HOW MANY PEOPLE CAN EARTH HOLD?

According to the United Nations, which follows these things closely, some 5.3 billion people enlivened our planet in 1990. By the time you read this, that number will have increased to 5.5 billion, an addition nearly equal to the population of the United States. Of course no one, including the UN, has a reliable crystal ball that reveals precisely how human numbers will change. Still, people have to plan for the future, and so the UN's analysts and computers have been busy figuring what might happen. ■ *One possibility they consider is that future world fertility rates will remain what they were in 1990. The consequences of this, with accompanying small declines in death rates, are startling. By 2025, when my 16-year-old daughter will have finished having whatever children she will have, the world would*

Our urge to go forth and multiply could, a century and a half from now, leave Earth with more than 694 billion people—some 125 times our current population.

BY JOEL E. COHEN

ILLUSTRATIONS BY BRIAN CRONIN

have 11 billion people, double its number today. Another doubling would take only a bit more than 25 years, as the faster-growing segments of the population become a larger proportion of the total. At my daughter's centennial, in 2076, the human population would have more than doubled again, passing 46 billion. By 2150 there would be 694,213,000,000 of us, a little over 125 times our present population.

There, in 2150, the projections of the United Nations Population Division stop. Perhaps they stop because the numbers were growing too long to print in their allotted column widths. Perhaps they stop because the computers grew weary of the thought of so many births to celebrate, so many marriages to consummate, so many dead to bury. At any rate, there, in 2150, the computers—and an unchanging urge to go forth and multiply—leave us, with a hypothetical 12,100 people for every square mile of land, or 3,500 people for every square mile of Earth's surface, oceans included. At this rate of growth the population would, before 2250, surpass 30 *trillion*, more than 200 people for every *acre* of the planet's surface, wet or dry.

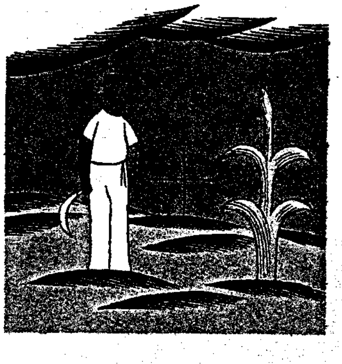
Surely the United States, though, with its wide-open spaces and its much more leisurely population growth, could never suffer such a crowded fate, right? Wrong. Back in 1970 Ansley Coale, a demographer at Princeton, observed that the population of the United States had increased by half since 1940. At that growth rate, he calculated, the U.S. population would "reach a billion shortly before the year 2100. Within six or seven more centuries we would reach one person per square foot of land area in the United States, and after about 1,500 years our descendants would outweigh the Earth if they continued to increase by 50 percent every 30 years. We can even calculate that, at that rate of increase, our descendants would, in a few thousand years, form a sphere of flesh whose radius would, neglecting relativity, expand at the velocity of light."

Here is what Coale concluded: "Every demographer knows that we cannot continue a positive rate of increase indefinitely. The inexorable arithmetic of compound interest leads us to absurd conditions within a calculable period of time. Logically we must, and in fact we will, have a rate of growth very close to zero in the long run."

I know of no qualified scientist who disagrees: The human population must ultimately approach a long-term average growth rate of zero. That is a law from which no country or region is exempt. According to every plausible calculation that's ever been done, Earth could not feed even the 694 billion people that the UN projected for 2150 if present fertility rates were to continue. Though there is tremendous uncertainty about the details of when, where, and how, the long-term constraint of an average population growth of zero is likely to come into play within the next century and a half.

Theories regarding the limitations on population growth have come and gone over the years. In an essay published in 1798, the English clergyman Thomas Robert Malthus argued that human numbers always increase more rapidly than food supplies and that humans are condemned always to breed to the point of misery and the edge of starvation. The two centuries since his famous essay have not been kind to Malthus's theory. In that time human numbers have increased from fewer than one billion to today's 5.5 billion. In many parts of the world, food production has grown faster than the population, thanks to the opening of new lands, mechanization, fertilizers, pesticides, better water control, improved breeds of plants and animals, and better farmer know-how. Though many of today's bottom billion people live in misery on the edge of starvation, Malthus would be astonished at the relative well-being of most of a vastly enlarged population.

That Malthus's theory failed widely during the past two centuries does not prove that it will remain wrong for the next two. Some observers see a coming vindication of Malthus in the recent faltering of growth rates of per capita food production in some regions. Many scientists have adopted Malthus's general strategy of supposing that limiting factors constrain populations, and in fact the theory has gained some scientific support from agricultural experiments. For example, if the yield of a crop field is limited by the paucity of nitrogen in the soil, then when nitrogen is added, the yield jumps until it is again limited by the shortage of another essential nutrient, such as phosphorus. When phosphorus is added to the nitrogen supplement, yield jumps again until, say, the crop becomes water-limited. In this way, crop yields are limited by the most constraining factor in a whole series of limiting factors. By analogy, human populations may be limited by land (for farming, living, and recreation), food (from marine as well as terrestrial sources), fresh water, energy, or biological diversity (to provide ecosystem services such as decomposition of organic wastes, the regeneration of oxygen, and natural enemies for pest species).



Naturally, different limiting factors may interact. For example, high-intensity fertilization of farmlands may pollute water supplies while increasing food yields. Since World War II computers have made it practical to study how limiting factors interact, and in recent years complex computer models have become useful for clarifying what will happen if certain assumptions about the future turn out to be true. Some models assume, for example, that agricultural production is ultimately limited; others, that it is ultimately limitless. Because assumptions are inevitable and arguable, complex system models, like demographic projections, are controversial as a means of making predictions about the future.

One of the assumptions that may pop up in such models involves the idea of "carrying capacity," which refers to the number of individuals of a species that an environment can support for some period. Carrying capacity is a useful concept in ecology because the behavior and ecological relationships of nonhuman species rarely change very rapidly. The human application of the concept, however, raises many questions. What level of technology is assumed? (Hunter-gatherers usually have a lower carrying capacity than farmers.) What levels of physical and human capital are assumed? What social and political institutions provide human infrastructure? (Is the parental plot of land inherited by a single child, or is it divided among several children?) What regional and international trade is permitted or encouraged? (Hong Kong does not depend on its topsoil to support its more than 14,000 people per square mile.) What is the culture of the people; that is, what do they want from life? (It has been reported that when African slaves were first brought to Haiti, they were adequately nourished because they brought with them the African practice of consuming rodents, which provided a plentiful source of animal protein. Once the slaves learned from the French colonists to disdain the eating of rats and mice in favor of French white bread, the nutritional state of the slaves fell rapidly.)

Moreover, every estimate of the carrying capacity of humans assumes some time horizon. The population that can be supported for 20, 50, or 100 years may differ substantially from the population that is sustainable indefinitely at a given level of well-being.

The use of topsoil dramatizes the difference between temporary and indefinite sustainability. Suppose a newly opened crop field has 60 inches of topsoil over bedrock. Suppose the crop requires 18 inches of topsoil to keep its roots happy, and farming practice wastes an inch of topsoil with each annual crop. For the first 42 years (60 minus 18) the crop yield gives no indication that the wastage of topsoil has any adverse effect. In the forty-third year the roots confront bedrock and as a result yields worsen.

If the farmer could foresee that the crop's roots were approaching bedrock, he might have time to modify his erosive farming or breed a miraculous crop with roots insensitive to rock. If he cannot foresee the problem, he may not have time to take corrective action.

The question of what population can be supported indefinitely is very difficult to ask in a quantitatively useful way. In cartoon form, the argument goes like this:

Ecologist: When a natural resource is being consumed faster than it is being replenished, an asset is being depleted, to the potential harm of future generations.

Technologist: If new knowledge and technology can produce an equivalent or superior alternative, then future generations may be better off.

Taxpayer: Which depleting natural resources are substitutable by technology yet to be invented, and which are not? Will there be enough time to develop an alternative technology and, when it exists, to implement it without avoidable pain and suffering? (No answer from ecologist or technologist.)

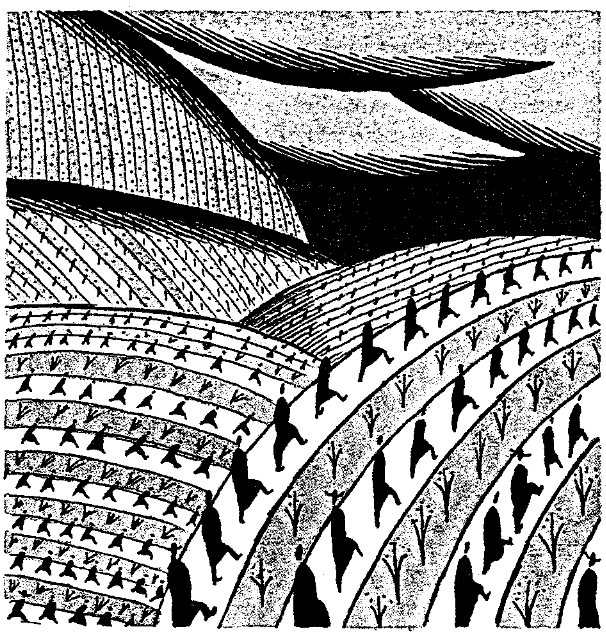
The human population that could be supported by Earth's capacity to produce food has been estimated many times, by many different means, and with many different results. In outline, if food is the limiting factor, the potentially supportable population equals the potentially arable land area times the yield per unit of area divided by the consumption per person. Easy enough. But of course, there is much uncertainty about the numerical values of arable area, yield, and consumption per capita. Estimates of agricultural carrying capacity have ranged from a low of 902 million in 1945 to a high of 147 billion in 1967. In 1965 Walter Schmitt of the University of California estimated that 30 billion people ultimately may lead "fairly free and enriched lives on this planet."

"At the moment," he wrote when the world population was estimated at 3 billion, "shortages in many areas of the world are caused not so much by lack of physical resources for food production but by economic and sociopolitical factors.... Socioeconomic restraints control food production before physical factors do because the potential of each major mode—agriculture, silviculture, aquaculture, and microbial culture—in terms of the production of organic matter, is greater than the requirements of 3 billion people, or even of the 30 billion projected for the future. Yet food shortages exist."

The World Hunger Program at Brown University estimates that, with present levels of food production and an equal distribution of food, the world could sustain either 5.5 billion vegetarians, 3.7 billion people who get 15 percent of their calories from animal products (as in much of South America), or 2.8 billion people who derive 25 percent of their calories from animal products (as in the wealthiest countries).

Globally, food supply is limited physically by the plant energy available for consumption by animals and decomposers. Ecologists call this quantity the net primary production (NPP). It is the total amount of solar energy annually converted into living matter, minus the amount of energy the plants themselves use for respiration. NPP is equivalent to about 225 billion metric tons of organic matter a year, an amount that contains enough calories to feed about 1,000 billion people. But that's only if every other consumer of green plants on Earth (including bacteria) were eliminated and at the same time people learned how to enjoy eating wood.

In 1986 Stanford biologists Peter Vitousek, Paul Ehrlich, and Anne Ehrlich and NASA ecologist Pamela Matson estimated that the 5 billion people then on Earth and their domestic animals directly consumed—that is, ate—about 3 percent



A TRIPLING OF THE HUMAN POPULATION WOULD COME AT THE EXCLUSION OF MOST OTHER SPECIES.

of NPP in the form of vegetables and other plants. But they also estimated that humans actually "co-opted" about 19 percent of NPP, a figure arrived at by adding to what was directly consumed the material indirectly consumed in such activities as clearing land or converting it for human use.

This aggregate figure of 19 percent, or roughly one-fifth, of NPP does not mean the planet can support about five times as many people as the 5 billion it had in 1986. That's because the 19 percent itself is an average of 31 percent of *terrestrial* NPP and 2 percent of *aquatic* NPP. Since people already consume nearly one-third of terrestrial NPP, Earth could support five times as many people only if we either exploited the oceans much more than at present or greatly increased the NPP of the land. The present terrestrial NPP and present human consumption patterns would permit little more than a tripling of the human population, perhaps to 16 billion people, to the practical exclusion of most other terrestrial species.

Several studies have estimated the populations that are supportable in the much nearer future. For example, in 1983 three international organizations estimated the population-supporting capacities of 117 countries, excluding China, in the year 2000. The estimates were based on both the level of farming technology employed and the physical potential of the land to produce food, taking into account such factors as the type of soil, the available moisture, and the length of the growing season. For all countries in the study, the estimated carrying capacity was 5.7 billion people with a low level of technology, 14.4 billion with an intermediate level, and 32.3 billion with a high level.

At a high level of farming technology, the study projected that by 2000 there would be 19 "critical" countries that could not supply the food their populations would need, even if all their arable land was devoted to growing food crops (rather than nonfood cash crops). At that point these unfortunate nations would have 48 million more people than they could feed. That's the good news. The bad news is that, at a *low* level of farming technology, there would be 64 critical countries, with a projected 503 million people more than they could feed. This number is twice the present population of the United States and nearly half the total population projected for those critical countries in 2000.

And even this is inevitably too simplistic, and possibly too rosy, an assessment. In 1987 Yale economist T. N. Srinivasan commented on this and similar studies: "There is virtually no economic analysis underlying these projections. . . . In particular, the investments in land, capital equipment, livestock, technical skills, and knowledge needed to attain the potential output will not be forthcoming unless the returns are adequate. . . . Furthermore, fundamental ideas of comparative advantage and gain from trade between regions within a country and between countries are absent in the analysis."

In short, there are large uncertainties in the estimates of global agricultural carrying capacities. Still, agricultural and ecological calculations confirm the demographers' expectations that human population growth rates must drop near or below zero, at most within a century or so. The nondemographic calculations are silent on whether growth will stop because of fewer births or more deaths.

Not everyone agrees with these conclusions, especially in political circles. When the U.S. Congress declared the week of October 20, 1991, World Population Week, President Bush issued a proclamation that stated: "Population growth in itself is a neutral phenomenon. . . . Every human being represents hands to work, and not just another mouth to feed." This statement voices an alluring partial truth. But if that partial truth is all they taught George Bush at Yale, he should have gone to Harvard, or even Princeton.

True, carrying capacity can be extended—sometimes immensely—through technological, social, and economic change. If you can't grow enough food, make computer chips and trade for food. True, every additional human being is one more producer (at least potentially, given good health and enough education) as well as one more consumer (inevitably). But the productivity of each additional pair of hands depends on other factors of production that are not currently in infinite supply and that are, sooner or later, subject to diminishing returns: land to work or live on, air, fresh water, geologic deposits, and others. When all other factors in human productivity are available in excess, an additional human being may be not merely neutral but a great asset. Frontier communities rightly celebrate the birth of children. When other factors in human productivity are already taxed to the point of severely diminishing returns, one more human being may represent one more perennially empty stomach, one more soul stunted before it can realize its share of the glory of being human.

George Bush may not see them, but the children of the poorest billion exist in rapidly growing numbers in many parts of the world. The American poet Vachel Lindsay described them in 1912:

> Not that they starve, but starve so
> dreamlessly,
> Not that they sow, but that they
> seldom reap,
> Not that they serve, but have no gods
> to serve,
> Not that they die but that they die like
> sheep.

Crowded House

The numbers tell a dramatic story: It took from the beginning of time to 1950 for Earth to acquire its first 2.5 billion people; begetting its second 2.5 billion took less than 40 years. At current growth rates Earth's population will double again between now and 2025 and will double nearly 7 times between today and 2150.

Fortunately, some statesmen see further than President Bush. Last March, Michael Heseltine, then the British Secretary of State for the Environment, stated, "As this last decade of the twentieth century develops, the environment and the issues of sustainable development will come to dominate the international agenda." And, quoting from a joint U.S.-British report, he said, "If current predictions of population growth prove accurate, and patterns of human activity on the planet remain unchanged, science and technology may not be able to prevent either irreversible degradation of the environment or continued poverty for much of the world."

The continuing uncertainty about how many people Earth can sustain for the indefinite future brings to mind the story of a little boy who wanted to know the sum of one plus one. First he asked a physicist, who said, "If one is matter, and the other is antimatter, then the answer is zero. But if one is a critical mass of uranium and the other is a critical mass of uranium, then that's an explosive question." Unenlightened, the boy asked a biologist. She said, "Are we talking bacteria, mice, or whales? And for how long?" In desperation, the boy hired an accountant, who peered closely at him and said, "Hmmm. One plus one? Tell me, how much do you want it to be?"

There were more dimensions to the question than the little boy had considered. Estimating the human population that Earth can sustain is difficult because there are more dimensions to the problem than demographic arithmetic.

To see the major dimensions of this problem, imagine a tetrahedron, a pyramid with a triangular base and three triangular sides. At the top is population, which includes size and growth rate, age structure (How many young people need schooling? How many old people need pensions?), health (Are people free of parasites and malnutrition? Are they in good mental health?), distribution (Are people in cities or rural areas?), and migration (Are people moving from poor countries?). At the three corners of the base, place environment, economy, and culture. The environment includes soil, fresh and salt water, air, all nonhuman living creatures, and Earth's stage of mountains, rivers, plains, oceans, volcanoes, earthquakes, meteorites, and solar flares. The economy includes all the human and material arrangements for the production and exchange of goods and services to satisfy people's wants and needs. Culture includes values (What do people want?), technology (What knowledge and artifacts—machines—do people inherit?), and social institutions (How do people interact in satisfying their wants?).

Obviously the boundaries between these four vertices are fuzzy. And each corner has its academic devotees. Demographers worship at the temple of population; ecologists are the priests of the environment; economists preside over the economy; and anthropologists and other social scientists claim to interpret culture. But as the pyramidal arrangement graphically emphasizes, each element interacts with the others. Nathan Keyfitz, a demographer who heads the population program at the International Institute for Applied Systems Analysis in Laxenburg, Austria, has attempted to show this linkage, bringing together three of the pyramid's four corners: population, economics, and the environment.

"The conclusion of most academic economists," he wrote, "... is that population growth does not greatly handicap economic development. Without opposing that result, one has to point out that the argument does not take into account the impact of humans on the biosphere, which is equivalent to saying that the conclusion applies in an infinite world. It is the finiteness of the ecosphere in all its dimensions to which biologists draw attention." Keyfitz also recognized the crucial role of culture, both in the population at large and among academics. "Thus two tribes, similar in physical environment and social structure, can differ in fertility and other practices because they interpret their situations differently. ... The !Kung and a hill tribe in Pakistan, economists and biologists, look at population differently. Some put one set of variables into their models, others use other variables. Scholars, as well as the people they study, have different ways of interpreting the world!"

To make more credible estimates of Earth's human carrying capacity, then, and of the path by which the human population growth rate will approach zero, scientists must learn more of the interactions of population, the environment, economy, and culture. The problem has at least those dimensions—and that's if we consider only one such abstract pyramid. In fact, the Earth is covered with thousands or millions of such pyramids. Populations, environments, economies, and cultures vary from place to place. Each local pyramid interacts with many others, often over great distances. The dust of the Sahara brings red sunsets to Miami; tremors on the Tokyo stock exchange shake Wall Street.

The moral aspects of population questions did not escape Keyfitz, either. "Every couple has a right to as few or as many children as it wishes. That sounds fair until one meets the parallel assertion that every child has the right to adequate nutrition. Suppose the world is made in such a way that these two rights cannot both exist once density goes above a certain point? Such incompatibilities of principles are not usually acknowledged in official documents."

Nearly two decades ago the ethicist Daniel Callahan saw the same problem: "Excessive population growth raises ethical questions because it threatens existing or desired human values and ideas of what is good. In addition, all or some of the possible solutions to the problem have the potential for creating difficult ethical dilemmas. The decision to act or not to act in the face of the threats is an ethical decision."

We all face the accountant's question to the little boy: How much do you want one plus one to be? Better knowledge of the pyramid of population, environment, economy, and culture will at least help us understand our options, their consequences, and the choices being made by our fellow human beings. D

POPULATION GROWTH RATES MUST DROP NEAR OR BELOW ZERO, AT MOST WITHIN A CENTURY OR SO.