanization.

Cultural Implosion. In recent decades, migrations from rural to urban regions and between countries, as well as business travel, tourism, radio, television, telephone, fax, Internet, cassettes, newspapers, and magazines, have shrunk the world stage, bringing cultures into contact and sometimes into conflict.

In 1800 roughly 1 in 50 people lived in cities; by 1995 almost 1 in 2 did. In 1950 the world had one city with more than 10 million people (New York). According to a United Nations study, in 1994 the world had 14 cities with more than 10 million people. Of those, only four were in rich countries (in decreasing order: Tokyo, New York, Los Angeles, Osaka); the remaining ten were in developing countries (in decreasing order: São Paulo, Mexico City, Shanghai, Bombay, Beijing, Calcutta, Seoul, Jakarta, Buenos Aires, Tianjin). On every continent, people who vary in culture, language, religion, values, ethnicity and race—and who share the same space for social, political, and economic activities—increasingly come into direct contact. The resulting frictions are evident in all parts of the world.

Between 1970 and 1990 the number of women who were economically active (that is, working for pay or looking for paid work) rose from 37 per 100 men to 62 per 100 men, while the world's population growth rate fell for the first time in modern history. Because of these changes in the roles of women, the number of economically active people rose much faster than the number of people of working age. Problems of employment are influenced as much by economic and cultural factors as by sheer population growth.

At the International Conference on Population and Development in Cairo in 1994, many delegates strongly advocated empowering women through education, paid jobs, credit, property rights, contraception, and political power. But in many cultures, empowering women in these ways conflicts directly with the goal of maintaining "full respect for the various religious and ethical values and cultural backgrounds," a goal often repeated in the final document of the Cairo conference. Cultural conflicts over women's and men's status, roles, and rights will not go away soon.

In summary, concerns about how many people the Earth can support involve not only population but also economics, the environment, and culture.

The Present

As of 1997, the world has about 5.8 billion people. At current birth rates, the worldwide average number of children born to a woman during her lifetime (the total fertility rate) is around 3.0. The population would double in 47 years if it continued to grow at its present rate of 1.5 percent per year, though that is not likely. These global summaries disguise two different worlds: the rich and the poor. The average number of children per woman ranges from almost 5.6 in Africa and 3.4 in the developing countries as a whole, to 1.6 in the wealthy countries.

In 1995 the 1.2 billion people in the world's richest countries enjoyed an average annual income of $19,300—a truly astounding achievement. The remaining 4.5 billion averaged roughly $1,000 per year. The poorest 2 billion lived on average incomes of $400 a year, or a dollar a day.

Roughly one in three people on Earth is infected with tuberculosis. Roughly half the people on Earth have no toilet. A billion adults are illiterate, and two-thirds of those are women.

Possible Futures

The future of the human population, like the futures of its economies, environment, and culture, is highly unpredictable. The United Nations regularly works out the demographic consequences of assumptions that it considers plausible and publishes projections in a range from high to low. A high projection published in 1992 assumed that worldwide average fertility would fall to 2.5 children per woman in the 21st century. In this scenario, population would grow to 12.5 billion in 55 years—within the lifetime of some of our children. The 1992 low projection of the UN assumed that population would peak at 7.8 billion in 2050 before beginning to decline.

One source of uncertainty that most demographers overlook is this: Can the Earth support the billions of additional people that the UN projects for 2050? Can the Earth continue to support the nearly 6 billion people it has now, at present levels or better? How many people can the Earth support?

In 1679 Antoni van Leeuwenhoek estimated not more than 13.4 billion. In 1994 five authors independently published estimates ranging from fewer than 3 billion up to

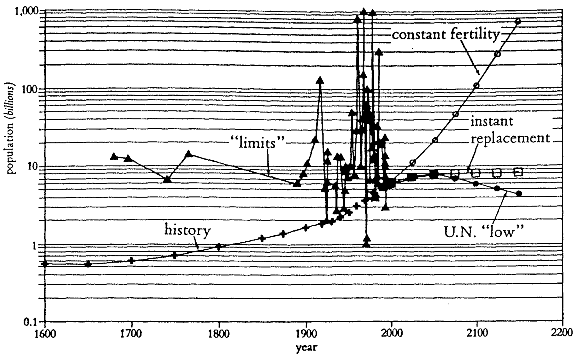

Fig. 1. Human population size 1600–1990, three United Nations (1992) scenarios of future population growth 1990–2150, and estimates of the Earth's maximum human population ("limits") by year of publication 1679–1994. The constant-fertility projection assumes that fertility in each region of the world remains at its level in 1990; in this scenario, the global average total fertility rate rises from 3.3 children per woman in 1990 to 5.7 children per woman in 2150 as the faster-growing regions become a larger share of world population. The instant-replacement projection assumes that the total fertility rate dropped to 2.06 children per woman in 1990 and remains at that level. The low-fertility projection assumes that the total fertility rate gradually moves to 1.7 children per woman everywhere. By the year 2050, according to these three projections, the world's population would number 21.2 billion, 7.7 billion, and 7.8 billion. The plotted estimates of the Earth's maximum human population are the highest given when an author stated a range. *Source:* Joel E. Cohen, *How Many People Can the Earth Support?* (Norton, 1995; p.368). Copyright © 1995 by Joel E. Cohen.

44 billion. Between 1679 and 1994 at least 60 additional estimates were published. Figure 1 plots the estimates as a function of the year in which the estimate was published. These 65 estimates of the Earth's maximum population range widely, from less than one billion to more than 1,000 billion. There is neither an increasing nor a decreasing trend in these estimates. The scatter has increased with time, contrary to what one might expect from estimates of a constant of nature. One conclusion is immediate: Many of the published answers cannot be nearly right—or there is no single right answer.

Why there is no single right answer becomes clear when the methods used to obtain

these estimates are examined carefully. One commonly used method assumes that a single factor, usually food, constrains population size. (That population often grows fastest in countries with the least food and slowest in the countries where food is most abundant does not seem to deter those who assume that food limits national population growth.) An estimate of the maximum possible annual global food production is divided by an estimate of the minimum possible annual food requirement per person to find the maximum possible number of minimal shares that the food supply could be divided into, and this number is taken as the maximum number of people the Earth could support.

The maximum possible food production depends not only on environmental constraints like soil, rainfall, terrain, and the length of the growing season, but also on human choices, individual and collective: which cultivars are chosen; the technology of cultivation; credit available to farmers; farmer education; infrastructure to produce and transport farm inputs (including irrigation capacity and hybrid seed development); infrastructure to transport, store, and process farm inputs; economic demand for food from other sections of the economy; and international politics and markets that affect trade inputs and outputs. Culture defines what is food: Where a Hindu may see a sacred cow, an American may see a hamburger on hooves. If edibility alone determined what is food, cockroaches would be in great demand.

The minimum food requirement depends not only on physiological requirements (about 2,000 kilocalories per person per day, averaged over most national populations) but also on cultural and economic standards of what is acceptable and desirable. Not everyone who has a choice will accept a vegetarian diet with no more than the minimum calories and nutrients required for normal growth.

Many authors of maximum population estimates recognized the difficulty of finding a single answer by giving a low estimate and a high estimate. The middle value, or median, of the high estimates is 12 billion. The median of the low estimates is 7.7 billion. This range of low to high medians, from 7.7 to 12 billion, is very close to the low and high UN projections for 2050: from 7.8 billion to 12.5 billion.

Recent population history has rapidly approached the level of many estimated limits, and the UN projections of future population lie at similar levels (Figure 1). Of course, a historical survey of estimated limits is no proof that limits really lie in this range. It is merely a warning signal that the human population has now entered, and is rapidly moving deeper into, a zone where limits on how many people the Earth can support have been anticipated and may be encountered.

How many people the Earth can support depends both on natural constraints, which are not fully understood, and on human choices. Many of these choices are unconscious decisions made by millions and billions of people in their daily lives (turn off the light when you leave the room, or leave it on; wash hands before eating, or don't bother; pick up litter in the schoolyard, or add to it). The cumulative results of what may be unconscious individual actions amount to major human choices: consume more or less fossil fuel; spread or prevent infectious diseases; degrade or beautify the environment.

Personal and collective choices affect the average level and the distribution of material well-being; technology; political institutions governing individual liberty, conflicts, and change (compare the breakup of Czechoslovakia with the breakup of Yugoslavia to see the impact of politics on the resources subsequently available for human well-being); economic arrangements regarding markets, trade, regulation, and externalities; family size and structure, migration, care of the young and elderly, and other demographic arrangements; physical, chemical, and biological environments (do we want a world of humans and wheat only?); variability or stability; risk or robustness; the time horizon (5 years ahead, or 50, or 500); and values, tastes, and fashions.

I emphasize the importance of values. Values determine how parents trade off the number of children against the quality of children; how they balance parents' freedom to reproduce and children's freedom to eat. Many choices that appear to be economic depend heavily on individual and cultural values. Should industrial economies seek now to develop renewable energy sources, or should they keep burning fossil fuels and leave the transition to future generations? Should women (and, by symmetry, should men) work outside their homes? How many people the Earth can support depends in part on how many will wear cotton and how many polyester; on how many will eat beef and how many bean sprouts; on how many will want parks and how many will want parking lots; on how many will want Jaguars with a capital *J* and how many will want jaguars with a small *j*. These choices change with time and circumstance, and so will how many people the Earth can support.

Implications for Action

What could be done now to ease future trade-offs in making these choices?

The "bigger pie" school says develop more technology. The "fewer forks" school says slow or stop population growth and reduce wants per person. The "better manners" school says improve the terms under which people interact (e.g., by defining property rights to open-access resources, removing economic irrationalities, reducing inequities and organized violence, improving governance). There is much value in all these approaches. None is sufficient by itself. Even in combination, they will not eliminate the need to make choices among competing values.

Lack of certainty about future constraints and choices does not justify lack of action now. Whenever I ride in a car, I put on my seatbelt, though I do not expect to be involved in a crash. I carry life insurance for my family, though I do not expect to die tomorrow. It is not necessary to be able to project the future with precision to recognize that more than 100 million women of childbearing age are estimated to lack desired access to means of fertility control; that, as Christopher Colclough and Keith Lewin have pointed out, 130 million girls and boys officially eligible for primary schooling in developing countries are out of school; that three-quarters of a billion people, more or less, were hungry yesterday, are hungry today, and will be hungry tomorrow; that humans leave their mark on the land, sea, air, and other species with which we share the planet; and that while life is better today for many people than it was in the past, there are also many people for whom life is more miserable than the available means require. We need no projections to identify problems that require action today.

Pyramid of Population, Economy, Environment, Culture

Many of the current statistics and future projections quoted here will change. But one message will remain useful: Population problems are not purely demographic. They also involve economics, the environment, and culture (including politics, law, and values).

Population, economy, environment, and culture may be envisioned as the corners of a symmetrical tetrahedron or pyramid. This image is my mental prophylaxis against omitting important dimensions when I listen to discussions of population problems. Each major dimension interacts with all three of the others. The symmetry of the pyramid means that culture or the environment or the economy could be placed on top without changing the message.

This pyramidal image is too simple in an important respect. Reality has not just a single pyramid, but thousands or millions of such pyramids, scattered over the globe, wherever humans live. Many of these local pyramids interact strongly over great distances, through worldwide financial and economic integration, through our shared commons of atmosphere and oceans and living species, and through global exchanges of people, microbes, and cultural symbols. Population problems vary from place to place but are globally interlinked.

The real issue with population is not just numbers of people, although numbers matter and statistics give us quantitative insight and prevent us from making fools of ourselves. The real crux of the population question is the quality of people's lives: the ability of people to participate in what it means to be really human; to work, play, and die with dignity; to have some sense that one's own life has meaning and is connected with other people's lives. That, to me, is the essence of the population problem.