HUMAN DIMENSIONS
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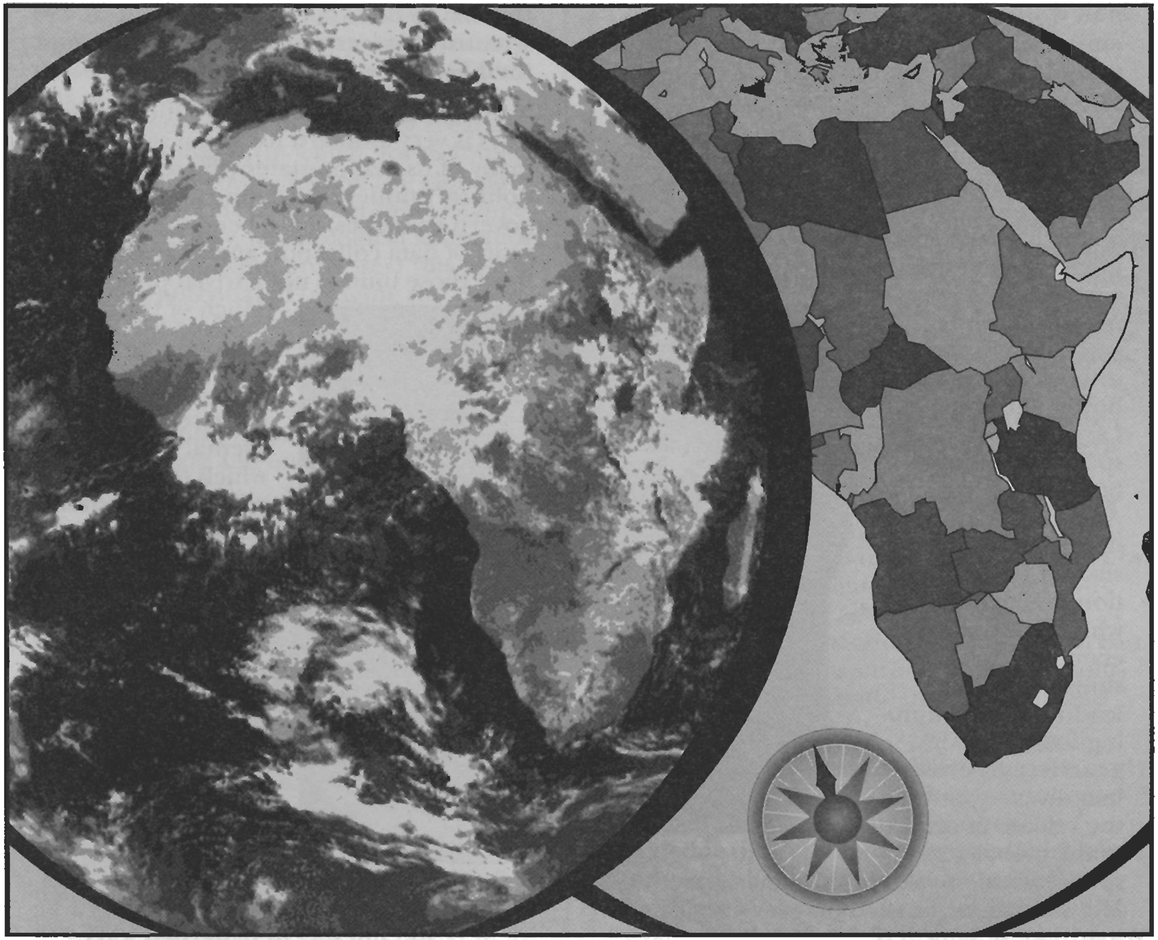


Special Feature

Graphical Representations of World Population Growth

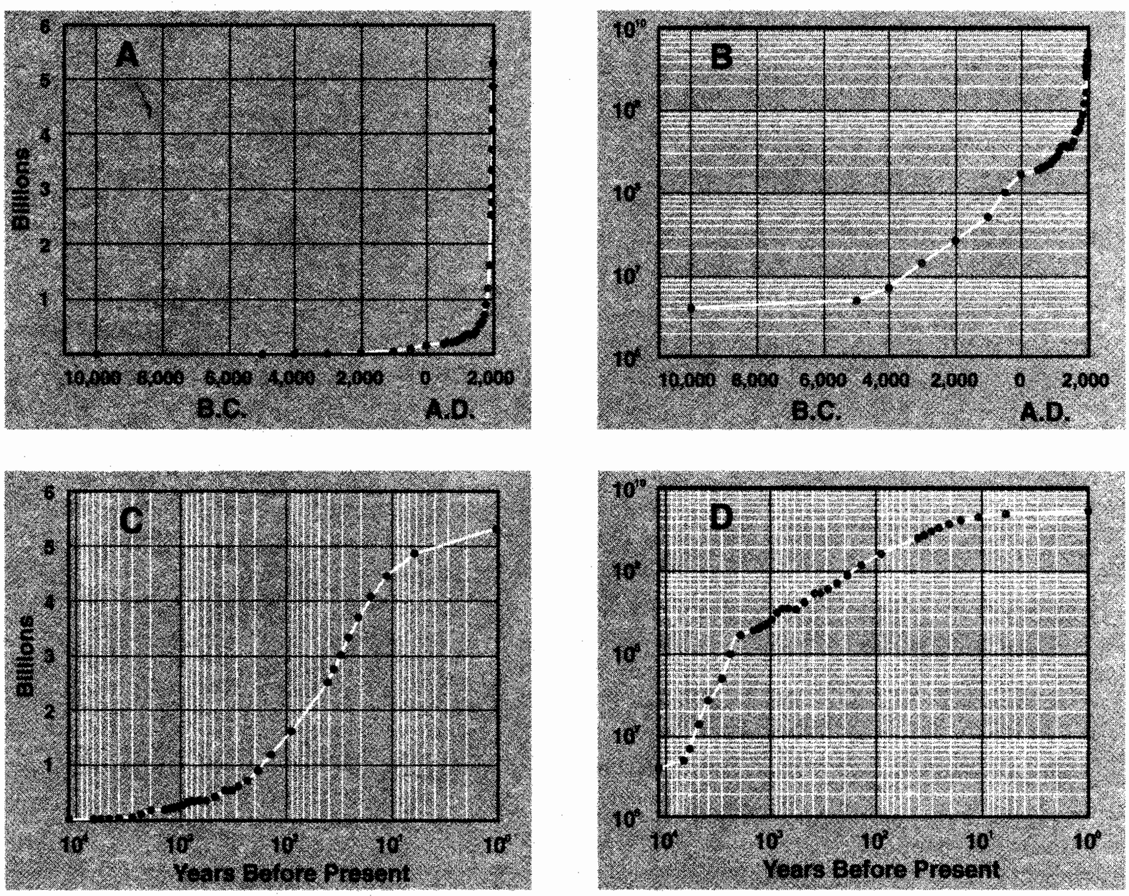
Alternative graphical representations of world population growth show how plotting the same data on different scales emphasizes different aspects of the data, which can lead to different interpretations of the past and projections for the future. Inspection of the four curves in Figure 1, each of which plots the identical world population data [1, 2] but with different scales, indicates the dramatic difference that scaling can have on the shape of the plotted data.

Panel A of Figure 1 shows world population data plotted with both axes linear, the most common way of plotting time-series data sets. Human population history appears as a single process culminating in exponential growth. The elbow is about 1800. This view emphasizes the uniqueness and explosiveness of the recent era, and implies collapse.

Alternatively, world population might soon become infinite. In fact, Von Foerster *et al.* [3] extrapolated the model implicit in the linear view and predicted in *Science* in 1960 that human population would become infinite on November 13, 2026. Of course, Von Foerster wanted to show the limits of the exponential growth model.

The linear scale hides the early growth of human numbers. In Panel A, the low numbers are compressed, and changes are almost indistinguishable during the first 8,000 years. Yet, world population increased by more than three orders of magnitude over the past 10,000 years, with steep rates of increase not limited to the recent period. Plotting the population data on a logarithmic scale reveals

Figure 1.



more effectively both the numbers involved in early growth and the varying rate of change, though it compresses the later differences between large numbers. Data on rapidly growing non-human populations, such as bacteria and flies, are commonly plotted in log-linear form. Panel B of Figure 1, which shows the human data plotted in this way, suggests the existence of two pulses of exponential growth, one "ancient" growth pulse from about 5,000 B.C. to the start of the Christian era and the steeper, modern pulse. Each encompasses about 1.5 orders of magnitude. Were this highly simplified pattern to repeat itself, one might expect a third pulse of growth raising world population to about 150 billion in the year 3000.

Advances in technology and social organization have already allowed human societies to increase the "carrying capacity" of the earth by billions. Some argue that the pace of innovation, mainly due to the success of science and engineering, has rapidly increased. Thus, change in a given time interval today is much greater than in the same interval earlier. By plotting the world population data with a logarithmic time (x) axis, the space on the graph shows the data from 1 to 10 years ago, 10 to 100 years ago, 100 to 1,000 years ago, and 1,000 to 10,000 years ago as equivalent intervals. In this "time-equivalent view," with population represented linearly (Panel C), growth appears as one neat S-shaped process. The point of inflection (moment of most rapid growth in this "time equivalent view") is around 1940, and the scaled rate of growth is decreasing.[1] Here it appears that human population will gradually increase and then stabilize, or perhaps oscillate, as S-shaped growth processes often do as saturation is approached.

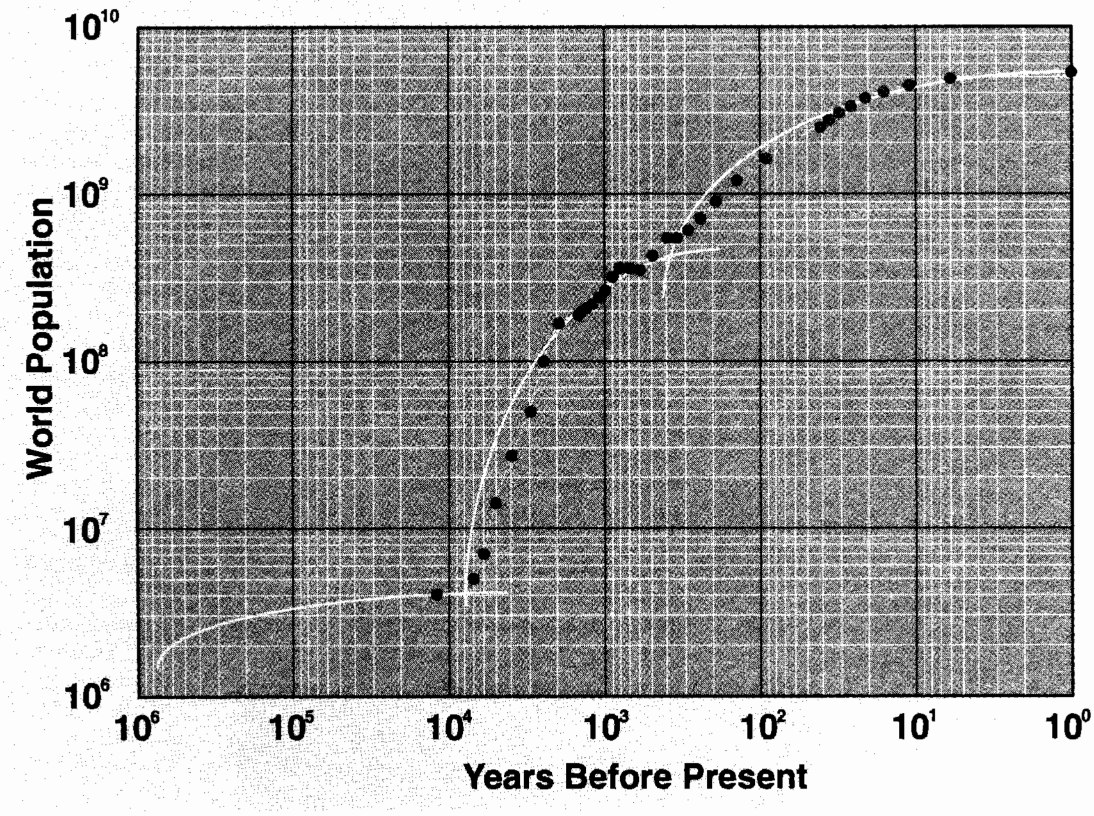
Panel D completes our 2 x 2 matrix, plotting the world population data with both x and y axes logarithmic. In 1960, the same year as Von Foerster's linear rocket, Deevey [4] schematically ascribed human population growth to three technological "revolutions" on the log-log scale. This view leads to the conclusion that human population is stabilizing, completely opposite to the conclusion drawn from Panel A.

In Figure 2 we fit the three Deevey revolutions to an extended representation of the data in Figure 1D. The first revolution, beginning some 10^6 years before present (YBP), Deevey labeled the "tool-making pulse." The invention and diffusion of stone and copper tools advantaged humans over other large mammals and enabled human population to rise to about 4 million people. The second growth pulse, mainly due to agricultural techniques, occurred from approximately 7,000 YBP to 300 YBP. In the Deevey optics, farming allowed the carrying capacity of the earth to increase from approximately 4 to 400 million people, which was fully two orders of magnitude. The third, "industrial" pulse began 300 YBP and associates with a further order of magnitude increase in population, now over 5 billion. We might speculate on a fourth "information" pulse starting now that would enable another order-of-magnitude rise.

It is remarkable how four views of the same data yield different interpretations. Depending on the perspective, human population history encompasses one, two, or three great pulses. In two views (A and B), we now have a population explosion and in two (C and D) a flattening. Similarly, A and B make the present era appear decisive, while the others suggest that major demographic transitions took place decades or centuries ago. However, B and D also suggest possible near-term discontinuities, to be followed by renewed growth. Extrapolation of "dynamics as usual" leads to estimates of future population ranging from a moderate increase, to an order of magnitude increase, to infinity (and collapse). At the least, examining the same data in several ways helps reveal our biases and mental models and may increase our sophistication in making and using predictions of world population. ■

[1] The growth rate of a population is defined as the derivative of the population at time t, dP/dt, graphically represented as the slope of the line tangent to the curve plotted with both axes linear (curve A). Thus, a straight line on curve A would indicate a region with a constant growth rate. However, curves B, C, and D are plotted on non-linear axes, and thus the slope of the curves does not equal the growth rate as defined. Instead, the slopes of curves B, C, and D can be thought of as "scaled" growth rates that are functions of the time or population. For example, a straight line or constant "scaled" growth on curve B would indicate pure exponential growth on curve A. Mathematically, dLog(P)/dt = "scaled" growth rate = 1/P*dp/t = constant, which yields P(t) = exp(c*t). The other "scaled" growth rates can be found in a similar fashion.

Figure 2.



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References

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