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Population Density and Growth

Last November an article by Von Foerster *et al.* appeared in *Science* [132, 1291 (1960)] in which it was contended that in about 66 years the growth rate of the world's human population would approach infinity, and that our descendants would be squeezed to death. Most demographers who read this article thought that it was intended as a joke, but the reaction of the press and a careful rereading indicate that the principal contentions were presented and widely received as serious.

The prediction of an infinite growth rate in A.D. 2027 is obtained in effect by fitting a curve to estimates of growth rates in world population from the beginning of the Christian era until the mid-1950's. A rectangular hyperbola provides a rather good fit to these estimates through 1957, and it is the extrapolation of this hyperbola that yields the approach to infinity for the rate of growth early in the next century. The choice of the rectangular hyperbola is dictated by a differential equation expressing the general notion that the growth rate has increased as population density has increased. The authors note that the familiar logistic curve may be derived from a differential equation expressing a *diminishing* rate of growth as density increases. They say that such a negative relationship is plausible for a population whose elements must compete with each other for limited resources available in nature. However, they conjecture that *Homo sapiens* has the capacity to form coalitions against nature, to be more efficient in the struggle to control nature as density increases, rather than less efficient. In other words, they visualize man as cooperating in extracting more from nature rather than as competing for a fixed endowment of resources. This view leads them to expect increasing growth rates with increasing density, and serves, as was stated above, as the rationale for a differential equation which in turn leads to the rectangular hyperbola as the appropriate curve to express the annual percentage increase in population.

This whole argument will not stand critical scrutiny. The following defects are the most conspicuous:

1) It is not true that population growth rates are positively associated with density, nor even that population growth rates are positively associated with man's control over nature. The populations currently residing in areas with a density of less than 100 persons per square mile are growing at more than twice the pace of populations residing in areas with a density of more than 500 persons per square mile. In other words, in the world today the association between growth and density is negative, not positive. Similarly, the countries which have come farthest in technology, in communication, and in what in any view should be considered control over nature have growth rates that range from the slowest in the world to about average, while the fastest growth rates are found in such areas as Malaya, Taiwan, Ceylon, Mexico, and Brazil—countries which certainly cannot be considered in the same class with the United States, Western Europe, or the Soviet Union in their control over nature.

2) Von Foerster and his co-authors neglect the causes of accelerated population growth in the world. Growth has accelerated wholly because of a reduction in mortality, because of a lower world death rate. There are no grounds for believing that there has been any upward trend in the world birth rate.

3) There are clear limits, moreover, to the growth rate that can be attained through reducing mortality rates. In fact, if mortality were reduced to zero and everyone lived forever, the growth rate of world population would initially be exactly equal to the world birth rate, estimated by the United Nations as 3.9 percent. In the long run, immortality would produce a somewhat *lower* growth rate than this as the proportion of population above childbearing ages became larger. In short, the extension to its logical extreme of the trend which has been wholly responsible for faster growth in the world population would lead to a growth rate of less than 4 percent. There are also biological limits to increases in fertility in the improbable event that these occur. If every woman were married by age 15 and bore children at a rate equaling the highest observed in any large human population, and if everyone were immortal, the growth rate would still be somewhat less than 6 percent. In fact, rates much above 6 percent cannot be achieved as long as childbearing is restricted to the ages between 15 and 50 and the period of gestation remains 9 months.

Another well-known fact that this article neglected was that the development of better communication, of better education, and of better control over nature has led universally to *declines* in the birth rate. One might say that in extending his control over nature man has learned to exercise rational control over the consequences of his own nature. There is not a single country in the world which has achieved a high degree of industrialization that does not have birth rates very substantially lower than those prevailing before industrialization. Included among the countries where the birth rate has dropped sharply are the Soviet Union, Japan, the United States, Canada, Australia, New Zealand, and all of the countries of Europe except Albania (not yet industrialized). In short, the most superficial examination of population trends makes it clear that if man *does* continue to extend his technology, the expected result will be a decline in birth rates in those parts of the world where they are now highest.

The especially rapid acceleration of growth in the mid-20th century has resulted from technological advances in medicine and public health. Among the most striking and far-reaching developments have been the antibiotics and the residual insecticides such as DDT. Developments of this sort have made it possible for countries which have not yet adopted modern technology in their economies to enjoy a very substantial measure of control over infectious disease. Thus Ceylon, which has undergone very little in the way of fundamental economic change, has cut its death rate by more than 50 percent since 1945. This situation gives the clearest urgency to programs for speeding the economic development of these areas, both to keep production expanding at least as rapidly as population and to provide the basis for the social and economic changes which will bring births under voluntary control.

These questions are among the most serious facing the world today, and to give wide currency to such clearly nonsensical ideas as an infinite birth rate and Doomsday in A.D. 2027 contribute nothing to their solution.

ANSLEY J. COALE
Office of Population Research,
Princeton University,
Princeton, New Jersey

Essentially three arguments against our "Doomsday" thesis are presented in Coale's letter. They are: (i) nonsensi-

cality for a parameter describing a finite physical system to approach infinity; (ii) misrepresentation of relationships between population growth rates, population densities, and technological status; and (iii) natural limitations of growth rates.

It is easy to dispose of these arguments.

1) In answering similar objections raised earlier we have tried to point out [*Science* **133**, 943 (1961)] that such singularities are usually interpreted as an indication of the system's instability in the vicinity of this singularity. In other words, a system may undergo drastic changes—for example, evaporation, rupture, disintegration—when passing through this critical state. Four examples were given, and references were cited. If this does not suffice, we recommend consulting the nearest physicist, who—we are convinced—will be glad to assist in overcoming this conceptual difficulty.

2) It is true that in many instances in various regions an inverse relationship between population density and population growth, or population density and technological status, may prevail, as Coale shows in numerous examples. However, an equal number of cases could be cited where the relationship is a direct one—for instance, if one compares the population density, growth rate, and technological standard of the population in New York with that, say, of the population in the Matto Grosso, or makes the same comparisons for the people of Japan and the people of Tierra del Fuego. Since our expressions for global population growth were derived for mean values over at least one generation—as explicitly stated at several points in our original article—it is obvious that our simple Eq. 11 is neither intended, nor able, to account for minute local and temporal fluctuations. On the other hand, if we apply "Coale's law" of the inverse relationship of population density with growth rate and technological know-how—as suggested in his letter—to the development of the human population as a whole over the last couple of millennia, we arrive at the peculiar conclusion that either Stone Age man was a technological wizard who carefully removed his technological achievements so as not to upset his inferior progeny, or that —if he was at the level at which most of us believe he was—our population dwindled from a once astronomical size to the mere three billions of today. Since we are neither archeologists nor demographers, we must leave the decision between these alternatives to the experts.

3) Four natural limits for growth rate are cited by Coale: period of gestation, onset and duration of fertility, and death. While Coale treats the first three physiological quantities as fixed quantities, unalterable through technological progress, and thus gives the endocrinologist an undeserved vote of no confidence, he puts his bets on the gerontologists, who, he theorizes, will eventually solve the problem of immortality; that is, the mean life span of man, t_m, will approach infinity. Noting with pleasure that Coale does not consider such a hypothesis nonsensical, and accepting for the sake of a fair argument his conjecture of an invariable global birth rate γ_0 throughout the history of man, we are now in a position to estimate man's life span as a function of time. Invoking our Eq. 7, which gives the productivity α (defined as $\gamma - 1/t_m$) in terms of dooms-time τ, we have

$$t_m = \frac{\tau}{\gamma_0 \tau - k}$$

Today, $\gamma_0 = 0.039$ per year (U.N.), $\tau = 67$ years, and with $k \approx 1$, the global mean life expectancy becomes 42 years. This seems to be a fair approximation (*1*) of present-day estimates ($40 \leqq t_m \leqq 45$) (*2*). This encourages us to take a step further and to determine the time when undertakers will be out of business. For $\tau = \tau^* = k/\gamma_0$, t_m approaches infinity, and when we use values as above; $\tau^* = 25.4$ years. In other words, around the spring of A.D. 2001 the "Perma-Life" pill will be on sale, and thereafter the population will grow merely according to an exponential.

Let us investigate what happens under these conditions, around doomsday $\tau \approx 0$, or $t =$ A.D. 2027. Expressing γ_0 in percentage per year, we have with our Eq. 11 and the suggested exponential the number of people N_D at doomsday:

$$N_D = 5.10^9 \gamma_0$$

and the annual population increase at that time

$$\left(\frac{dN}{dt}\right)_D = 5.10^7 \gamma_0^2$$

With Coale's permission, we take $\gamma_0 \approx 6$ percent and obtain the frightening result that in 67 years the world population amounts to 30 billion souls, and that this population produces in that year 1.8 billion immortal babies. In other words, a number of people equal to the entire world population in 1927 will thus be added in a single year.

A reader unfamiliar with demographic numerology should be cautioned that almost nothing changes in these figures if the immortality assumption is dropped, as Coale has shown elsewhere (*3*). However, drastic changes for the worse can be predicted if medicine should succeed in making only small advances in extending years of fertility, or if our culture should promote a shift to slightly earlier marriages.

We leave it to the poets to describe this terrestrial inferno, and to the anthropologists, sociologists, and psychologists to give their verdict on the stability of our human condition under such circumstances.

We hope that in this exchange of arguments about a few side issues the reader has not lost track of the real issue at stake—namely, whether or not the time has come when man must take control over his fate in this matter and attempt to launch perhaps the most ambitious, most difficult and most grandiose enterprise in his entire history: the establishment of a global control mechanism, a population servo, which would keep the world's population at a desired level. It is depressing to discover the complete lack of comprehension of the dimension of this problem in a leading demographer, who seriously believes that sending gadgets to the "underdeveloped" will quickly alter their ancient cultural habits. He even dares to cite the recent fast decline of the birth rate in Japan. Indeed, there were only three gadgets involved: a curet, a dilator, and penicillin. With these, in the years 1950 to 1956, about 12 million successful abortions were carried out, reducing the live-birth rate in Japan from 3 percent to 1.8 percent (*4*) and thus demonstrating—after Coale—the comforting principle of reduced birth rates with improved technical skill.

The tragic error made by Coale and others of his school of thought is to insist that mankind has to be treated—like fruit flies—as a set of independent elements whose only properties are their fertility and their mortality schedules, which are established *ad hoc* by looking

into census figures. Very little indeed can be expected from such an approach, which not only fails to describe the past of the human population beyond a dozen generations (*5*) but also is invalid for projecting population trends over such short an interval as only one generation (*6*). Therefore, it does not come as a surprise that recognition of an obvious trait in man—namely, his capacity to form coalitions, the ability of two men *jointly* to do things which the two independently are never able to achieve—immediately leads to expressions which adequately describe human population growth over several hundred generations, from the prehistoric past up to today. As we pointed out, the process which governed the growth rate for a couple of thousand of years and which is still acting today, exhibits a most dangerous intrinsic instability, which is now—so to say—around the corner. It is clear that this process has to be interrupted, and, as we believe we have shown, to suggest stepped-up industrialization is to propose to put out a fire with gasoline.

The real problem is that today we have to prepare each single member in a family of 3 billion to face soon a decision—namely, either to persist in enjoying his children and to pay for it by having no more than two and remaining mortal, or to reach for individual immortality and remain childless forever. In 20 years, of course, 4 billions will have to make this decision.

HEINZ VON FOERSTER

PATRICIA M. MORA
LAWRENCE W. AMIOT
Department of Electrical Engineering, University of Illinois, Urbana

References and Notes

1. A better approximation is of form $t_m = (1/\gamma_0) + (1/\tau\gamma_0^2)$, with $\gamma_0 = 0.034$. Compare with E. S. Deevey, Jr., *Sci. American* **203**, No. 3, 200 (1960). This, however, results in a slowly increasing birth rate.
2. H. F. Dorn, in *The Study of Populations*, P. M. Hauser and O. D. Duncan, Eds. (Univ. of Chicago Press, Chicago, 1959), p. 455.
3. A. J. Coale, in *Trans. Intern. Population Conf.* (Vienna, 1959), pp. 40–44.
4. P. H. Gebhard, W. P. Pomeroy, C. E. Martin, C. V. Christenson, *Pregnancy, Birth and Abortion* (Harper, New York, 1958), p. 219.
5. W. E. Howland, *Science* **133**, 939 (1961).
6. Official population projections for 1980 made in 1950 are now revised by adding a mere 500 million people to the old estimate. Compare *Population Bull. No. 1* (United Nations, New York, 1951), pp. 1–3, and *ECOSOC Report*, *Time* **77**, No. 16, 31 (1961).