Impact of Population Growth
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Impact of Population Growth

Complacency concerning this component of man’s predicament is unjustified and counterproductive.

Paul R. Ehrlich and John P. Holdren

The interlocking crises in population, resources, and environment have been the focus of countless papers, dozens of prestigious symposia, and a growing avalanche of books. In this wealth of material, several questionable assertions have been appearing with increasing frequency. Perhaps the most serious of these is the notion that the size and growth rate of the U.S. population are only minor contributors to this country’s adverse impact on local and global environments (1, 2). We propose to deal with this and several related misconceptions here, before persistent and unrebutted repetition entrenches them in the public mind— if not the scientific literature. Our discussion centers around five theorems which we believe are demonstrably true and which provide a framework for realistic analysis:

1) Population growth causes a disproportionate negative impact on the environment.

2) Problems of population size and growth, resource utilization and depletion, and environmental deterioration must be considered jointly and on a global basis. In this context, population control is obviously not a panacea—it is necessary but not alone sufficient to see us through the crisis.

3) Population density is a poor measure of population pressure, and redistributing population would be a dangerous pseudosolution to the population problem.

4) “Environment” must be broadly construed to include such things as the physical environment of urban ghettos, the human behavioral environment, and the epidemiological environment.

5) Theoretical solutions to our problems are often not operational and sometimes are not solutions.

We now examine these theorems in some detail.

Population Size and Per Capita Impact

In an agricultural or technological society, each human individual has a negative impact on his environment. He is responsible for some of the simplification (and resulting destabilization) of ecological systems which results from the practice of agriculture (3). He also participates in the utilization of renewable and nonrenewable resources. The total negative impact of such a society on the environment can be expressed, in the simplest terms, by the relation

\[ I = P \cdot F \]

where \( P \) is the population, and \( F \) is a function which measures the per capita impact. A great deal of complexity is subsumed in this simple relation, however. For example, \( F \) increases with per capita consumption if technology is held constant, but may decrease in some cases if more benign technologies are introduced in the provision of a constant level of consumption. (We shall see in connection with theorem 5 that there are limits to the improvements one should anticipate from such “technological fixes.”)

Pitfalls abound in the interpretation of manifest increases in the total impact \( I \). For instance, it is easy to make mistakes in the composition of resource demand or environmental impact for absolute per capita increases, and thus to underestimate the role of the population multiplier. Moreover, it is often assumed that population size and per capita impact are independent variables, when in fact they are not. Consider, for example, the recent article by Coale (1), in which he disparages the role of U.S. population growth in environmental problems by noting that since 1940 “population has increased by 50 percent, but per capita use of electricity has been multiplied several times.” This argument contains both the fallacies to which we have just referred.

First, a closer examination of very rapid increases in many kinds of consumption shows that these changes reflect a shift among alternatives within a larger (and much more slowly growing) category. Thus the 760 percent increase in electricity consumption from 1940 to 1969 (4) occurred in large part because the electrical component of the energy budget was (and is) increasing much faster than the budget itself. (Electricity comprised 12 percent of the U.S. energy consumption in 1940 versus 22 percent today.) The total energy use, a more important figure than its electrical component in terms of resources and the environment, increased much less dramatically—140 percent from 1940 to 1969. Under the simplest assumption (that is, that a given increase in population size accounts for an exactly proportional increase in consumption), this would mean that 38 percent of the increase in energy use during this period is explained by population growth (the actual population increase from 1940 to 1969 was 53 percent). Similar considerations reveal the imprudence of citing, say, aluminum consumption to show that population growth is an “unimportant” factor in resource use. Certainly, aluminum consumption has swelled by over 1400 percent since 1940, but much of the increase has been due to the substitution of aluminum for steel in many applications. Thus a fairer measure is combined consumption of aluminum and steel, which has risen only 117 percent since 1940. Again, under the simplest assumption, population growth accounts for 45 percent of the increase.

The “simplest assumption” is not valid, however, and this is the second flaw in Coale’s example (and in his
networks. All these activities increase typically, attempts are made both to
we are obliged to use lower-grade ores, 
plies of these resources and those near-
In the case of partly renewable re-
late dramatically when the human 
our per capita use of energy and our 
esthetic, and ecological costs of mas-
growth.
As one example of diminishing re-
turns, consider the problem of provid-
ning nonrenewable resources such as 
As the richest sup-
plies of these resources and those near-
est to centers of use are consumed, 
we are obliged to use lower-grade ores, 
drill deeper, and extend our supply 
flows into farmland, air pollution in-
coming mechanisms of the lungs, thus in-
stant as population doubles. This means 
leaves dramatic when the human 
population demands more than is 
locally available. Here the loss of free-
flowing rivers and other economic, 
esthetic, and ecological costs of mas-
sic water-movement projects repre-
sent increased per capita diseconomies 
directly stimulated by population 
growth.
Diminishing returns are also opera-
tive in increasing food production to 
meet the needs of growing populations. 
Typically, attempts are made both to 
overproduce on land already farmed 
and to extend agriculture to marginal 
land. The former requires dispropor-
tionate energy use in obtaining and dis-
tributing water, fertilizer, and pesti-
cides. The latter also increases per 
capita energy use, since the amount of 
energy invested per unit yield increases 
as less desirable land is cultivated.

Similarly, as the richest fisheries stocks 
are depleted, the yield per unit effort 
life. more and more energy per 
capita is required to maintain the supply 
shr (P). Once a stock is depleted it 
may not recover—it may be nonre-
newable.

Population size influences per capita 
impact in ways other than diminishing 
returns. As one example, consider the 
oversimplified but instructive situation 
in which each person in the popula-
tion has links with every other person 
roads, telephone lines, and so forth. 
These links involve energy and ma-
terials in their construction and use. 
Since the number of links increases 
much more rapidly than the number of 
people (6), so does the per capita 
consumption associated with the links. 
Other factors may cause much 
steeped positive slopes in the per capita 
impact function, F (P). One such 
phenomenon is the threshold effect. 
Below a certain level of pollution trees 
will survive in smog. But, at some 
point, when a small increment in 
population produces a small increment 
in smog, living trees become dead 
trees. Five hundred people may be 
able to live around a lake and dump 
their raw sewage into the lake, and the 
natural systems of the lake will be 
able to break down the sewage and 
keep the lake from undergoing rapid 
ecological change. Five hundred and 
five people may overload the system 
and result in a "polluted" or eutrophic 
lake. Another phenomenon capable of 
causing near-discontinuities is the 
synergism. For instance, as cities push 
out into farmland, air pollution incre-
sively becomes a mixture of agri-
cultural chemicals with power plant 
and automobile effluents. Sulfur diox-
ide from the city paralyzes the clean-
ning mechanisms of the lungs, thus in-
creasing the residence time of potential 
carcinogens in the agricultural chemi-
cals. The joint effect may be much 
more than the sum of the individual 
effects. Investigation of synergistic ef-
fects is one of the most neglected areas 
of environmental evaluation.

Not only is there a connection be-
tween population size and per capita 
damage to the environment, but the 
size of maintaining environmental 
quality at a given level escalates dis-
proportionately as population size 
increases. This effect occurs in part be-
cause costs increase very rapidly as one 
tries to reduce contaminants per unit 
volume of effluent to lower and lower 
levels (diminishing returns again!). 
Consider municipal sewage, for ex-
ample. The cost of removing 80 to 90 
percent of the biochemical and chem-
ical oxygen demand, 90 percent of the 
suspended solids, and 60 percent of the 
resistant organic material by means of 
secondary treatment is about 8 cents 
per 1000 gallons (3785 liters) in a large 
plant. But if the volume of sewage is 
such that its nutrient content creates a 
serious eutrophication problem (as is 
the case in the United States today), 
or if supply considerations dictate the 
reuse of sewage water for industry, 
agriculture, or groundwater recharge, 
advanced treatment is necessary. The 
cost ranges from two to four times 
as much as for secondary treatment 
(17 cents per 1000 gallons for carbon 
absorption; 34 cents per 1000 gallons 
for disinfection to yield a potable sup-
ply). This dramatic example of dimin-
ishng returns in pollution control 
could be repeated for stack gases, au-
mobile exhausts, and so forth.

Now consider a situation in which 
the limited capacity of the environ-
ment to absorb abuse requires that we 
hold man's impact in some sector con-
stant as population doubles. This means 
per capita effectiveness of pollution 
control in this sector must double 
(that is, effluent per person must be 
halved). In a typical situation, this 
would yield doubled per capita costs, 
or quadrupled total costs (and proba-
ly energy consumption) in this sector 
for a doubling of population. Of course, 
diminishing returns and threshold ef-
efts may be still more serious: we 
may easily have an eightfold increase 
in control costs for a doubling of popu-
lation. Such arguments leave little 
ground for the assumption, popularized 
by Barry Commoner (2, 8) and others, 
that a 1 percent rate of population 
growth spawns only 1 percent effects.

It is to be emphasized that the pos-
sible existence of "economies of scale" 
does not invalidate these arguments. 
Such savings, if available at all, would 
apply in the case of our sewage ex-
ample to a change in the amount of 
effluent to be handled at an installation 
of a given type. For most technologies, 
the United States is already more than 
populous enough to achieve such econ-
omies and is doing so. They are ac-
counted for in our example by citing 
figures for the largest treatment plants 
of each type. Population growth, on
countries complain that world demand for their raw materials is too low (1). The analyst, on the other hand, forces us into quantitative and qualitative changes in how we handle each unit volume of effluent—what fraction and what kinds of material we remove. Here economies of scale do not apply at all, and diminishing returns are the rule.

Global Context

We will not deal in detail with the best example of the global nature and interconnections of population resource and environmental problems—namely, the problems involved in feeding a world in which 10 to 20 million people starve to death annually (9), and in which the population is growing by some 70 million people per year. The ecological problems created by high-yield agriculture are awesome (3, 10) and are bound to have a negative feedback on food production. Indeed, the Food and Agriculture Organization of the United Nations has reported that in 1969 the world suffered its first absolute decline in fisheries yield since 1950. It seems likely that part of this Using the 1963 model, one can see that the developed countries are enjoying about the same rate of growth per capita that they did in the 1950s, but that there is an absolute decline in the world's nonrenewable resources (12) as well as in appropriating much more than their share of the world's protein. Population Density and Distribution

Theorem 3 deals with a problem related to the inequitable utilization of world resources. One of the commonest errors made by the uninitiated is to assume that population density (people per square mile) is the critical measure of overpopulation or underpopulation. For instance, Wattenberg states that the United States is not very crowded by "international standards" because Holland has 18 times the population density (13). We call this notion "the Netherlands fallacy." The Netherlands actually requires large chunks of the earth's resources and vast areas of land not within its borders to maintain itself. For example, it is the second largest per capita importer of protein in the world, and it imports 63 percent of its cereals, including 100 percent of its corn and rice. It also imports all of its cotton, 77 percent of its wool, and all of its iron ore, antimony, bauxite, chromium, copper, gold, lead, magnesium, manganese, mercury, molybdenum, nickel, silver, tin, tungsten, vanadium, zinc, phosphate rock (fertilizer), potash (fertilizer), asbestos, and diamonds. It produces energy equivalent to some 20 million metric tons of coal and consumes the equivalent of over 47 million metric tons (14).

A certain preoccupation with density as a useful measure of overpopulation is apparent in the article by Coale (1). He points to the existence of urban problems such as smog in Sydney, Australia, "even though the total population of Australia is about 12 million in an area 80 percent as big as the United States," as evidence that environmental problems are unrelated to population size. His argument would be more persuasive if problems of population distribution were the only ones with environmental consequences, and if population distribution were unrelated to resource distribution and population size. Actually, since the carrying capacity of the Australian continent is far below that of the United States, one would expect distribution problems—of which Sydney's smog is one symptom—to be encountered at a much lower total population there. Resources, such as water, are in very short supply, and people cluster where resources are available. (Evidently, it cannot be emphasized enough that carrying capacity includes the availability of a wide variety of resources in addition to space itself, and that population pressure is measured relative to the carrying capacity. One would expect water, soils, or the ability of the environment to absorb wastes to be the limiting resource in far more instances than land area.)

In addition, of course, many of the most serious environmental problems are essentially independent of the way in which population is distributed. These include the global problems of weather modification by carbon dioxide and particulate pollution, and the threats to the biosphere posed by man's massive inputs of pesticides, heavy metals, and oil (15). Similarly, the problems of resource depletion and ecosystem simplification by agriculture depend on how many people there are and their patterns of consumption, but...
not in any major way on how they are distributed.

Naturally, we do not dispute that smog and most other familiar urban ills are serious problems, or that they are related to population distribution. Like many of the difficulties we face, these problems will not be cured simply by stopping population growth; direct and well-conceived assaults on the problems themselves will also be required. Such measures may occasionally include the redistribution of population, but the considerable difficulties and costs of this approach should not be underestimated. People live where they do not because of a perverse intention to add to the problems of their society but for reasons of economic necessity, convenience, and desire for agreeable surroundings. Areas that are uninhabited or sparsely populated to-necessity, convenience, and desire for we justify the rape of Canada's rivers be underestimated. People live where they are deficient in some of the requi-sites for such deficiencies—for example, the provision of water and power to the wastelands of central Nevada—would be extraordinarily expensive in dollars, energy, and resources and would probably create environmental havoc. (Will we justify the rape of Canada's rivers to "colonize" more of our western deserts?)

Moving people to more "habitable" areas, such as the central valley of California or, indeed, most suburbs, exacerbates another serious problem—the paving-over of prime farmland. This is already so serious in California that, if current trends continue, about 50 percent of the best acreage in the nation's leading agricultural state will be destroyed by the year 2020 (16). Encouraging that trend hardly seems wise.

Whatever attempts may be made to solve distribution-related problems, they will be undermined if population growth continues, for two reasons. First, population growth and the aggregation of distribution problems are correlated—part of the increase will surely be absorbed in urban areas that can least afford the growth. Indeed, barring the unlikely prompt reversal of present trends, most of it will be absorbed there. Second, population growth puts a disproportionate drain on the very financial resources needed to combat its symptoms. Economist Joseph Spengler has estimated that 4 percent of national income goes to support our 1 percent per year rate of population growth in the United States (17). The 4 percent figure now amounts to about $30 billion per year. It seems safe to conclude that the faster we grow the less likely it is that we will find the funds either to alter population distribution patterns or to deal more comprehensively and realistically with our problems.

Meaning of Environment

Theorem 4 emphasizes the comprehensiveness of the environment crisis. All too many people think in terms of national parks and trout streams when they say "environment." For this reason many of the suppressed people of our nation consider ecology to be just one more "racist shuck" (18). They are apathetic or even hostile toward efforts to avert further environmental and sociological deterioration, because they have no reason to believe they will share the fruits of success (19). Slums, cockroaches, and rats are ecological problems, too. The correction of ghetto conditions in Detroit is neither more nor less important than saving the Great Lakes—both are imperative.

We must pay careful attention to sources of conflict both within the United States and between nations. Conflict within the United States blocks progress toward solving our problems; conflict among nations can easily "solve" them once and for all. Recent laboratory studies on human beings support the anecdotal evidence that crowding may increase aggressiveness in human males (20). These results underscore long-standing suspicions that population growth, translated through the inevitable uneven distribution into physical crowding, will tend to make the solution of all of our problems more difficult.

As a final example of the need to view "environment" broadly, note that human beings live in an epidemiologi-cal environment which deteriorates with crowding and malnutrition—both of which increase with population growth. The hazard posed by the prevalence of these conditions in the world today is compounded by man's unprecedented mobility: potential carri-ers of diseases of every description move routinely and in substantial numbers from continent to continent in a matter of hours. Nor is there any reason to believe that modern medi-cine has made widespread plague im-possible (21). The Asian influenza epidemic of 1968 killed relatively few people only because the virus happened to be nonfatal to people in other-wise good health, not because of pub-lic health measures. Far deadlier viruses, which easily could be scourges without precedent in the population at large, have on more than one oc-casion been confined to research workers largely by good luck [for example, the Marburg virus incident of 1967 (22) and the Lassa fever incident of 1970 (21, 23)].

Solutions: Theoretical and Practical

Theorem 5 states that theoretical solutions to our problems are often not operational, and sometimes are not solutions. In terms of the problem of feeding the world, for example, techn-ological fixes suffer from limitations in scale, lead time, and cost (24). Thus potentially attractive theoretical approaches—such as desalting seawater for agriculture, new irrigation systems, high-protein diet supplements—prove inadequate in practice. They are too little, too late, and too expensive, or they have sociological costs which hobble their effectiveness (25). Moreover, many aspects of our technological fixes, such as synthetic organic pesti-cides and inorganic nitrogen fertilizers, have created vast environmental prob-lems which seem certain to erode global productivity and ecosystem stability (26). This is not to say that important gains have not been made through the application of technology to agriculture in the poor countries, or that further technological advances are not worth seeking. But it must be stressed that even the most enlightened tech-nology cannot relieve the necessity of grappling forthrightly and promptly with population growth [as Norman Borlaug aptly observed on being notified of his Nobel Prize for development of the new wheats (27)].

Technological attempts to ameliorate the environmental impact of population growth and rising per capita afflu-ence in the developed countries suffer from practical limitations similar to those just mentioned. Not only do such measures tend to be slow, costly, and insufficient in scale, but in addition they most often shift our impact rather than remove it. For example, our first generation of smog-control devices in-
creased emissions of oxides of nitrogen while reducing those of hydrocarbons and carbon monoxide. Our unhappiness about eutrophication has led to the replacement of phosphates in detergents with compounds like NTA—nitrilotriacetic acid—which has carcinogenic breakdown products and apparently enhances teratogenic effects of heavy metals (28). And our distaste for lung diseases apparently induced by sulfur dioxide inclines us to accept the hazards of radioactive waste disposal, fuel reprocessing, routine low-level emissions of radiation, and an apparently small but finite risk of catastrophic accidents associated with nuclear fission power plants. Similarly, electric automobiles would simply shift part of the environmental burden of personal transportation from the vicinity of highways to the vicinity of power plants.

We are not suggesting here that electric cars, or nuclear power plants, or substitutes for phosphates are inherently bad. We argue rather that they, too, pose environmental costs which must be weighed against those they eliminate. In many cases the choice is not obvious, and in all cases there will be some environmental impact. The residual per capita impact, after all the best choices have been made, must then be multiplied by the population engaging in the activity. If there are too many people, even the most wisely managed technology will not keep the environment from being overstressed.

In contending that a change in the way we use technology will invalidate these arguments, Commoner (2, 8) claims that our important environmental problems began in the 1940's with the introduction and rapid spread of certain "synthetic" technologies: pesticides and herbicides, inorganic fertilizers, plastics, nuclear energy, and high-compression gasoline engines. In so arguing, he appears to make two unfounded assumptions. The first is that man's pre-1940 environmental impact was innocuous and, without changes for the worse in technology, would have remained innocuous even at a much larger population size. The second assumption is that the advent of the new technologies was independent of the attempt to meet human needs and desires in a growing population. Actually, man's record as a simplifier of ecosystems and plunderer of resources can be traced from his probable role in the extinction of many Pleistocene mammals (29), through the destruction of the soils of Mesopotamia by salination and erosion, to the deforestation of Europe in the Middle Ages and the American dustbowls of the 1930's, to cite only some highlights. Man's contemporary arsenal of synthetic technological bludgeons indisputably magnifies the potential for disaster, but these were evolved in some measure to cope with population pressures, not independently of them. Moreover, it is worth noting that, of the four environmental threats viewed by the prestigious Williamstown study (13) as globally significant, three are associated with pre-1940 technologies which have simply increased in scale [heavy metals, on the one hand, and carbon dioxide and particulates in the atmosphere, the latter probably due in considerable part to agriculture (30)]. Surely, then, we can anticipate that supplying food, fiber, and metals for a population even larger than today's will have a profound (and destabilizing) effect on the global ecosystem under any set of technological assumptions.

Conclusion

John Platt has aptly described man's present predicament as "a storm of crisis problems" (31). Complacency concerning any component of these problems—sociological, technological, economic, ecological—is unjustified and counterproductive. It is time to admit that there are no monolithic solutions to the problems we face. Indeed, population control, the redirection of technology, the transition from open to closed resource cycles, the equitable distribution of opportunity and the ingredients of prosperity must all be accomplished if there is to be a future worth having. Failure in any of these areas will surely sabotage the entire enterprise.

In connection with the five theorems elaborated here, we have dealt at length with the notion that population growth in industrial nations such as the United States is a minor factor, safely ignored. Those who so argue often add that, anyway, population control would be the slowest to take effect of all possible attacks on our various problems, since the inertia in attitudes and in the age structure of the population is so considerable. To conclude that this means population control should be assigned low priority strikes us as curious logic. Precisely because population is the most difficult and slowest to yield among the components of environmental deterioration, we must start on it at once. To ignore population today because the problem is a tough one is to commit ourselves to even gloomier prospects 20 years hence, when most of the "easy" means to reduce per capita impact on the environment will have been exhausted. The desperate and repressive measures for population control which might be contemplated then are reason in themselves to proceed with foresight, alacrity, and compassion today.
The central feature of this analysis is the role played by the sensory and nonsensory variables. A large body of literature is available on signal detection theory in psychophysics (2) and the use of ROC curves (3).

Signal Detectability and Medical Decision-Making

Signal detectability studies help radiologists evaluate equipment systems and performance of assistants.

Lee B. Lusted

Signal detection theory can be used to investigate two problems of interest to radiologists. First, the central concern in the study of radiographic image quality is to gain knowledge of the way in which physical image quality affects a diagnosis, not necessarily to design high fidelity imaging systems (1). Second, the increasing demand for diagnostic radiology examinations has stimulated studies to determine whether the effectiveness and efficiency of radiologists can be increased by the use of trained technical assistants.

Detection theory is a basis for treating discrimination experiments in psychophysics. In such experiments, one attempts to learn something about a sensory system by determining just how small a change in some aspect of the stimulus can be reliably detected. A central feature of this analysis is the distinction made between the criterion that the observer uses to decide whether a signal is present and his sensory capabilities as a signal detector. Receiver operating characteristic (ROC) curves can be used to separate the sensory and nonsensory variables. A large body of literature is available on signal detection theory in psychophysics (2) and the use of ROC curves (3).

ROC Curve for Interpreting Chest Roentgenograms

In 1946 a group of radiologists and phthisiologists began an investigation to evaluate the effectiveness of various roentgenographic and photofluorographic techniques in detecting active pulmonary tuberculosis. Yerushalmy, who helped to initiate the study, has recently reviewed the results and the studies which followed (4). In the course of the investigation it was discovered that the variation in the interpretations of chest roentgenograms was of a disturbing magnitude: a physician would disagree with the diagnosis of a colleague on an average of one out of three times; on a second, independent reading of the same series of chest films, a physician would disagree with his own previous diagnosis on an average of one out of five times.

The results of the intensive studies of this phenomenon, which came to be known as observer error, are shown in an ROC graph in Fig. 1. The ROC curve is plotted on normal–normal coordinates (codex 41,453), according to the detection theory convention of false positive and true positive diagnoses on the x- and y-axes, respectively. Two parameters are abstracted from an ROC curve: the slope, and the sensitivity index $d'$, where $d'$ is defined as twice the normal deviates of the intersection of the ROC curve and the negative diagonal. The slope is interpreted as the ratio of the standard deviations of two distributions that, hypothetically, underlie the detection process. The measure $d'$ is normalized by averaging the two variances of the underlying data-generating distributions. The more sensitively the observer performs as a signal detector, the larger the value of $d'$.

The ROC curve in Fig. 1 can explain the variation in the interpretation of roentgenogram interpretation. Suppose that the six points on the curve represent the diagnoses of six different physicians who have identical sensory capabilities for detecting the signals (film densities) of tuberculosis on the chest roentgenogram, but they have different criteria for what densities should actually be called tuberculosis. One assumes that they have the same sensory capabilities because the index of detectability, $d'$, is the same for each physician.

The upper points on the curve represent individuals with more liberal decision criteria, whereas the lower...