9

Exponential Growth of Populations

Historians took a long time to appreciate the importance of biological factors in human history. As the French naturalist Jean Henri Fabre (1823–1915) said: "History celebrates the battlefields whereon we meet our death, but scorns to speak of the plowed fields whereby we thrive. It knows the names of the King's bastards, but cannot tell us the origin of wheat." No doubt Fabre's criticism helped in turning the tide against the old-fashioned sort of history. History books now being written are more inclusive, more interesting. Some of them even mention population.

A century before Fabre was born, even the fact of population growth was denied by some otherwise well-informed scholars. In 1721 the Baron de Montesquieu asked, in all sincerity, "How does it happen that the world is so thinly peopled in comparison with what it once was?"[1] Until the nineteenth century the taking of censuses was a sporadic activity; most of the world, most of the time, lived uncensused. Primitive travel and slow communication made the counting of population over large areas difficult—and perhaps pointless. Without censuses or sampling, general impressions had to serve. When speaking of "the world" as "it once was," the baron, an educated European, no doubt had in mind the last days of the Roman Empire.

There is much uncertainty about the size of world population in the olden days, but the following estimates are probably not far off.[2] Over a period of about thirteen hundred years, ending in Montesquieu's time, the population of the world increased from some 190 million to about 610 million. This was more than a threefold increase, but an intelligent European could easily be unaware of both the direction and the extent of the change—for several reasons.

To begin with, most of the increase in population took place outside Europe. Despite reports like Marco Polo's, to European eyes Europe *was* the world. Viewing the sparsely inhabited ruins of Rome, eighteenth-century Europeans deduced a decrease in world population.

Awareness of long-term growth was made more difficult by erratic (but normal) fluctuations in populations. It was quite common for a region to lose a percent or two of its population during a single year because of disease. A 2 percent loss would be 20 times the average annual gain of 0.1 percent. During the Black Plague in the middle of the fourteenth century, Europe lost 25 percent of its population in just two years. Such a two-year loss was 125 times the average long-term gain.

Two centuries after the Black Plague, Europe was losing people by emigration to the New World. And of course, at all times wars took their toll of particular

regions, while migration within Europe itself redistributed considerable numbers of people. Considering all the crosscurrents of history it would have taken unusual ability to detect any long-term population growth. Fluctuations were obvious, trends imperceptible: no wonder few historians were aware of the long-term growth trend. As was pointed out in Chapter 3, the oldest paradigms of history are the golden age and the endless cycle. Against this background Malthus's emphasis on the reality and *ordinariness* of population increase struck many as astonishing. The gist of his argument is reprinted in Box 9-1. Since the paradigm of progress was developing rapidly in his day, the public soon equated growth with progress.

The new orientation speedily won support among the ruling class of England, but as late as 1820 William Godwin was still denying that growth could be a normal

Box 9-1. Malthus: The Core Mathematical Argument.

In the United States of America, where the means of subsistence have been more than ample, the manners of the people more pure, and consequently the checks to early marriages fewer than in any of the modern states of Europe, the population has been found to double itself in twenty-five years.

This ratio of increase, though short of the utmost power of population, yet as the result of actual experience, we will take as our rule, and say, that population, when unchecked, goes on doubling itself every twenty-five years or increases in a geometrical ratio. . . .

Taking the population of the world at any number, a thousand millions, for instance, the human species would increase in the ratio of—1, 2, 4, 8, 16, 128, 256, 512, &c. and subsistence as—1, 2, 3, 4, 5, 6, 7, 8, 9, 10, &c. In two centuries and a quarter, the population would be to the means of subsistence as 512 to 10: in three centuries as 4096 to 13, and in two thousand years the difference would be almost incalculable, though the produce in that time would have increased to an immense extent. . . .

The constant effort towards population, which is found to act even in the most vicious societies, increases the number of people before the means of subsistence are increased. The food therefore which before supported seven millions must now be dividied among seven millions and a half or eight millions. . . . During this season of distress, the discouragement to marriage, and the difficulty of rearing a family are so great that population is at a stand. In the mean time the cheapness of labour, the plenty of labourers, and the necessity of an increased industry amongst them, encourage cultivators to employ more labour upon their land, to turn up fresh soil, and to manure and improve more completely what is already in tillage, till ultimately the means of subsistence become in the same proportion to the population as at the period from which we set out. The situation of the labourer being then again tolerably comfortable, the restraints to population are in some degree loosened, and the same retrograde and progressive movements with respect to happiness are repeated.

This sort of oscillation will not be remarked by superficial observors, and it may be difficult even for the most penetrating mind to calculate its periods. . . .

Many reasons occur why this oscillation has been less obvious, and less decidedly confirmed by experience, than might naturally be expected.

One principal reason is that the histories of mankind that we possess are histories only of the higher classes. We have but few accounts that can be depended upon of the manners and customs of that part of mankind, where these retrograde and progressive movements chiefly take place.

An Essay on the Principle of Population, (chap. 2), 1798.

characteristic of populations: "We have no authentic documents to prove any increase in the numbers of mankind."[3] If one italicizes the words *documents* and *prove,* Godwin's assertion has the sort of surface plausibility that sometimes wins cases in a court of law. But by 1820 most thoughtful people felt that Malthus had made a good case for the *naturalness* of the *drive* toward population growth. For a biologist, of course, it is difficult, if not impossible, to imagine a species of animal that lacks this drive.

Though Malthus did not use the word "exponential," it is clear from the passage in Box 9-1 that this pioneer economist had a clear conception of exponential growth and its important consequences for human populations.[4] Was he the first to be so impressed? Not quite: before him Benjamin Franklin had a glimpse of the phenomenon, but he referred to the matter briefly and then dropped it. The excerpt given in Box 9-2 reveals Franklin's position.

Note the difference in thrust of the statements by Franklin and Malthus. Malthus was trying to get people to worry about the consequences of exponential growth. In contrast, Franklin was saying "Not to worry": he wanted to relieve the English of anxiety that emigration to the colonies might depopulate their homeland. Reproduction would soon fill the places left vacant by out-migration. Franklin's essay was consistently upbeat about the exuberance of reproduction; it was the sort of message one might expect from a chamber of commerce—a quintessentially American institution not invented until long after Franklin's time.

So who should get the credit for understanding the exponential growth of human populations, Franklin or Malthus? The philosopher Alfred North Whitehead has written: "To come very near to a true theory, and to grasp its precise appli-

Box 9-2. Benjamin Franklin on Population.

There is in short, no Bound to the prolific Nature of Plants or Animals, but what is made by their crowding and interfering with each others Means of Subsistence. Was the Face of the Earth vacant of other Plants, it might be gradually sowed and overspread with one Kind only; as, for Instance, with Fennel; and were it empty of other Inhabitants, it might in a few Ages be replenish'd from one Nation only; as, for Instance, with Englishmen. Thus there are suppos'd to be now upwards of One Million English Souls in North-America, (tho' 'tis thought scarce 80,000 have been brought over Sea) and yet perhaps there is not one the fewer in Britain, but rather many more, on Account of the Employment the Colonies afford to Manufacturers at Home. This Million doubling, suppose but once in 25 Years, will in another Century be more than the People of England, and the greatest Number of Englishmen will be on this Side the Water. What an Accession of Power to the British Empire by Sea as well as Land! What Increase of Trade and Navigation! What Numbers of Ships and Seamen! . . . How careful should [England] be to secure Room enough, since on the Room depends so much the Increase of her People?

In fine, A Nation well regulated is like a Polypus; take away a Limb, its Place is soon supply'd; cut it in two, and each deficient Part shall speedily grow out of the Part remaining. Thus if you have Room and Subsistence enough, as you may by dividing, make ten Polypes out of one, you may of one make ten Nations, equally populous and powerful; or rather, increase a Nation ten fold in Numbers and Strength.

"Observations Concerning the Increase of Mankind," 1755.

cation, are two very different things, as the history of science teaches us. Everything of importance has been said before by somebody who did not discover it."[5] Franklin came close to stating a general population theory, but he did not quite make it. All things considered, there is no need to substitute "Franklinian" for "Malthusian" in the history of population thought,

Fertility, Like Usury, Needs to Be Curbed

To recapitulate the major point of the preceding chapter, *money is sterile.* This bald statement depends on two assumptions. First, by "money" we mean something that constitutes a demand on gold or some specified material substance found on or in the earth. (Real estate on one of of Sirius's planets is out of the picture.) Second, by "sterile" we mean "not invariably fertile," that is, not indefinitely interest-bearing. The fertility of usury is bearable provided periods of compound interest are interspersed with corrective actions, such as the financial disasters discussed in Chapter 8.

The mathematics of biological reproduction is logically identical with the mathematics of usury. Money earns interest, animals have babies. In the living world different "accounts" (species) earn "interest" (babies) at different rates. The preferred form of the mathematical growth equation[6] during any period in which reproduction encounters no environmental resistance is this:

$$y = ke^{bt}$$

where y is the size of the population at time t, e is the base of natural logarithms, k is a scaling constant, and b stands for the "biotic potential" of the species. This information may be more than the reader hankers after, but it is given to arm him against the one-upmanship that mathematicians are inclined to practice in their dealings with the unanointed public. The equation for biological reproduction is the same as the one for money-at-interest: one merely has to redefine the symbols. In both cases, so long as b ("biotic potential," in biology) is greater than zero, by however small an amount, the potential of exhausting earthly resources must be met by countervailing forces. For usury, the corrective forces are the various financial disasters; for biology, the many modes of death.

Because usury can be continued indefinitely "on paper," the necessity of countervailing forces in economics escapes the attention of many people. The essential long-term instability of exponential growth (of debt) is not obvious. But where biology is concerned observors cannot long remain blind to the need for countervailing forces. Animal populations make withdrawals from the environment every day, every minute. The demand for "subsistence" (to use Malthus's term) never goes away.

The Rate of Growth—Does it Matter?

Even the most casual observer is impressed by the fecundity of living organisms. Unconsciously using our own species as a standard we are astounded when we learn that many female fish produce eggs by the hundred thousand, while a female oyster

may release 50 million eggs at a time. Yet the world is not being taken over by either fish or oysters. There is little correlation between fecundity and ubiquity. Maybe fecundity doesn't matter?

What matters most is the fraction of fertilized eggs that survive to produce fecund adults. Demographers (in contradistinction to standard dictionaries) distinguish between "fecundity" and "fertility." *Fecundity* is defined as a measure of the *potential* reproductive power of a species; *fertility* is a measure of the *actual* increase from one generation to another. Since accomplishment is more important than promise, fertility is the more important of the two measures in accounting for the success of a species. Oysters are frightfully fecund, but their fertility is nothing to write home about.

Intent on convincing the public that human reproduction threatened humanity, Malthus took some pains to determine the maximum fertility of our species under the most favorable conditions. He settled on twenty-five years as the time required to double a population, obtaining that figure from Benjamin Franklin. Not only his critics, but Malthus himself spent an unpardonable amount of time trying to refine this fertility figure. The first edition of Malthus's *Essay* shows a fine grasp of essentials. Subsequent editions, three times as large, are overloaded with inconclusive data. Malthus seemed to think that the particular value for the human biotic potential (a term unknown to him) is something that needs to be determined with precision. He was wrong: it isn't.

Charles Darwin, a quarter of a century after Malthus's death, penetrated to the heart of the population problem when he showed that it matters very little how great the biotic potential is. He said: "There is no exception to the rule that every organic being naturally increases at *so high a rate,* that, if not destroyed, the earth would soon be covered by the progeny of a single pair."[7] Italics have been added to focus attention on the key point. The phrase "so high a rate" could easily mislead incautious readers to assume that *only* very high rates of fertility could produce this overwhelming result, but (without correcting his rhetoric) Darwin immediately set his readers straight with a telling example.

> The elephant is reckoned the slowest breeder of all known animals, and I have taken some pains to estimate its probable minimum rate of natural increase; it will be safest to assume that it begins breeding when thirty years old, and goes on breeding till ninety years old, bringing forth six young in the interval, and surviving till one hundred years old; if this be so, after a period of from 740 to 750 years there would be nearly nineteen million elephants alive descended from the first pair.

A little calculation shows that the doubling time for Darwin's elephants is thirty-five years, which corresponds to an interest rate of 2 percent per year. At that rate, would the earth "soon be covered by the progeny of a single pair" of elephants? "Soon" is undefined, so let us carry the calculations farther.

Assuming that the average elephant occupies an area of 12 square meters, the 148.847×10^6 square kilometers of land area could accommodate 12×10^{12} elephants. How long would it take the elephant population to reach that figure, starting with a single pair and increasing by 2 percent per year? Just 1,486 years—a mere three-quarters of the Christian era. Darwin's point is solidly established.

Habituated to interest rates on borrowed money ranging from 5 percent (on savings) to 19 percent (on credit card debits), many people find it hard to take a

mere 2 percent rate seriously. But over time—and biological organisms have all the time in the world—any and every positive rate of interest must be taken seriously. In recognizing this fact Darwin showed his genius for seeing the significance of small causes operating over long periods of time.

To bring home the relative unimportance of the particular value of a species' fertility we can create a single curve that represents the growth rate of populations of *all* species (Figure 9-1). We do this by presenting a wide choice of scales on the horizontal dimension, ranging from minutes for common bacteria to years for elephants.

Note that this curve, like the curve for usurious increase, potentially heads off "toward infinity." As concerns the reproduction of biological species, *any rate even minutely greater than zero* is "so high a rate" of increase that, if some of the progeny were not destroyed, "the earth would soon be covered by the progeny of a single pair."

As for the human species, we now know that the doubling time of 25 years assumed by Franklin and Malthus underestimated the full horror of the human potential. Shortly after the end of World War II, in the name of national defense, the U.S. military decided it would have to use Bikini Island as a testing ground for

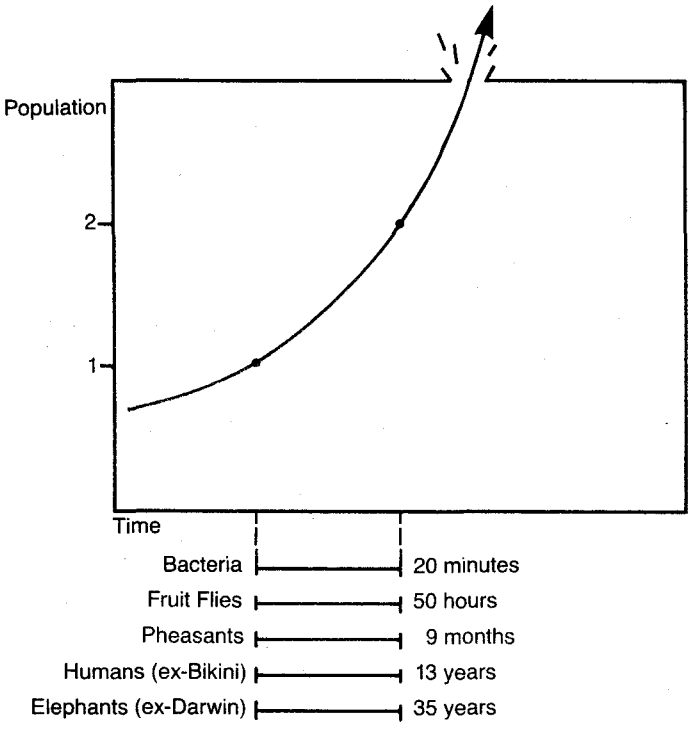

Figure 9-1. The potential population growth of any living species, headed for infinity in the absence of countervailing forces. By a suitable adjustment of the scale of the abscissa, "One curve fits all." The numerals on the vertical axis stand for hundreds, millions or whatever unit is convenient for a particular population.

nuclear explosions. Anticipating persistent radioactivity from the fallout of the explosions, our military evacuated the native population to other islands in the South Pacific. Our government then took on the responsibility of keeping the reluctant refugees alive and in good health in their new homes.[8]

With good health, and little to do but live and reproduce, this population grew from 161 in 1946 to more than 1,260 by 1985. The annual rate of increase was 5.4 percent. The doubling time, the shortest ever recorded for a human population, was thirteen years (which number is reflected in Figure 9-1). Today's Bikinians, living on charity, have lost their old skills. Had the experiment never been performed, the Bikinians would have remained self-supporting on Bikini, and their population might have been about 161 still. But the experiment *was* performed, and their numbers have swelled nearly eightfold. Unless the present policy is abandoned, in another 39 years the population will have swelled to more than 10,000; and in the next 39 years it should reach 80,000.

(Question for moralists: If the United States had massacred the Bikinians, the crime would have been called "genocide." America, by taking total responsibility for the refugees, has totally released Bikinians from personal responsibility. What name will the world give to the crime we *did* commit?)

In a finite world the destructive potential of usury is kept under control by such unwelcome events as inflation, bank failures, repudiation of debts, and the downfall of nations. *How, then, if humanity is to take control of its destiny, is the destructive potential of biological reproduction to be circumvented?* There, in a nutshell, is the "population problem."

When we try to deal rationally with this problem, our thinking is disrupted by primordial assumptions adopted long before men and women understood the nature and consequences of exponential growth. The biblical commandment, "Be fruitful and multiply," needs to be reexamined.[9]

Is Any Positive Rate of Growth "Small"?

Many influential writers deny that there is a human population problem. Others grudgingly admit that a problem may develop *someday,* but they judge this future to be too remote to worry about. Their denials may be punctuated by coughs caused by urban smog, curses at gridlocked automobile traffic, or anguished complaints about the inflating prices of real estate. That these discomforts have any connection with population growth seems not to occur to population optimists.

Psychological denial is a standard defense against unwelcome conclusions. In the present situation there are also understandable intellectual reasons for the denials. First, it is always difficult to detect a trend in the presence of great variation. During most of human history, the long-term trend toward global population increase was masked by much greater short-term fluctuations in local populations.

Consider a medieval village of 100 souls with an *average* annual increase of 0.1 percent over a period of 70 years. Figure 9-2 shows the population graph of our hypothetical village. The end point is 7 percent higher than the beginning point; but, in the light of the considerable yearly fluctuations, who would be so bold as to say that the population was growing? Today the population growth rate is many

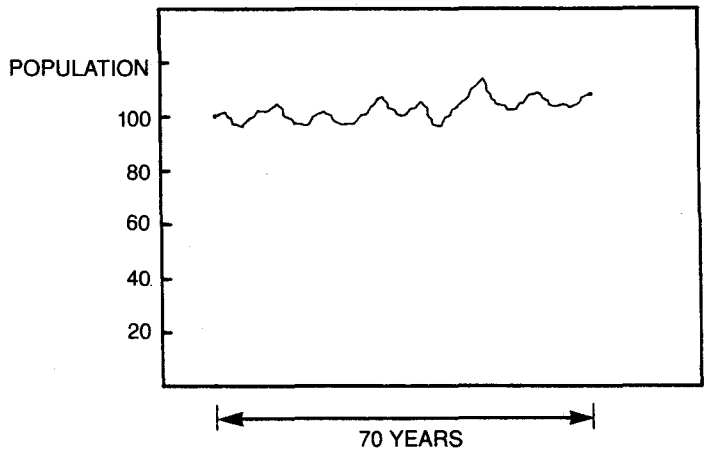

Figure 9-2. Hypothetical population history of a village in ancient, medieval, or Renaissance times, showing that year-to-year variations were more obvious than a lifetime increase of 7 percent.

times what it was in medieval days, and the yearly fluctuations less. An economics bias leads most people to dismiss a population growth rate of 1 percent as "miniscule."[10]

To a politician, all positive growth rates are good, since they supply him with more constituents. (Advertisers and merchants agree.) In 1987 a Canadian government agency issued a report that predicted the future population of Canada under various assumptions of fertility and immigration rates.[11] At no point did the prognosticators so much as mention the possibility that the aggregate population growth rate might ever be less than 1 percent: such a minimum rate was, for them, quite literally *unthinkable.*

For another example of unconscious and harmful bias, consider the implications of the following quotation from a literary periodical: "In recent years the alarmist view [of population growth] has been in retreat, in part because . . . instead of growing rapidly the global population growth rate fell back from 2 percent to 1.7 percent."[12] First, a factual correction is in order: population "alarmists" have *not* been saying that the growth rate itself would continue to grow rapidly, but rather that the present growth rate is (over time) insupportable. Even a much smaller growth rate would soon become insupportable.

Secondly, a decline in the growth rate from 2 percent to 1.7 percent is no reason to plan a celebration. For perspective, compare both rates with the average rate over the past million years of the human species' existence. Assuming that our species began with a single pair (Adam and Eve?) a million years ago, the average growth rate of world population has been just 0.015 percent per year (with a doubling time of 4,667 years). If we define this as normal, the recent fall in population growth rate has been from a rate 133 times normal to a rate 113 times normal. Admittedly, that's better than an increase in growth rate; but if there are good reasons for bringing population growth to an end, we are a long way from being out of danger.

Anyone who lectures to the general public on population frequently encounters comments like this: "I read in the paper that America's population has stopped growing. In fact we've already reached ZPG—zero population growth. So why worry?"

What such a questioner read in the paper was probably something like this: "America's growth *rate* has fallen; the rate is still declining. Our population is growing at a rate no greater than 0.7 percent per year; and the rate is expected to fall further." But a growth rate of 0.7 percent per year operating on a population of 250 million produces an increase of 1,750,000 per year. That's a long way from ZPG! If we ignore immigration, that's how fast the United States is growing as we approach the end of the twentieth century. (Immigration, inaccurately measured, may double the rate.)

The word *rate* apparently has trouble catching the eye of the average newspaper reader. Told that the "rate" of population growth is falling, his mind is all too likely to record "the population is now decreasing." Many journalists make the same mistake.

As for the world population, its growth *rate* has slowly declined from a bit over 2.0 percent per year in the early 1960s to 1.7 percent in the late 1980s. But a rate of increase of 1.7 percent per year operating on a base of 5 billion produces a yearly increase of 85 million—equal to the combined populations of the United Kingdom and Scandinavia.[13] For how long can population increase? That is one of the questions Malthus thought he had answered. But he had not, as we shall see in the next chapter.

Population Disappears from Economics

If ever someone constructs a carefully documented graph of the public attitude toward population after Malthus, it surely will look like a roller-coaster ride. Malthus, while not lacking opposition, was strongly supported during his lifetime by the power structure of Great Britain . (He died in 1834, three years before Victoria became queen.) He became a respected economist in his time, and was still highly praised by England's John Maynard Keynes a century later. But the position of population theory among the bulk of economists changed over that period. As the economist George Stigler noted: "In 1830, no general work in economics would omit a discussion of population, and in 1930, hardly any general work said anything about population."[14] The reasons for this puzzling change deserve to be investigated by historians of ideas.

No doubt many threads are involved in the tapestry of this history. One of the threads is the attitude of scholars toward rates that have small exponents. Scholars in economics and ecology differ sharply in the importance they assign to processes with small exponents. Economists tend to ignore such processes, no doubt because the rates economists professionally deal with can themselves change so fast. Ecologists, inspired by Darwin, take even the smallest of rates seriously. Working with nonhuman populations, ecologists tend to see rates as stable. Economists tend to see human rates as changeable; they know that speaking out sometimes changes

them. (Economics is an information-mutable science.) Ecologists see the exponential growth curve (whether of money or organisms) as headed "out of this world." Economists merely see that the curve is headed up. And they seldom worry about the state of the world more than five years from now.

Ecology Enters History

Economists deserve no special blame, however, for their neglect of population principles: they have merely breathed in what Germans call the *Zeitgeist*—the spirit of the times (which, of course, they helped create!). Historians have breathed the same air. Well into the twentieth century some of the most fashionable histories diverged little from the style criticized by Fabre. The most ambitious history produced by a single individual in the present century was A. J. Toynbee's *A Study of History,* which was published in twelve massively documented volumes during the years 1934–1961. It aimed to be all-inclusive, but Aldous Huxley, the author of the novel *Brave New World,* pointed out the omissions and failings listed in Box 9-3.[15] Though Huxley's vocation was thoroughly in the literary milieu, he had numerous family associations with biology. His grandfather, T. H. Huxley, was "Darwin's bulldog"; his brother, Julian, did important work in animal behavior and was a successful science popularizer; another brother, Andrew, won the Nobel prize for his work in physiology; and a nephew became an expert on cacti. No doubt this scientifically rich family environment helped make Aldous aware of the human

Box 9-3. Environment & History: Huxley on Toynbee.

In the index at the end of the sixth volume of Dr. Toynbee's *A Study of History,* Popilius Laenas gets five mentions and Porphyry of Batamaea, two; but the word you would expect to find between these two names, Population, is conspicuous by its absence. In his second volume, Mr. Toynbee has written at length on "the stimulus of pressures"—but without ever mentioning the most important pressure of them all, the pressure of population on available resources. And here is a note in which the author describes his impressions of the Roman Campagna after twenty years of absence. "In 1911 the student who made a pilgrimage of the Via Appia Antica found himself walking through a wilderness. . . . When he repeated the pilgrimage in 1931, he found that, in the interval, Man had been busily reasserting his mastery over the whole stretch of country that lies between Rome and the Castelli Romani. . . . The tension of human energy on the Roman Campagna is now beginning to rise again for the first time since the end of the third century B.C." And there the matter is left, without any reference to the compelling reason for this "rise of tension." Between 1911 and 1931 the population of Italy had increased by the best part of eight million. Some of these eight millions went to live in the Roman Campagna. . . .

One would like to know something about the Famines of earlier ages, but the nearest one gets to them in Mr. Toynbee's index is a blank space between Muhammad Faiak-al-Din and Gaius Fannius. . . . Agriculture [is] not referred to in Mr. Toynbee's index, though Agrigentum gets two mentions and Agis IV, King of Sparta, no less than forty-seven. . . . One looks up Erosion . . . but finds only Esarhaddon, Esotericism and Esperanto; one hunts for Forests, but has to be content, alas, with Formosus of Porto.

Tomorrow and Tomorrow and Tomorrow, 1956.

importance of biology: he, more than anyone else (except possibly Rachel Carson), is responsible for introducing the word "ecology" to the general public in the 1960s.

By contrast, A. J. Toynbee's distinguished relatives were all on the humanist side and unlikely to sensitize him to the importance of scientific facts. In fairness to the historian, however, it needs to be said that, in his last years, Toynbee acknowledged the importance of environmental and biological matters in the making of human history.

Has ecology produced the final restructuring of historical knowledge? Certainly not: each generation must rewrite history. Rewriting is done in terms of the latest increase in human understanding. We can do no better than use the ecological and evolutionary framework of our time. This is certainly better than that of the previous century, but the final word is never said.